REN21 Renewable Energy Policy Network for the 21st Century

RENEWABLES 2017
GLOBAL STATUS REPORT

REPORT CITATION

REN21. 2017.
Renewables 2017 Global Status Report
(Paris: REN21 Secretariat).

ISBN 978-3-9818107-6-9

DISCLAIMER:

REN21 releases issue papers and reports to emphasise the importance of renewable energy and to generate discussion on issues central to the promotion of renewable energy. While REN21 papers and reports have benefited from the considerations and input from the REN21 community, they do not necessarily represent a consensus among network participants on any given point. Although the information given in this report is the best available to the authors at the time, REN21 and its participants cannot be held liable for its accuracy and correctness.

This report was commissioned by REN21 and produced in collaboration with a global network of research partners. Financing was provided by the German Federal Ministry for Economic Cooperation and Development (BMZ), the German Federal Ministry for Economic Affairs and Energy (BMWi), UN Environment and the Inter-American Development Bank (IDB). A large share of the research for this report was conducted on a voluntary basis.

UN environment

BID Banco Interamericano de Desarrollo

Gefördert durch:

Bundesministerium für Wirtschaft und Energie

Federal Ministry for Economic Cooperation and Development

aufgrund eines Beschlusses des Deutschen Bundestages

TABLE OF CONTENTS | GSR 2017

Endnotes: see full version online at www.ren21.net/gsr

TABLE OF CONTENTS | GSR 2017

TABLES

SIDEBARS

REFERENCE TABLES

FIGURES

REN21 MEMBERS

INDUSTRY ASSOCIATIONS

Alliance for Rural Electrification (ARE)
American Council on Renewable Energy (ACORE)
Association for Renewable Energy of Lusophone Countries (ALER)
Chinese Renewable Energy Industries Association (CREIA)
Clean Energy Council (CEC)
European Renewable Energies Federation (EREF)
Global Off-Grid Lighting Association (GOGLA)
Global Solar Council (GSC)
Global Wind Energy Council (GWEC)
Indian Renewable Energy Federation (IREF)
International Geothermal Association (IGA)
International Hydropower Association (IHA)
Portuguese Renewable Energy Association (APREN)
Renewable Energy Solutions for the Mediterranean (RES4MED)
World Bioenergy Association (WBA)
World Wind Energy Association (WWEA)

INTERNATIONAL ORGANISATIONS

Asian Development Bank (ADB)
Asia Pacific Energy Research Centre (APERC)
ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE)
European Commission (EC)
Global Environment Facility (GEF)
International Energy Agency (IEA)
International Renewable Energy Agency (IRENA)
Regional Center for Renewable Energy and Energy Efficiency (RCREEE)
United Nations Development Programme (UNDP)
UN Environment (UNEP)
United Nations Industrial Development Organization (UNIDO)
World Bank (WB)

NGOS

Climate Action Network (CAN)
Council on Energy, Environment and Water (CEEW)
Fundación Energías Renovables (FER)
Global Alliance for Clean Cookstoves (GACC)
Global Forum on Sustainable Energy (GFSE)
Greenpeace International
ICLEI – Local Governments for Sustainability, South Asia
Institute for Sustainable Energy Policies (ISEP)
Mali Folkecenter (MFC)
Partnership for Sustainable Low Carbon Transport (SLoCaT)
Renewable Energy Institute (REI)
World Council for Renewable Energy (WCRE)
World Future Council (WFC)
World Resources Institute (WRI)
World Wildlife Fund (WWF)

MEMBERS AT LARGE

Michael Eckhart
Mohamed El-Ashry
David Hales
Kirsty Hamilton
Peter Rae

NATIONAL GOVERNMENTS

Afghanistan
Brazil
Denmark
Germany
India
Norway
South Africa
Spain
United Arab Emirates
United Kingdom
United States of America

SCIENCE AND ACADEMIA

Fundación Bariloche (FB)
International Institute for Applied Systems Analysis (IIASA)
International Solar Energy Society (ISES)
National Renewable Energy Laboratory (NREL)
South African National Energy Development Institute (SANEDI)
The Energy and Resources Institute (TERI)

CHAIR

Arthouros Zervos
National Technical University of Athens (NTUA)

EXECUTIVE SECRETARY

Christine Lins
REN21

FOREWORD

The 2017 edition of the *REN21 Renewables Global Status Report* (GSR) reveals a global energy transition well under way, with record new additions of installed renewable energy capacity, rapidly falling costs, particularly for solar PV and wind power, and the decoupling of economic growth and energy-related carbon dioxide emissions for the third year running. Innovative and more sustainable ways of meeting our energy needs are accelerating the paradigm shift away from a world run on fossil fuels.

Despite these positive trends, the pace of the transition is not on track to achieve the goals established in the Paris Agreement to keep global temperature rise well below 2 degrees Celsius. So how can we speed up the energy transition with renewables?

It is clear that policy is essential. Policy support for renewables in 2016, as in past years, focused mostly on power generation, whereas policies for the heating and cooling and transport sectors have remained virtually stagnant. This has to change. A systems approach is also needed across all sectors. There is a need to broaden the definition of a renewables-based energy system to one that moves beyond the traditional, narrow construct of renewable energy sources to one that looks at the role of supporting infrastructure, supply and demand balancing measures, efficiency measures and sector coupling, as well as a wide range of enabling technologies. The systems approach should become the norm in energy and infrastructure planning, financing and policy development.

We also need to intensify efforts to provide modern energy services to the billions of people who lack access. It is crucial that renewable energy and enabling technologies aimed at maximum system flexibility are prioritised, and that the most energy-efficient technologies are used. And rather than investing in fossil fuel or nuclear "baseload" power, efforts should focus on developing dispatchable renewable energy and mobilising flexibility options to manage higher shares of variable renewables.

In an attempt to put the findings of the GSR 2017 in the broader perspective of the global energy transition, the REN21 Secretariat has produced *Advancing the Global Renewable Energy Transition: Highlights of the REN21 Renewables 2017 Global Status Report in Perspective*. This is a complement to the meticulously documented data found in the GSR.

Similar to the field of renewables, the *Renewables Global Status Report* is the sum of many parts. At its heart is a multi-stakeholder network that collectively shares its insight and knowledge. More than 800 experts engage in the GSR process, giving their time, contributing data and providing comment. A big thanks to all of them, as without their invaluable contribution it would not be possible to produce the most comprehensive and accurate overview of the global status of renewable energy available today.

On behalf of the REN21 Secretariat, I would like to thank all those who have contributed to the successful production of this year's report. These include Janet L. Sawin together with lead authoring team members Kristen M. Seyboth and Freyr Sverrisson, the section authors, GSR Project Manager Hannah E. Murdock, Research Coordinator Rana Adib and the dedicated team at the REN21 Secretariat, under the leadership of its Executive Secretary Christine Lins.

Arthouros Zervos

Chair of REN21

RENEWABLE ENERGY POLICY NETWORK FOR THE 21st CENTURY

REN21 is the global renewable energy policy multi-stakeholder network that connects a wide range of key actors. REN21's goal is to facilitate knowledge exchange, policy development and joint action towards a rapid global transition to renewable energy.

REN21 brings together governments, non-governmental organisations, research and academic institutions, international organisations and industry to learn from one another and build on successes that advance renewable energy. To assist policy decision-making, REN21 provides high-quality information, catalyses discussion and debate, and supports the development of thematic networks.

REN21 facilitates the collection of comprehensive and timely information on renewable energy. This information reflects diverse viewpoints from both private and public sector actors, serving to dispel myths about renewable energy and to catalyse policy change. It does this through six product lines:

Global Status Report: yearly publication since 2005

	2004	2005	2006	2007	2008	2009	2010
REN21 publications:		First GSR published				Chinese Renewable Energy Status Report	Indian Renewable Energy Status Report; Renewables Interactive Map
REN21 events:	Renewables 2004, Bonn	BIREC, Beijing International Renewable Energy Conference			WIREC, Washington International Renewable Energy Conference		DIREC, Delhi International Renewable Energy Conference

REN21 PRODUCTS

RENEWABLES GLOBAL STATUS REPORT (GSR)

First released in 2005, REN21's *Renewables Global Status Report* (GSR) has grown to become a truly collaborative effort, drawing on an international network of over 800 authors, contributors and reviewers. Today it is the most frequently referenced report on renewable energy market, industry and policy trends.

REGIONAL REPORTS

These reports detail the renewable energy developments of a particular region; their production also supports regional data collection processes and informed decision making.

RENEWABLES INTERACTIVE MAP

The Renewables Interactive Map is a research tool for tracking the development of renewable energy worldwide. It complements the perspectives and findings of REN21's Global and Regional Status Reports by providing infographics from the reports as well as offering detailed, exportable data packs.

GLOBAL FUTURES REPORTS (GFR)

REN21 produces reports that illustrate the credible possibilities for the future of renewables within particular thematic areas.

RENEWABLES ACADEMY

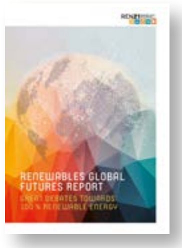
The REN21 Renewables Academy provides an opportunity for lively exchange among the growing community of REN21 contributors. It offers a venue to brainstorm on future-orientated policy solutions and allows participants to actively contribute on issues central to a renewable energy transition.

INTERNATIONAL RENEWABLE ENERGY CONFERENCES (IREC)

The International Renewable Energy Conference (IREC) is a high-level political conference series. Dedicated exclusively to the renewable energy sector, the biennial IREC is hosted by a national government and convened by REN21.

Regional Reports

www.ren21.net/map



Global Futures Reports

REN21 Renewables Academy

REN21 Renewables Academy

International Renewable Energy Conferences

2011
- Global Status Report on Local Renewable Energy Policies

2012

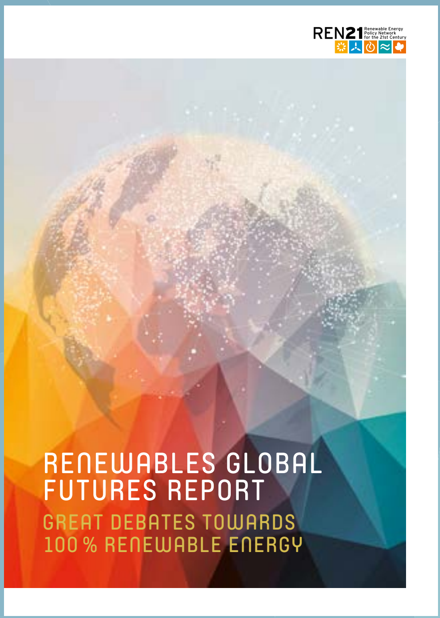
2013
- Global Futures Report
- MENA Renewable Energy Status Report
- ADIREC, Abu Dhabi International Renewable Energy Conference

2014
- ECOWAS Renewable Energy and Energy Efficiency Status Report
- First REN21 Renewables Academy, Bonn

2015
- SADC and UNECE Renewable Energy and Energy Efficiency Status Reports
- Renewables Interactive Map revamp
- SAIREC, South Africa International Renewable Energy Conference

2016
- EAC Renewable Energy and Energy Efficiency Status Report
- First GSR Microsite

2017
- Renewables 100% Global Futures Report
- UNECE Renewable Energy Status Report
- Renewable Energy Tenders and Community [em]Power[ment]
- MEXIREC, Mexico International Renewable Energy Conference, 11-13 September 2017



RENEWABLES GLOBAL FUTURES REPORT: Great debates towards 100% renewable energy

The *Renewables Global Futures Report: Great debates towards 100% renewable energy* was released in April 2017. The report documents global views about the feasibility of achieving a 100% renewable energy future by mid-century.

1. 100% Renewables: A logical consequence of the Paris Agreement?
2. Global Energy Demand Development: Efficiency on a global level?
3. Renewable Power Generation: The winner takes all?
4. The Future of Heating: Thermal or electrical application?
5. Renewables for Transport: Electrification versus biofuels
6. Interconnection of Sectors: System thinking required
7. Storage: Supporter or competitor of the power grid?
8. Technology versus Costs: Which should come first?
9. Scaling Up Investments and Work Force: 100% renewables for socio-economic change
10. Utilities of the Future: What will they look like?
11. Mega Cities: Mega possibilities
12. Energy Access Enabled Through Renewables: How to speed up connections?

While there may be agreement that we need to decarbonise our energy system, there is no one way to achieve this; what works in one country does not necessarily work in another. Finding solutions for some sectors is easier than for others. Views are influenced by different regional perspectives, by the current stage of development within a region and by the part of the energy sector being discussed.

The report analyses the views of over 110 renowned energy experts from around the world who were interviewed over the course of 2016. The results are clustered under topics defined as "12 Great Debates". The report does not predict the future. It is meant to spur debate about the opportunities and challenges of a 100% renewable energy future and, in turn, to support good decision making.

The *Global Futures Report* complements REN21's *Renewables Global Status Report* series. The former presents thinking about how a renewable energy future will evolve; the latter provides a real-time snapshot of what is happening. Decision makers can use the two reports together to plan a trajectory between where we are now and where we need to be to achieve an energy transition with renewables.

The report can be downloaded at www.REN21.net.

ACKNOWLEDGEMENTS

SUSTAINABLE
ENERGY FOR ALL

The UN Secretary-General's initiative Sustainable Energy for All mobilises global action to achieve universal access to modern energy services, double the global rate of improvement in energy efficiency and double the share of renewable energy in the global energy mix by 2030. REN21's *Renewables 2017 Global Status Report* contributes to this initiative by demonstrating the role of renewables in increasing energy access. A chapter on distributed renewable energy – based on input from local experts primarily from developing countries – illustrates how renewables are providing needed energy services and contributing to a better quality of life through the use of modern cooking, heating/cooling and electricity technologies. REN21 is working closely with the SEforALL initiative towards achieving the three objectives of the Decade for Sustainable Energy for All (2014–2024).

The Global Trends in Renewable Energy Investment report (GTR), formerly Global Trends in Sustainable Energy Investment, was first published by the Frankfurt School–UNEP Collaborating Centre for Climate & Sustainable Energy Finance in 2011. This annual report was produced previously (starting in 2007) under UNEP's Sustainable Energy Finance Initiative (SEFI). It grew out of efforts to track and publish comprehensive information about international investments in renewable energy. The latest edition of this authoritative annual report tells the story of the most recent developments, signs and signals in the financing of renewable power and fuels. It explores the issues affecting each type of investment, technology and type of economy. The GTR is produced jointly with Bloomberg New Energy Finance and is the sister publication to the REN21 Renewables Global Status Report (GSR). The latest edition was released in April 2017 and is available for download at www.fs-unep-centre.org.

RESEARCH DIRECTION AND LEAD AUTHORSHIP

Janet L. Sawin (Sunna Research)
Kristin Seyboth (KMS Research and Consulting)
Freyr Sverrisson (Sunna Research)

PROJECT MANAGEMENT AND GSR COMMUNITY MANAGEMENT (REN21 SECRETARIAT)

Rana Adib
Hannah E. Murdock

CHAPTER AUTHORS

Fabiani Appavou (Ministry of Environment and Sustainable Development, Mauritius)
Adam Brown
Ilya Chernyakhovskiy (NREL and 21st Century Power Partnership)
Bärbel Epp (solrico)
Lon Huber (Strategen Consulting)
Christine Lins (REN21 Secretariat)
Jeffrey Logan (NREL and 21st Century Power Partnership)
Lorcan Lyons (Lorcan Lyons Consulting)
Michael Milligan (National Renewable Energy Laboratory (NREL) and 21st Century Power Partnership)
Evan Musolino
Thomas Nowak (European Heat Pump Association)
Pia Otte (Centre for Rural Research)
Janet L. Sawin (Sunna Research)
Kristin Seyboth (KMS Research and Consulting)
Jonathan Skeen (SOLA Future Energy)
Benjamin Sovacool (Aarhus University / University of Sussex)
Freyr Sverrisson (Sunna Research)
Bert Witkamp (AVERE, The European Association for Electromobility)
Owen Zinaman (NREL and 21st Century Power Partnership)

SPECIAL ADVISOR

Adam Brown

RESEARCH AND PROJECT SUPPORT (REN21 SECRETARIAT)

Isobel Edwards, Martin Hullin, Linh H. Nguyen, Satrio S. Prillianto, Katharina Satzinger

COMMUNICATION SUPPORT

Laura E. Williamson, Lewis Ashworth

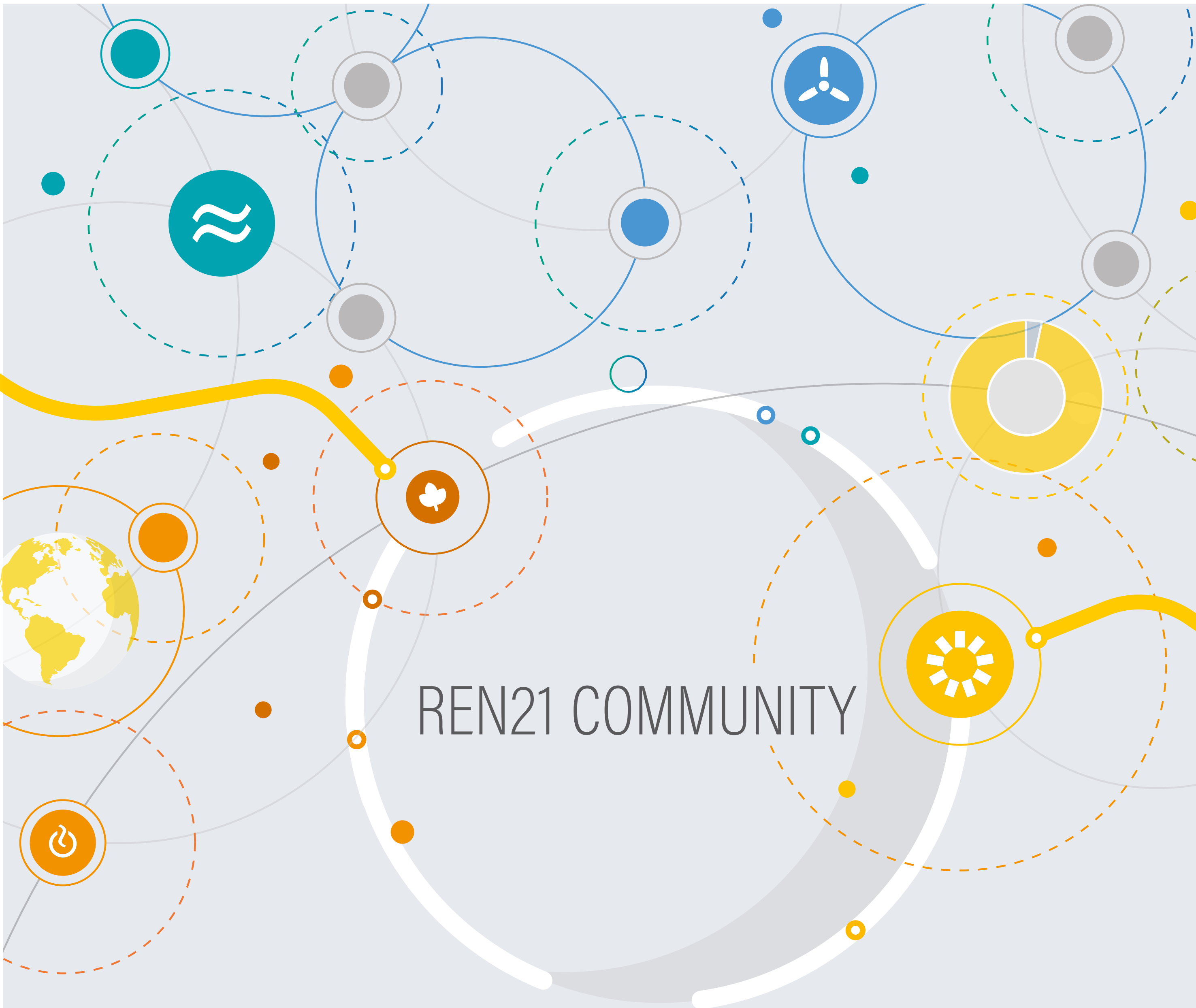
EDITING, DESIGN AND LAYOUT

Lisa Mastny, Editor
weeks.de Werbeagentur GmbH, Design

PRODUCTION

REN21 Secretariat, Paris, France

REN21 COMMUNITY



REN21 is a multi-stakeholder network that spans the private and public sectors. Collectively this network of renewable energy, energy access and energy efficiency experts shares its insight and knowledge, helping the REN21 Secretariat produce its annual *Renewables Global Status Report* as well as regional reports. Today the network has over 800 active contributors and reviewers.

These experts engage in the GSR process, giving their time, contributing data and providing comment in the peer review process. The result of this collaboration is an annual publication that has established itself as the world's most frequently referenced report on the global renewable energy market, industry and policy landscape.

→ Tracking **155** countries

→ Covering **96%** of global GDP

→ Representing **96%** of global population

REN21 Renewable Energy Policy Network for the 21st Century

ACKNOWLEDGEMENTS (continued)

SIDEBAR AUTHORS

Jenny Corry (Collaborative Labelling and Standards Partnership - CLASP)

Rabia Ferroukhi (International Renewable Energy Agency - IRENA)

Celia García-Baños (IRENA)

Matt Jordan (CLASP)

Arslan Khalid (IRENA)

Ari Reeves (CLASP)

Michael Renner (Worldwatch Institute)

Michael Taylor (IRENA)

REGIONAL CONTRIBUTORS

Asia and Oceania

Atul Raturi (University of the South Pacific)

Katerina Syngellakis (Global Green Growth Institute)

Alix Willemez (consultant)

Central and Eastern Africa

Rafael Diezmos, Allan Kinuthia (African Solar Designs)

Fabrice Fouodji Toche (Global Village Cameroon)

Joseph Ngwawi (Southern African Research and Documentation Centre – SARDC)

ECOWAS

Dennis Akande (ECOWAS Centre for Renewable Energy and Energy Efficiency – ECREEE)

Latin America and Caribbean

Gonzalo Bravo; Lucas Furlano (Fundación Bariloche)

Peter Krenz (Deutsche Gesellschaft für Internationale Zusammenarbeit – GIZ)

Middle East and North Africa

Tarek Abdul Razek (Regional Center for Renewable Energy and Energy Efficiency – RCREEE)

LEAD COUNTRY CONTRIBUTORS (continued)

Afghanistan
Ahmad Murtaza Ershad and Hameedullah Zaheb (Kabul University)

Albania
Lira Hakani (EDEN Center), Artan Leskoviku (National Agency of Natural Resources), Erlet Shaqe (Albania Energy Association)

Algeria
Samy Bouchaib (Centre de Développement des Energies Renouvelables)

Argentina
Claudio A. Reineri (Universidad Nacional de Río Cuarto), Gastón A. Turturro (Universidad de Buenos Aires)

Armenia
Levon Vardanyan (Revelle Group)

Australia
Veryan Hann (Pitt & Sherry Engineering, University of Tasmania), Dylan McConnell (Melbourne Energy Institute), Ramadas Narayanan (Central Queensland University)

Austria
Dagmar Henner (University of Aberdeen)

Azerbaijan
Turkay Gasimzade, Rauf Gurbanov, Parvin Mammadzada (State Agency on Alternative and Renewable Energy Sources)

Bangladesh
Syed Ahmed (Rahimafrooz Renewable Energy Ltd.)

Belarus
Hanna Berazanskaya (Belarusian Heat and Power Institute), Vladimir Zui (Belarusian State University)

Belgium
Eros Artuso (ProQuest Consulting Ltd.), Michel Huart (APERe), Dirk Vansintjan (REScoop.eu)

Bolivia
Franklin Molina Ortiz (consultant), Juan Pablo Vargas-Bautista (Private University of Bolivia)

Bosnia and Herzegovina
Slađana Božić and Admir Softic (Ministry of Foreign Trade and Economic Relations of Bosnia and Herzegovina), Eldar Hukić (Regulatory Commission for Energy in the Federation of Bosnia and Herzegovina)

Brazil
Jesse Bortoli Cruz (Instituto de Energia e Ambiente, Universidade de São Paulo – IEE/USP); Maria Beatriz Monteiro (Grupo de Pesquisa em Bioenergia, IEE/USP), Camila Ramos (CELA Clean Energy Latin America), Julio Cesar Madureira Silva (Centro Federal de Educação Tecnológica de Minas Gerais)

Burundi
Jean-Marie Nibizi (SHINE)

Cambodia
Neeraj Joshi (University of Oldenburg)

Canada
Michael Paunescu (Natural Resources Canada), Ian Thomson (Advanced Biofuels Canada)

Chile
Natalia Osorio (Pontificia Universidad Católica de Chile)

China
Frank Haugwitz (Asia Europe Clean Energy (Solar) Advisory Co. Ltd.)

Colombia
Juan Camilo Gómez Trillos (University of Oldenburg), Javier Rodriguez (consultant)

Costa Rica
Mauricio Solano-Peralta (Infratec Ltd.).

Cuba
Gina Carrasco

Ecuador
Sebastian Espinoza (Instituto Nacional de Eficiencia Energética y Energías Renovables - INER)

Egypt
Ahmed Hamza H. Ali (Assiut University), Assem Korayem (RCREEE)

Estonia
Erki Ani (Estonian Renewable Energy Association)

France
Romain Zissler (Renewable Energy Institute)

Georgia
Natalia Jamburia (Ministry of Energy of Georgia), Grigol Jorbenadze (Eco Power), Archil Kokhtashvili (Georgian State Electrosystem), Nato Kurkhuli (Tbilisi City Hall), Murman Margvelashvili (World Experience for Georgia), Maia Tskhvaradze (Ministry of Environment and Natural Resources Protection of Georgia)

ACKNOWLEDGEMENTS (continued)

LEAD COUNTRY CONTRIBUTORS (continued)

Germany
Sebastian Hermann (German Environment Agency), Lars Holstenkamp (Leuphana University of Lüneburg), Stefanie Seitz (Deutsches Biomasseforschungszentrum GmbH - DBFZ), Marco Tepper (BSW-Solar e.V.), Daniela Thrän (Helmholtz-Zentrum für Umweltforschung GmbH – UFZ), Marius Weckel (Smart Hydro Power GmbH)

Greece
Ioannis Tsipouridis (R.E.D. Pro Consultants)

Haiti
Tom Adamson (S. A. Filature et Corderie d'Haiti - SAFICO)

Honduras
Zeron Vanessa (University of Oldenburg)

Iceland
María Guðmundsdóttir (National Energy Authority of Iceland)

India
Raghuraman Chandrasekaran (E-Hands Energy India Private Limited), Kanika Chawla (Council on Energy, Environment and Water), Keshav Jha (ICLEI – Local Governments for Sustainability, South Asia - ICLEI SEAS), Neeraj Joshi (University of Oldenburg), Kamlesh Kholiya (Beroe Consulting Pvt. Ltd), Nikhil Kolsepatil (ICLEI SEAS), Saurabh Kwatra (Innovation, Patents Without Borders), Pallav Purohit (International Institute for Applied Systems Analysis), John Tkacik (Renewable Energy and Energy Efficiency Partnership), Ashish Verma (AMP Solar India)

Indonesia
Wanhar Abdurrachim (Asia Pacific Energy Research Centre - APERC)

Iran
Niloofar Barekati (University of Tehran), Mohammadhosein Seyyedan (SAMANIR)

Israel
Noam Segal (Israel Energy Forum)

Italy
Antonello Di Pardo (Gestore dei Servizi Energetici - GSE), Matteo Giacomo Prina (Politecnico di Milano)

Japan
Takanobu Aikawa (Renewable Energy Institute), Hironao Matsubara (Institute for Sustainable Energy Policies - ISEP)

Jordan
Rabab Saleh (Friedrich-Alexander-Universität Erlangen-Nürnberg), Samer Zawaydeh (Association of Energy Engineers)

Kazakhstan
Raygul Bulekhbayeva (Ministry of Energy, Kazakhstan), Zharas Takenov (consultant)

Kenya
Naomi Wagura (African Solar Designs)

Korea, Republic of
Seong Hoo Lee (Jeonbuk National University)

Kosovo
Ilija Batas Bjelic (University of Belgrade), Noah Kittner (University of California at Berkeley)

Kyrgyzstan
Kasymov Gulsara (Research Institute of Energy and Economy), Melisande F. Liu (Center for International Migration / Unison Group)

Lao PDR
Noah Kittner (University of California at Berkeley)

Lebanon
Sonia Al Zoghoul (RCREEE), Rawad Rizk (RCREEE)

Macedonia, Former Yugoslav Republic of
Aleksandar Dedinec (Macedonia Academy of Sciences and Arts), Darko Janevski (Winrock International)

Malawi
Joss Blamire (Scottish Government on assignment to the Government of Malawi)

Mexico
Julio Eisman (Fundación ACCIONA Microenergia), Luis Carlos Gutierrez-Negrin (GEOCONSUL, S.A. de C.V.), Gabriela Hernández-Luna (Universidad Autónoma del Estado de Morelos), Eduardo René Narváez (Energy Regulatory Commission), Raúl Tauro (Red Mexicana de Bioenergía)

Moldova, Republic of
Ruslan Surugiu (AO Pro-Energy)

Mongolia
Myagmardorj Enkhmend (Mongolian Wind Energy Association)

Montenegro
Sanja Orlandic (Green Home), Jasna Sekulovic (GIZ)

Morocco
El Mostafa Jamea (MENA Renewables and Sustainability – MENARES)

Mozambique
Francis Masawi (Energy and Information Logistics (Pvt) Ltd)

Myanmar
Simon Bittner (GIZ), Christopher Greacen (Palang Thai), Adriana Karpinska (Pact Myanmar)

Nepal
Kushal Gurung (WindPower Nepal)

Netherlands
Luuk Beurskens (Energy Research Centre of the Netherlands - ECN), Tineke van der Schoor (Hanze University of Applied Sciences)

Nigeria
Adedoyin Adeleke, Ayooluwa Adewole (Centre for Petroleum Energy Economics and Law, University of Ibadan), Sunday Udochukwu Bola Akuru (University of Nigeria), David Davies (Renewable Energy Professional Network, UK), Eseoghene Hobson (University of Oldenburg), Shehu Ibrahim Khaleel (Rendanet), Ekene Ngadaonye (PSC Solar), Eromosele Omomhenle (Dimension Data)

Oman
Maimuna Al Farie (Public Authority for Electricity and Water, Oman)

Note: Some individuals have contributed in more than one way to this report. To avoid listing contributors multiple times, they have been added to the group where they provided the most information. In most cases, the lead country, regional, and topical contributors also participated in the Global Status Report (GSR) review and validation process.

LEAD COUNTRY CONTRIBUTORS (continued)

Pakistan
Muhammad Haris Akram (Standing Committee on Scientific and Technological Cooperation of the Organisation of Islamic Cooperation), F.H. Mughal (consultant), Kazim Saeed Akhtar (ZTE Corporation Pakistan), Alizeh Saigal (Nizam Energy), Rafi-us Samad (Renewables Unlimited)

Papua New Guinea
Mauricio Solano-Peralta (Infratec Ltd.)

Paraguay
Fabio Lucantonio (consultant)

Peru
Luis Camacho and Alexander Kabalinskiy (APERC), Pedro Flores (Universidad Nacional San Agustin de Arequipa)

Philippines
Julie Dulce (Meralco), Marvin Lagonera (ICLEI SEAS), Ferdinand Larona (GIZ)

Poland
Izabela Kielichowska (Polish Wind Energy Association)

Portugal
João Graça Gomes and Susana Serôdio (Portuguese Renewable Energy Association - APREN), Hugo Santos (INEGI Porto)

Qatar
Zeineb Abdmouleh (Qatar University), Faraj Saffouri (Cyprus International University)

Romania
Gheorghe Dunca (Faculdade de Ciências da Universidade de Lisboa)

Russian Federation
Talyat Aliev (Ministry of Energy of the Russian Federation), Georgy Ermolenko (University Higher School of Economics)

Saudi Arabia
Roue Yussuf (Creative Group International Inc.)

Serbia
Ilija Batas Bjelic (University of Belgrade), Predrag Milanovic (Ministry of Mining and Energy)

Singapore
Lars Kvale (APX, Inc.)

South Africa
Alan Brent (Centre for Renewable and Sustainable Energy Studies), Arvind Sastry Pidaparthi (Solar Thermal Energy Research Group)

Spain
Concha Canovas (Fundacion Renovables), Juan Francisco Martínez-Berganza (Asensio Institute for Energy Diversification and Saving - IDAE)

Suriname
Roger Sallent (Inter-American Development Bank - IDB)

Sweden
Robert Fischer (Luleå University of Technology)

Switzerland
Laura Antonini (Swiss Federal Office of Energy), Ulrich Reiter (TEP Energy GmbH)

Taipei (China)
Kuang-Jung Hsu (National Taiwan University)

Tajikistan
Timur Valamat-Zade (Ministry of Energy and Industry of the Republic of Tajikistan)

Tanzania
Rachel English (Helios Social Enterprise)

Togo
Sossouga Dosse (Amis des Etrangers au Togo - ADET)

Turkey
Tulin Keskin (Yeşil Güç Energy and Environment Consultancy)

Turkmenistan
Rustam Bekmuradov (consultant)

Ukraine
Andriy Konechenkov (Ukrainian Wind Energy Association), Galyna Trypolska (Institute for Economics and Forecasting, Ukraine National Academy of Science), Juliia Usenko (All-Ukrainian Sustainable Development and Investment Agency)

United Kingdom
Frank Aaskov (Renewable Energy Association, UK), Dagmar Henner (University of Aberdeen)

United States
Robert Sandoli (US Department of Energy)

Uruguay
Gabriela Horta and Wilson Sierra (Ministry of Industry, Energy and Mining)

Uzbekistan
Nizomiddin Rakhmanov (Tashkent State Technical University), Bakhtiyar Sadriddinov (IKS Company)

Vietnam
Linh Dan Nguyen (APERC), Stefan Salow (GIZ)

Zambia
Peter Cattelaens (GIZ Zambia)

Zimbabwe
Nithin Jacob Cherian (University of Oldenburg), Zvirevo Chisadza (International Institute of Engineers), Apoorva Satpathy (University of Oldenburg)

ACKNOWLEDGEMENTS (continued)

LEAD TOPICAL CONTRIBUTORS

Bioenergy

Kjell Andersson (Svebio), Helena Chum (NREL), Suani Coelho and Javier Escobar (Institute of Energy and Environment, University of São Paulo), Gabriela Cretu (Energy Community), Patrick Lamers (Idaho National Laboratory), Tami Sandberg (NREL)

Concentrating Solar Thermal Power

Luis Crespo (European Solar Thermal Electricity Association), Frederick H. Morse (Morse Associates)

Distributed Renewable Energy for Energy Access

Marcel Alers (United Nations Development Programme (UNDP) Global Energy Team), Kirstin Bretthauer (GIZ), Miguel Chamochín (Energias sin Fronteras), Toby Couture (E3 Analytics), Alex Doukas (Oil Change International), Yasemin Erboy (UN Foundation), Cecilia Flatley (Global Alliance for Clean Cookstoves – GACC), David Fullbrook (DNV-GL), Stephan Gnos (REPIC), Sebastian Groh (SOLshare), Felix Heegde (SNV Netherlands Development Organisation), Christoph Henrich (UNDP Global Energy Team), Caitlyn Hughes (Solar Cookers International), Bozhil Kondev (GIZ), Anna Leidreiter (World Future Council), Niemetz Martin (Sustainable Energy for All – SEforALL), Angela Mastronardi (REPIC), Magdalena Muir (University of Calgary), Stefan Nowak (REPIC), Dorothea Otremba (GIZ), Carlos Rubén Pascual Guzmán (SINTEF), Bahareh Seyedi (UNDP Global Energy Team), Scott Sklar (The Stella Group Ltd.), SteamaCo, Yusuf Suleiman (Blue Camel Energy Limited), Laura Sundblad (Global Off-Grid Lighting Association – GOGLA), Thomas Walter (Easy Smart Grid GmbH)

Electric Vehicles

Jose Pontes (EV Volumes)

Energy Efficiency

Tyler Bryant, David Morgado (International Energy Agency – IEA)

Feature

David Infield (University of Strathclyde), Aaron Leopold (Power for All)

Geothermal Power and Heat

Philippe Dumas (European Geothermal Energy Council - EGEC), John Lund (consultant)

Global Overview

Heymi Bahar (IEA), Rainer Hinrichs-Rahlwes (European Renewable Energies Federation), Ernesto Macías Galan (Solarwatt), Ryan Wiser (Lawrence Berkeley National Laboratory)

Heating and Cooling

Inés Arias Iglesias and Dana Popp (Euroheat), Ute Collier (IEA), Miika Rämä (VTT Technical Research Centre of Finland), Gerhard Stryi-Hipp (Fraunhofer Institute for Solar Energy Systems)

Hydropower / Ocean Energy

Nathalie Almonacid (Marine Energy Research and Innovation Center), Josh Klemm (International Rivers), Ana Brito e Melo (WavEC), Mathis Rogner and Richard Taylor (International Hydropower Association)

Investment

Christine Gruening and Karol Kempa (United Nations Environment Programme – Frankfurt School), Angus McCrone (Bloomberg New Energy Finance)

Policy Landscape

Chris Beaton and Richard Bridle (International Institute for Sustainable Development - IISD), Marie-Laetitia Gourdin (Ecopreneurs for the Climate), Lourdes Sanchez (IISD), Jørgen Villy Fenhann (Technical University of Denmark)

Power

Zuzana Dobrotkova (World Bank), Jelte Harnmeijer (Scene Consulting), Anna Leidreiter (World Future Council), Eric O'Shaughnessy (NREL), Gevorg Sargsyan (World Bank), Holger Schneidewindt (Consumer Association of North Rhine-Westphalia, Germany)

Solar PV

Thomas Döring (SolarPower Europe), GTM Research, Denis Lenardič (pvresources), Philippe Macé (Becquerel Institute), **Gaëtan Masson** (Becquerel Institute and IEA Photovoltaic Power Systems Programme), Andrés Pinto-Bello Gomez (SolarPower Europe), Dave Renné (International Solar Energy Society), Michael Schmela (SolarPower Europe)

Solar Thermal Heating and Cooling

Hongzhi Cheng (Shandong SunVision Management Consulting), Jan-Olof Dalenbäck (Chalmers University of Technology), Pedro Dias (European Solar Thermal Industry Federation), Uli Jakob (Green Chiller Verband für Sorptionskälte e.V.), Daniel Mugnier (Tescol), **Monika Spörk-Dür** and **Werner Weiss** (AEE – Institute for Sustainable Technologies – AEE INTEC)

Storage

Jake Bartell and Cedric Christensen (Strategen Consulting); Simon Currie, Rachel Dawes, Kathryn Emmett and Matthijs van Leeuwen (Norton Rose Fulbright)

Transport

Heather Allen (Partnership on Sustainable, Low Carbon Transport - SLoCaT), Robert Boyd (International Air Transport Association), Gabriel Castanares Hernandez (International Union of Railways - UIC), Nick Craven (UIC), Paul Gilbert (University of Manchester), Cornie Huizenga (SLoCaT)

Wind Power

American Wind Energy Association, Stefan Gsänger (World Wind Energy Association - WWEA), Aloys Nghiem (WindEurope), Shi Pengfei (Chinese Wind Energy Association - CWEA), Jean-Daniel Pitteloud (WWEA), **Steve Sawyer** and Shruti Shukla (Global Wind Energy Council), **Feng Zhao** (FTI Consulting)

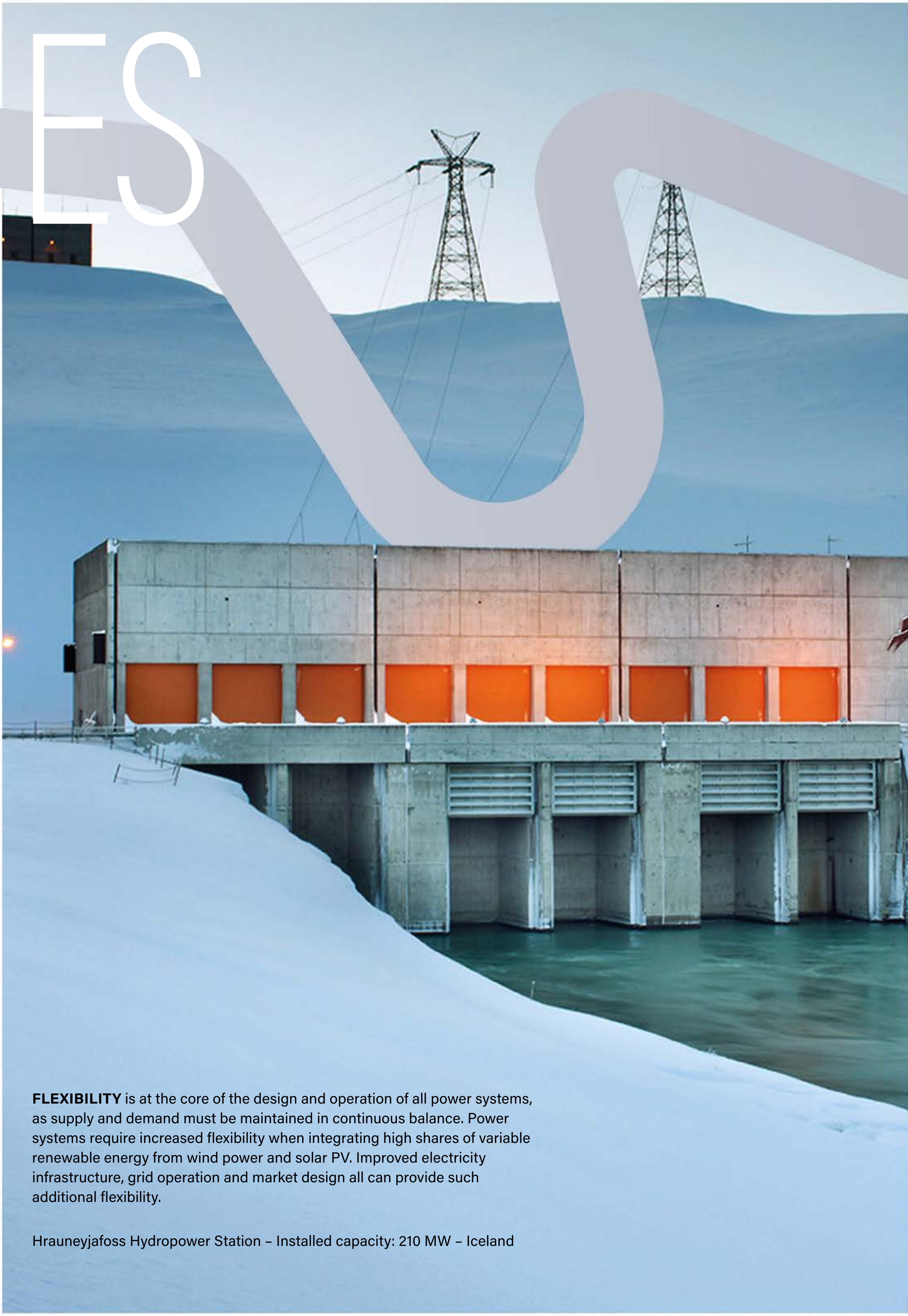
PEER REVIEWERS AND OTHER CONTRIBUTORS

Jordi Abadal Colomina (IDB), Diego Acevedo (Bluerise), Emmanuel Ackom (Denmark Technical University), Max Ahman (Lund University), Klibi Amira (Organisation de l'Agence Nationale pour la Maîtrise de l'Energie), Rachel Andalaft (REA Consult), Doug Arendt (NREL), Jennifer Baca (Solmex), Manjola Banja (European Commission), Alexander Batteiger (TU Berlin), Raffaella Bellanca (consultant), Nikolay Belyakov (Hilti), Luca Benedetti (GSE), Ron Benioff (NREL), Miguel Ángel Benítez Torreblanca (National Autonomous University of Mexico), Anna L. Berka (Scene Connect), Peter Bickel (Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg - ZSW), Rina Bohle Zeller (Vestas), Jan Borchgrevink (Nordteco), Roman Buss (Renewables Academy - RENAC), Catherina Cader (Reiner Lemoine Institut), Concha Canovas del Castillo (Fundación Renovables), Valeria Cantello (Energrid), Emmanuel Chimamkpam (Vibratricity Inc., GACC), Kung-Ming Chung (National Cheng Kung University), Piero De Bonis (European Commission), Krystyna Dawson (BSRIA), Bruno Deremince (European Biogas Association), Johanna Diecker (GOGLA), Paul Donohoo-Vallett (US Department of Energy), Pieter Eikelenboom (Axiturn), David Ferrari (Sustainability Victoria), Ezequiel Ferrer (SolarPACES), Daniel Garcia (Fabricantes Mexicanos en las Energías Renovables A.C. - FAMERAC), Christian Gertig (consultant), Marlen Görner (GIZ), Rakesh Goyal (Tetra Tech), Matthew Gravatt (Sierra Club), Ken Guthrie (Sustainable Energy Transformation Pty Ltd), Abiola Hammed (Centre for Petroleum, Energy Economics and Law), Edgar Hernan Cruz Martinez (SQ Consult B.V.), Harald Hirschhofer (The Currency Exchange Fund), Birte Holst Jørgensen (Technical University of Denmark), Christian Holter (S.O.L.I.D.), Andrei Ilas (IRENA), Jacob Irving (Canadian Hydropower Association), Arnulf Jaeger-Waldau (European Commission, Joint Research Centre (EC JRC), Berend Jan Kleute (Delft University of Technology), Rod Janssen (Energy In Demand), Ranndolf Javier (AC Energy Development Co., Inc.), Rashmi Jawahar Ganesh (UN Environment), He Jieying (CWEA), Patrick Jochem (Institute for Industrial Production), Izabela Kielichowska (Polish Wind Energy Association), Wim Jonker Klunne (Energy & Environment Partnership), Aris Karcanias (FTI Consulting), John Keane (GOGLA), Binod Prasad Koirala (TU Delft), Karin Kritzinger (Stellenbosch University), Arun Kumar (Indian Institute of Technology, Roorkee), Bikash Kumar Sahu (Gandhi Institute for Education and Technology), Sigrid Kusch (University of Padua), Oliver Lah (Wuppertal Institute), Benoît Lebot (International Partnership for Energy Efficiency Cooperation), Debora Ley (Latinoamérica Renovable), Detlef Loy (Loy Energy Consulting), Jaideep Malaviya (Solar Thermal Federation of India), Ana Marques (ICLEI), Romain Mauger (North West University), Marcelo Mesquita (ABRASOL), Simon Müller (IEA), Julia Münch (Fachverband Biogas e.V.), Frederico Musazzi (Anima), Om Prakash Nangia (New Era Solar Solutions), Les Nelson (International Association of Plumbing and Mechanical Officials), Jan Erik Nielsen (PlanEnergi), Dorothea Otremba (GIZ), Binu Parthan (Sustainable Energy Associates), Karl Peet (SLoCaT), Josep Puig (Eurosolar Spain), Randy Rakhmadi (Climate Policy Initiative), Anjali Ramakrishna (Council on Energy, Environment and Water), Robert Rapier (consultant), Shirin Reuvers (Driving Sustainable Economies - CDP), Christoph Richter (Deutsches Zentrum für Luft- und Raumfahrt e.V. - DLR), Wilson Rickerson (Rickerson Energy), Roberto Román (University of Chile), Heather Rosmarin (InterAmerican Clean Energy Institute), Jo Rowbotham (Tewhiti), Kumiko Saito (Solar System Development Association), Kaare Sandholt (China National Renewable Energy Centre), Burkhard Sanner (EGEC), Michael Schimpe (Technical University of Munich), Miguel Schloss (Surinvest Ltd.), Stephanie Searle (International Council on Clean Transportation), Smail Semaoui (Renewable Energy Development Center Algeria), Eder Semedo (ECREEE), Lovemore Seveni (US Agency for International Development - USAID), Eli Shilten (Elson), Tejas P Shinde (ICLEI), Galyna Shmidt (Ukranian Wind Energy Association), Ruth Shortall (EC JRC), Ralph Sims (Massey University College of Sciences), Anoop Singh (Indian Institute of Technology, Kanpur), Yogesh Singh (National Institute of Solar Energy India), Emilio Soberón Bravo (Mexico Low Emission Development Program (MLED-II) of USAID), Karla Solis (United Nations Framework Convention on Climate Change), Janusz Starościk (Association of Manufacturers and Importers of Heating Appliances - SPIUG), David Stickelberger (Swissolar), Geoff Stiles (Carbon Impact Consultants), Paul Suding (elsud), Emaan Tabet (Qatar Foundation), Cecilia Tam (APERC), Pierre Telep (GIZ), Marco Tepper (BSW-Solar), Sven Teske (University of Technology Sydney), Tony Tiyou (O'wango & TT Smart, UK), Ralph Torrie (Torrie Smith Associates), Lana Tran (California Public Utilities Commission), Costas Travasaros (Greek Solar Industry Association - EBHE), Daniel Trier (PlanEnergi), Ramiro Juan Trujillo Blanco (TRANSTECH), Maloba Tshehla (GreenCape), Kutay Ulke (Bural Heating), James Vandeputte (US Department of Energy), Arnaldo Vieira de Carvalho (IDB), Olola Vieyra Mifsud (consultant), Thibaud Voïta (SEforALL), René Vossenaar (consultant), Brian Walker (US Department of Energy), Frank Wilkins (CSP Alliance), William Wills (EOS Environmental), Qiaoqiao Xu (ICLEI East Asia), Dai Yanjun (Shanghai Jiao Tong University), Komali Yenneti (Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences), Irfan Yousuf (Alternative Energy Development Board of Pakistan), Sufang Zhang (North China Electric Power University), Gaetano Zizzo (Università di Palermo).

LEAD AUTHOR EMERITUS

Eric Martinot (ISEP)

ES



FLEXIBILITY is at the core of the design and operation of all power systems, as supply and demand must be maintained in continuous balance. Power systems require increased flexibility when integrating high shares of variable renewable energy from wind power and solar PV. Improved electricity infrastructure, grid operation and market design all can provide such additional flexibility.

Hrauneyjafoss Hydropower Station – Installed capacity: 210 MW – Iceland

EXECUTIVE SUMMARY

1. GLOBAL OVERVIEW

Renewable energy technologies increase their hold across developing and emerging economies throughout the year

The year 2016 saw several developments and ongoing trends that all have a bearing on renewable energy, including the continuation of comparatively low global fossil fuel prices; dramatic price declines of several renewable energy technologies; and a continued increase in attention to energy storage.

For the third consecutive year, global energy-related carbon dioxide emissions from fossil fuels and industry were nearly flat in 2016, due largely to declining coal use worldwide but also due to improvements in energy efficiency and to increasing use of renewable energy.

As of 2015, renewable energy provided an estimated 19.3% of global final energy consumption, and growth in capacity and production continued in 2016. The power sector experienced the greatest increases in renewable energy capacity in 2016, whereas the growth of renewables in the heating and cooling and transport sectors was comparatively slow.

Most new renewable energy capacity is installed in developing countries, and largely in China, the single largest developer of renewable power and heat over the past eight years. In 2016, renewable energy spread to a growing number of developing and emerging economies, some of which have become important markets.

For the more than 1 billion people without access to electricity, distributed renewable energy projects, especially those in rural areas far from the centralised grid, offer important and often cost-effective options to provide such access.

The renewable energy sector employed 9.8 million people in 2016, an increase of 1.1% over 2015. By technology, solar PV and biofuels provided the largest numbers of jobs. Employment shifted further towards Asia, which accounted for 62% of all renewable energy jobs (not including large-scale hydropower), led by China.

The development of community renewable energy projects continued in 2016, but the pace of growth in some countries is in decline. In a new trend, such projects have begun to expand into energy retailing (supply), storage and demand-side management.

Government policy at all levels remained important for renewable energy developments. The 2015 Paris Agreement of the United Nations Framework Convention on Climate Change (UNFCCC) formally entered into force at the 22nd Conference of the Parties (COP22) in November 2016. However, renewable energy markets were affected only indirectly during the year. A number of governments implemented new renewable energy targets, and several cities established new commitments to 100% renewable energy. Despite the importance of the heat and transport sectors to energy demand and global emissions, policy makers focused predominantly on the power sector.

POWER

Record numbers reached for newly installed renewable power generating capacity

Renewable power generating capacity saw its largest annual increase ever in 2016, with an estimated 161 gigawatts (GW) of capacity added. Total global capacity was up nearly 9% compared to 2015, to almost 2,017 GW at year's end. The world continued to add more renewable power capacity annually than it added (net) capacity from all fossil fuels combined. In 2016, renewables accounted for an estimated nearly 62% of net additions to global power generating capacity.

Solar PV saw record additions and, for the first time, accounted for more additional capacity, net of decommissioning, than did any other power generating technology. Solar PV represented about 47% of newly installed renewable power capacity in 2016, and wind and hydropower accounted for most of the remainder, contributing 34% and 15.5%, respectively.

The ongoing growth and geographical expansion of renewable power capacity was driven by the continued decline in prices for renewable energy technologies; by rising power demand in some countries; and by targeted renewable energy support mechanisms. Some well-established renewable energy technologies, such as hydropower and geothermal energy, have long since become cost-competitive with fossil fuels where resources are plentiful. Solar PV and wind power are now joining in, challenging fossil fuels in a growing number of locations.

Plants owned by utilities or large investors dominated renewable electricity production in 2016, and the scale of renewable energy plants continued to grow. Major corporations and institutions around the world continued to make large commitments to purchase renewable electricity.

HEATING AND COOLING

Modest improvements achieved, but renewable heating and cooling still constrained by low fossil fuel prices and lack of policy support

Modern renewable energy supplies approximately 9% of total global heat demand. In 2016, the vast majority of renewable heat continued to be supplied by biomass, with smaller contributions from solar thermal and geothermal energy. While additional capacities of modern bio-heat and solar thermal were installed in 2016, growth in both markets has slowed.

District heating systems are incorporating solar thermal energy for larger installations. Interest is expanding in the use of district heating as a way to provide flexibility to power systems, by storing energy from the electric power grid as heat, which reflects a more general increased interest in the electrification of the heating sector.

Continued improvements of materials, systems and industrial processes in the heating and cooling sector facilitated increases in renewable energy use. In general, however, deployment of renewable technologies in this market continued to be constrained by a number of factors including comparatively low fossil fuel prices and a relative lack of policy support.

TRANSPORT

Liquid biofuels remain the primary renewable energy in the transport sector, but electrification continues to expand

Liquid biofuels continued to represent the vast majority of the renewable energy contribution to the transport sector. In 2016, they provided around 4% of world road transport fuels, which account for the majority of transport energy use.

Biogas use in transport grew substantially in the United States and continued to gain shares of the transport fuel mix in Europe. Although other regions have established natural gas infrastructure into which biogas could be incorporated, deployment has remained limited.

Electrification of the transport sector expanded during the year. Direct links between renewable energy and electric vehicles (EVs) were few, but the share of renewables in electrified transport is rising as the share of renewables in grid power increases. Further electrification of the transport sector has the potential to create a new market for renewable energy and to facilitate the integration of variable renewable energy.

Policy support for renewable energy in the transport sector lags behind such support in the power sector. While there was increased attention to the decarbonisation of transport at the international level in 2016, direct links with renewable energy were limited in this arena as well.

RENEWABLE ENERGY INDICATORS 2016

		2015	2016
INVESTMENT			
New investment (annual) in renewable power and fuels[1]	billion USD	312.2	**241.6**
POWER			
Renewable power capacity (total, not including hydro)	GW	785	**921**
Renewable power capacity (total, including hydro)	GW	1,856	**2,017**
Hydropower capacity[2]	GW	1,071	**1,096**
Bio-power capacity	GW	106	**112**
Bio-power generation (annual)	TWh	464	**504**
Geothermal power capacity	GW	13	**13.5**
Solar PV capacity	GW	228	**303**
Concentrating solar thermal power capacity	GW	4.7	**4.8**
Wind power capacity	GW	433	**487**
HEAT			
Solar hot water capacity[3]	GW_{th}	435	**456**
TRANSPORT			
Ethanol production (annual)	billion litres	98.3	**98.6**
Biodiesel production (annual)	billion litres	30.1	**30.8**
POLICIES			
Countries with policy targets	#	173	**176**
States/provinces/countries with feed-in policies	#	110	**110**
States/provinces/countries with RPS/quota policies	#	100	**100**
Countries with tendering/public competitive bidding[4]	#	16	**34**
Countries with heat obligation/mandate	#	21	**21**
States/provinces/countries with biofuel mandates[5]	#	66	**68**

[1] Investment data are from Bloomberg New Energy Finance and include all biomass, geothermal and wind power projects of more than 1 MW; all hydro projects of between 1 and 50 MW; all solar power projects, with those less than 1 MW estimated separately; all ocean energy projects; and all biofuel projects with an annual production capacity of 1 million litres or more.

[2] The GSR 2016 reported a global total of 1,064 GW of hydropower capacity at end-2015. The value of 1,071 GW shown here reflects the difference between end-2016 capacity (1,096 GW) and new installations in 2016 (25 GW). Differences are explained in part by uncertainty regarding capacity retirements and plant repowering each year. Note also that the GSR strives to exclude pure pumped storage capacity from hydropower capacity data.

[3] Solar hot water capacity data include water collectors only. The number for 2016 is a preliminary estimate.

[4] Data for tendering/public competitive bidding reflect all countries that have held tenders at any time up through the year of focus.

[5] Biofuel policies include policies listed both under the biofuels obligation/mandate column in Table 3 (Renewable Energy Support Policies) and in Reference Table R25 (National and State/Provincial Biofuel Blend Mandates).

Note: All values are rounded to whole numbers except for numbers <15, biofuels and investment, which are rounded to one decimal point.

2. MARKET AND INDUSTRY TRENDS

BIOMASS ENERGY

Despite challenges, bioenergy production increases

Despite a number of challenges, in particular from low oil prices and policy uncertainty in some markets, bioenergy production continued to increase in 2016. Bioenergy development and deployment activities continued spreading into new regions and countries, noticeably in India, and some promising initial developments also were seen in Africa.

Bio-heat production grew slowly in 2016, although the use of bioenergy in industry has stabilised in recent years. Bio-power production has increased more quickly – by some 6% in 2016 – with rapid growth in the European Union (EU) and in Asia, where generation rose particularly sharply in the Republic of Korea.

Global ethanol production was stable, with record levels in the United States and sharp increases in China and India. The year also saw new initiatives in Africa, notably in Nigeria and South Africa. Global production of biodiesel recovered after a fall in 2015, with particularly strong growth in Indonesia and Argentina. Production of hydrotreated vegetable oil (HVO) increased 20% in 2016. Biomethane use in transport also grew sharply, due largely to growth in the United States, stimulated by the Renewable Fuel Standard.

The year saw continuing progress in the commercialisation and development of advanced biofuels, with expansion in the capacity and production of fuels by both thermal and biological routes and the announcement of new plants in China and India, widening the geographical range of such facilities.

GEOTHERMAL POWER AND HEAT

Geothermal industry sees measured progress in some key markets

The geothermal industry continued to face challenges in 2016, burdened by the inherent high risk of geothermal exploration and project development, the associated lack of risk mitigation, and the constraints of financing and competitive disadvantage relative to low-cost natural gas. Yet the industry made progress with new project developments in key markets, and industry leaders cemented partnerships to pursue new opportunities.

Indonesia and Turkey each added about 200 megawatts (MW) of capacity, representing the bulk of additions in 2016 for a total of 13.5 GW. Globally, geothermal power produced an estimated 78 terawatt-hours (TWh) during the year. Geothermal direct use amounted to an estimated 286 petajoules (PJ) in 2015 (79 TWh). Expansion of geothermal direct use continued in 2016, including in several district heating systems in Europe.

HYDROPOWER

Global generation of hydropower rises, with China retaining the global lead; climate risk remains a pressing concern for the industry

At least 25 GW of new hydropower capacity (excluding pumped storage) was commissioned in 2016, increasing global capacity to approximately 1,096 GW. Drought conditions improved notably in the Americas and Asia; it is estimated that global generation rose by more than 3% relative to 2015, to about 4,100 TWh. China's domestic market continued to contract, but the country retained the global lead with 8.9 GW added. Significant capacity also was added in Brazil, Ecuador, Ethiopia, Vietnam, Peru, Turkey, Lao PDR, Malaysia and India.

Modernisation and retrofitting of existing facilities continues to be a significant part of industry operations, including the implementation of advanced control technologies and data analytics for digitally enhanced power generation. Climate risk in the context of project financing and operations remains a pressing concern for the industry, and efforts were made to improve understanding of the climate impacts of hydropower projects as well as of their climate mitigation benefits and resilience.

Ocean Energy

Ocean energy companies continue to advance and deploy their technologies

For the ocean energy industry, the year was similar to 2015, with a growing number of companies around the world advancing their technologies and deploying new and improved devices. However, commercial success for ocean energy technologies remained in check due to perennial challenges. These include financing obstacles in an industry characterised by relatively high risk and high upfront costs and by the need for improved planning, consenting and licensing procedures. Global ocean energy capacity, mostly tidal power generation, was about 536 MW by the end of 2016.

SOLAR PHOTOVOLTAICS (PV)

Solar PV leads the way in power generating capacity and is considered a cost-competitive source of new generation in many emerging markets across the world

Solar PV was the world's leading source of additional (net of decommissioning) power generating capacity in 2016. The annual market increased nearly 50% to at least 75 GWdc – equivalent to more than 31,000 solar panels installed every hour – raising the global total to at least 303 GWdc. The top five countries, led by China, accounted for 85% of additions. Yet emerging markets on all continents are contributing significantly to global growth, and many see solar PV as a cost-competitive source for increasing electricity production and for providing energy access.

Nevertheless, markets in most locations continue to be driven largely by government policies.

Despite tremendous demand growth, the year brought unprecedented price reductions, particularly for modules. Downwards pressure on prices has challenged manufacturers. But declining capital expenditures and improving capacity factors are helping to make solar PV increasingly competitive with traditional power sources, and new record low bids were set in tenders in 2016. Falling prices and rising demand lured new players into the industry, including electric utilities and oil and gas companies.

At least 17 countries had enough solar PV capacity by year's end to meet 2% or more of their electricity demand, and several countries met far higher shares during 2016, including Honduras (9.8%), Italy (7.3%), Greece (7.2%) and Germany (6.4%).

CONCENTRATING SOLAR THERMAL POWER (CSP)

Integration of thermal energy storage into CSP plants is enabling the provision of dispatchable power

In 2016, 110 MW of concentrating solar thermal power (CSP) capacity came online, bringing global capacity to more than 4.8 GW by year's end. This was the lowest annual growth rate in total global capacity in 10 years, at just over 2%. Even so, CSP remains on a strong growth trajectory, with as much as 900 MW expected to enter operation during the course of 2017.

For the second year in a row, all new facilities that came online incorporated thermal energy storage (TES), which is now seen as central to the value that CSP technology can add by providing dispatchable power to grids with high penetrations of variable renewables. Parabolic trough and tower technologies continued to dominate the market.

CSP furthered its push into developing countries that have high direct normal irradiance (DNI) levels and specific strategic and/or economic alignment with the benefits of CSP technology. In this respect, CSP is receiving increased policy support in countries with limited oil and gas reserves, constrained power networks, a need for energy storage, or strong industrialisation and job creation agendas. Research and development – under way in Australia, Europe, the United States and elsewhere – continued to focus on improvements in TES.

SOLAR THERMAL HEATING AND COOLING

Capacity grows worldwide and across different sectors, despite market challenges

Approximately 36.7 gigawatts-thermal (GW_{th}) of new solar thermal capacity was commissioned in 2016, increasing total global capacity by 5% to approximately 456 GW_{th}. China accounted for about 75% of global additions, followed by Turkey, Brazil, India and the United States. Moreover, globalisation of solar thermal heating and cooling technologies continued with sales picking up in several new emerging markets, including Argentina, the Middle East and parts of Eastern and Central Africa.

The year 2016 was challenging in the larger, established markets due to a number of factors, including low oil and gas prices; declining demand from homeowners, long the core market segment for the solar thermal industry; and reduced interest in solar thermal technology among installers. Many suppliers of these systems responded by successfully diversifying their portfolios for commercial clients.

Significant growth was registered in several non-residential segments. In Denmark, the installed area of new solar district heating almost doubled relative to 2015, increasing interest in other European countries, especially Germany, which saw intensive project development during 2016. Air collector systems for drying agricultural products had a strong year in Germany and Austria. The use of solar thermal technologies in industry expanded quickly in Mexico and India in particular. Solar cooling systems are used increasingly in sun-rich countries to supply cooling in commercial and public buildings in conjunction with year-round solar hot water.

WIND POWER

Onshore wind power proves competitive; offshore wind power in Europe sees record-low bid prices

Almost 55 GW of wind power capacity was added in 2016, bringing the global total to nearly 487 GW. China again led for new installations, despite a significant decline in the country's annual market. Asia represented about half of added capacity, with Europe and North America accounting for most of the rest, but new markets continued to open around the world. By year's end, more than 90 countries had seen commercial activity. At least 24 countries met 5% or more of their annual electricity demand with wind power in 2016, and at least 13 met more than 10%.

The year 2016 was good for top turbine manufacturers, and technology innovation continued in the face of competition from low-cost natural gas and, increasingly, from solar PV. Challenges to the industry included curtailment, particularly in China, and policy uncertainty.

Onshore wind power is the most cost-effective option for new grid-based power in an increasing number of markets. Offshore, about 2.2 GW of capacity was connected to grids, including the first commercial projects in the Republic of Korea and the United States, and substantial new capacity in Germany, the Netherlands and China. In Europe, offshore wind power saw record low bids for tenders in Denmark and the Netherlands, bringing the region's industry closer to its goal to produce offshore wind power more cheaply than coal by 2025.

3. DISTRIBUTED RENEWABLE ENERGY FOR ENERGY ACCESS

DRE deployment expands in the developing world, although financing remains limited

Approximately 1.2 billion people (about 16% of the global population) live without electricity, and about 2.7 billion people (38% of the global population) are without clean cooking facilities. The vast majority of people without access to both electricity and clean cooking are in sub-Saharan Africa and in the Oceania region, and most of them live in rural regions.

New business models and technologies are accelerating access to distributed renewable energy (DRE) systems in the developing world. The old paradigm of energy access through grid extension alone is becoming obsolete as bottom-up customer demand is motivating hundreds of millions of households to generate their own modern energy to provide services through off-grid units or community-scale mini-grids. Mobile technology, Pay-As-You-Go (PAYG) business models, the availability of microloans, the viability of micro-grids and falling technology prices continue to support DRE deployment worldwide. The most popular business models within the DRE sector in 2016 were distributed energy service companies (DESCOs) for mini/micro/pico-grids, the PAYG model for stand-alone systems, and microfinance and microcredit.

Perhaps the biggest barrier to universal access to DRE systems is lack of investment. Funding from multilateral organisations and bilateral donors continued to be the main source of financing for energy access investments, although DRE investment accounts for only a fraction of their energy access investment portfolios.

In 2016, many countries implemented policy measures aiming to support DRE deployment, including dedicated electrification targets, fiscal incentives, regulations, auctions and exemptions on value-added tax (VAT) and import duties. Quality Assurance (QA) frameworks also were adopted, particularly for off-grid solar products, to reduce the sale of low-quality products on the market.

4. INVESTMENT FLOWS

Investment declines, but installation of renewable power capacity worldwide hits a record high

Global new investment in renewable power and fuels (not including hydropower projects larger than 50 MW) was USD 241.6 billion in 2016[i]. Although this represents a decrease of 23% compared to 2015, the decline accompanied a record installation of renewable power capacity worldwide. Investment in renewable power and fuels has exceeded USD 200 billion per year for the past seven years. Including investments in hydropower projects larger than 50 MW, total new investment in renewable power and fuels was at least USD 264.8 billion in 2016.

For the fifth consecutive year, investment in new renewable power capacity (including all hydropower) was roughly double that in fossil fuel generating capacity. Investment in renewables continued to focus on solar power, followed closely by wind power, although investment in both sectors was down relative to 2015. Asset finance of utility-scale[ii] projects, such as wind farms and solar parks, dominated investment during the year, at USD 187.1 billion. Small-scale solar PV installations (less than 1 MW) accounted for USD 39.8 billion worldwide, representing a decline of 28%.

Developing and emerging economies overtook developed countries in renewable energy investment for the first time in 2015, but developed countries retook the lead in 2016. Investment in developing and emerging countries dropped by 30% to USD 116.6 billion, while that in developed countries fell 14% to USD 125 billion.

Trends in renewable energy investment varied by region in 2016, with investment up in Europe and Australia; down in China, the United States, the Middle East, Africa, Asia-Oceania (except Australia) and Latin America; and stable in India. China accounted for 32% of all financings of renewable energy, followed by Europe (25%), the United States (19%) and Asia-Oceania (excluding China and India; 11%), and the Americas (excluding Brazil and the United States), Brazil, and the Middle East and Africa accounted for 3% each.

There were two main reasons for the decline in investment in renewable energy during 2016. One was the slowdown in investments in Japan, China and some other emerging countries. The other was the significant cost reductions in solar PV and in onshore and offshore wind power, which also improved the cost-competitiveness of those technologies. The result was that in 2016 investors were able to acquire more renewable energy capacity for less money.

i Investment-related data do not include hydropower projects larger than 50 MW, except where specified.

ii "Utility-scale" refers to wind farms, solar parks and other renewable power installations of 1 MW or more in size, and to biofuel production facilities with capacity exceeding 1 million litres.

TOP FIVE COUNTRIES

Annual Investment / Net Capacity Additions / Production in 2016

	1	2	3	4	5
Investment in renewable power and fuels (not including hydro > 50 MW)	**China**	United States	United Kingdom	Japan	Germany
Investment in renewable power and fuels per unit GDP[1]	**Bolivia**	Senegal	Jordan	Honduras	Iceland
Geothermal power capacity	**Indonesia**	Turkey	Kenya	Mexico	Japan
Hydropower capacity	**China**	Brazil	Ecuador	Ethopia	Vietnam
Solar PV capacity	**China**	United States	Japan	India	United Kingdom
Concentrating solar thermal power (CSP) capacity[2]	**South Africa**	China	–	–	–
Wind power capacity	**China**	United States	Germany	India	Brazil
Solar water heating capacity	**China**	Turkey	Brazil	India	United States
Biodiesel production	**United States**	Brazil	Argentina/Germany/Indonesia		
Fuel ethanol production	**United States**	Brazil	China	Canada	Thailand

Total Capacity or Generation as of End-2016

	1	2	3	4	5
POWER					
Renewable power (incl. hydro)	**China**	United States	Brazil	Germany	Canada
Renewable power (not incl. hydro)	**China**	United States	Germany	Japan	India
Renewable power capacity *per capita* (not including hydro[3])	**Iceland**	Denmark	Sweden/Germany		Spain/Finland
Bio-power generation	**United States**	China	Germany	Brazil	Japan
Geothermal power capacity	**United States**	Philippines	Indonesia	New Zealand	Mexico
Hydropower capacity[4]	**China**	Brazil	United States	Canada	Russian Federat.
Hydropower generation[4]	**China**	Brazil	Canada	United States	Russian Federat.
CSP capacity	**Spain**	United States	India	South Africa	Morocco
Solar PV capacity	**China**	Japan	Germany	United States	Italy
Solar PV capacity *per capita*	**Germany**	Japan	Italy	Belgium	Australia/Greece
Wind power capacity	**China**	United States	Germany	India	Spain
Wind power capacity *per capita*	**Denmark**	Sweden	Germany	Ireland	Portugal
HEAT					
Solar water heating collector capacity[5]	**China**	United States	Turkey	Germany	Brazil
Solar water heating collector capacity *per capita*[5]	**Barbados**	Austria	Cyprus	Israel	Greece
Geothermal heat capacity[6]	**China**	Turkey	Japan	Iceland	India
Geothermal heat capacity *per capita*[6]	**Iceland**	New Zealand	Hungary	Turkey	Japan

[1] Countries considered include only those covered by Bloomberg New Energy Finance (BNEF); GDP (at purchasers' prices) data for 2015 from World Bank. BNEF data include the following: all biomass, geothermal and wind power projects of more than 1 MW; all hydropower projects of between 1 and 50 MW; all solar power projects, with those less than 1 MW (small-scale capacity) estimated separately; all ocean energy projects; and all biofuel projects with an annual production capacity of 1 million litres or more. Small-scale capacity data used to help calculate investment per unit of GDP cover only those countries investing USD 200 million or more.

[2] Only two countries brought CSP plants online in 2016, which is why no countries are listed in places 3, 4 and 5.

[3] Per capita renewable power capacity (not including hydropower) ranking based on data gathered from various sources for more than 70 countries and on 2015 population data from World Bank.

[4] Country rankings for hydropower capacity and generation differ because some countries rely on hydropower for baseload supply whereas others use it more to follow the electric load and to match peaks in demand.

[5] Solar water heating collector rankings for total capacity and per capita are for year-end 2015 and are based on capacity of water (glazed and unglazed) collectors only. Data from International Energy Agency Solar Heating and Cooling Programme. Total capacity rankings are estimated to remain unchanged for year-end 2016.

[6] Not including heat pumps.

Note: Most rankings are based on absolute amounts of investment, power generation capacity or output, or biofuels production; if done on a basis of per capita, national GDP or other, the rankings would be different for many categories (as seen with per capita rankings for renewable power not including hydropower, solar PV, wind power, solar water collector and geothermal heat capacity).

5. POLICY LANDSCAPE

New or revised renewable energy targets have been adopted in all regions; policy makers continue to implement a range of support policies

As of 2016, nearly all countries supported renewable energy development and deployment directly through some mix of policies enacted at the national, sub-national and local levels. Policy makers continued to implement a range of renewable energy targets and direct support policies during the year to attract investment, drive deployment, foster innovation, encourage greater flexibility in energy infrastructure and support the development of enabling technologies such as energy storage.

New or revised targets were adopted in all regions of the globe in 2016. Notably, at COP22 leaders of 48 developing nations committed to work towards achieving 100% renewable energy in their respective nations. Throughout the year, 117 countries submitted their first Nationally Determined Contributions (NDCs) under the Paris Agreement, and 55 of these countries featured renewable energy targets.

A broad range of policies – including feed-in tariffs (FITs), tendering, net metering and fiscal incentives – provided support aimed at economy-wide economic development, environmental protection and national security. Technology advances, falling costs and rising penetration of renewables in many countries also have continued to require that policies evolve to stimulate both deployment and integration as effectively as possible. As in past years, policy support was focused mostly on the power sector, whereas support for renewable technologies in the heating and cooling and transport sectors has developed at a slower pace.

POLICIES FOR ELECTRICITY

The power sector continues to be the primary focus of renewable energy policy support

FITs remained the most widely utilised form of regulatory support to the renewable power sector. However, tenders (competitive bidding or auctions) for renewable energy are the most rapidly expanding form of support for renewable energy project deployment and are becoming the preferred policy tool for supporting deployment of large-scale projects. During 2016, several countries – including Malawi and Zambia – held their first renewable energy tenders, and China tendered 5.5 GW of capacity. Poland, Greece and Slovenia all adopted hybrid policy schemes that support small-scale projects through FITs and large projects through tenders. Decision makers in many countries continued to advance policies to facilitate integration of variable renewable generation into national energy systems.

POLICIES FOR HEATING AND COOLING

Renewable heating and cooling technologies see support through mandates and incentives

Policy makers continued to focus on financial incentives in the form of grants, loans or tax incentives to increase deployment of renewable heating and cooling technologies. In addition, some enacted policies designed to advance technological development. Several countries, including Bulgaria, Chile, Hungary, Italy, the Netherlands, Portugal, Romania, the Slovak Republic and the United States enacted new financial support mechanisms or revised existing ones; in South Africa, bidding closed for the country's long-delayed solar water heater supply, delivery and warehousing tender. Despite these positive developments, the renewable heating and cooling sector faced policy uncertainty in several countries.

RENEWABLE ENERGY TRANSPORT POLICIES

Biofuels for road transport attract continued attention from policy makers, while aviation and maritime sectors make slow progress

Biofuel blend mandates and financial incentives for biofuel blending programmes remained the most common forms of support for renewable energy in the transport sector. Despite ongoing debates over biofuel production and use, including sustainability concerns, biofuel support policies were adopted throughout 2016. Biofuel blend mandates were added or revised in Argentina, India, Malaysia, Panama and Zimbabwe, and the United States released new blending mandates under its Renewable Fuel Standard. The year also brought increased policy support for development and use of advanced biofuels, including Denmark's advanced biofuels mandate.

CITY AND LOCAL GOVERNMENT RENEWABLE ENERGY POLICIES

The number of cities around the world committing to 100% renewable energy continues to grow

Local policy makers have spearheaded the promotion of renewable energy in municipalities around the world through the use of their unique purchasing and regulatory authority. The number of cities committed to transitioning to 100% renewable energy in total energy use or in the electricity sector has continued to rise. In 2016, the Australian Capital Territory added a new commitment, and several other large cities – such as Calgary (Canada), Tokyo (Japan), Cape Town (South Africa) and New York (United States) – set significant targets during the year.

6. ENABLING TECHNOLOGIES AND ENERGY SYSTEMS INTEGRATION

Enabling technologies help foster a greater uptake of renewable energy in all sectors

The GSR's first chapter on Enabling Technologies aims to convey information on current developments in various energy technologies, infrastructure, markets and institutional frameworks that advance and facilitate expanded deployment of renewable energy technologies. Enabling technologies can take many forms, including storage systems, heat pumps and electric vehicles (EVs).

Enabling technologies can create new markets for renewable energy in buildings, industry and transport. For example, electrification of vehicles not only reduces local air pollution, but also allows for rapidly growing renewable power technologies to displace fossil fuels in a sector where renewables other than biofuels previously were barred from entry. In such instances, air quality is enhanced further, along with other benefits of expanded renewables deployment. Heat pumps allow renewable power to substitute for fossil fuels in buildings and for industrial heat applications. Energy storage solutions help to balance grid-connected renewable energy supply against energy demand and to facilitate off-grid renewable energy deployment.

Enabling technologies also help to better accommodate rapidly growing shares of variable renewable electricity generation. Power systems have always required flexibility to accommodate ever-changing electricity demand, system constraints and supply disruptions, but growing shares of variable generation may require additional flexibility from the broader energy system. The increased integration of the electricity sector with thermal applications in buildings and industry and with transport is one such approach, as is increased use of energy storage.

About 0.8 GW of new advanced, non-pumped energy storage capacity became operational in 2016, bringing the year-end capacity total to an estimated 6.4 GW. Most of the growth was in battery (electro-chemical) storage. By year's end, total European installed heat pump capacity reached about 73.6 GW_{th}, producing 148 TWh of useful energy. In 2016, global sales of EVs reached an estimated 775,000 units – representing around 1% of global passenger car sales, and more than 2 million passenger EVs were on the world's roads by year's end.

7. ENERGY EFFICIENCY

New targets, additional investment, declining energy intensity

Action to improve energy efficiency increased during 2016 in all sectors and at all levels of government and in the private sector. Worldwide, there is a growing recognition that energy efficiency plays a key role in reducing pollution and that it can provide multiple additional benefits, including enhanced energy security, reduced fuel poverty and improved health. Energy savings help renewable energy to meet a higher share of energy demand and to enter new markets.

Despite lower oil prices, households, businesses and governments worldwide continue to invest strongly in energy efficiency improvements. Incremental investments in energy efficiency in buildings, industry and transport increased by 6% in 2015, to USD 221 billion.

Primary energy intensity improved by 2.6% in 2015. Improvements were more marked in developing and emerging economies, most of which are still growing rapidly and have more efficiency potential remaining. High primary energy intensity can be driven by high shares of relatively energy-intensive economic activities, use of less-efficient technologies, under-utilisation of productive capacity, or a large share of thermal power generation, in particular coal, rather than non-thermal renewable power.

Energy intensity per square metre in the buildings sector has improved, but not fast enough to offset the doubling of floor area since 1990. Energy demand for several appliance and equipment categories also continues to rise, despite improvements in efficiency, due largely to a rapid increase in units per household, in addition to the growing number of electrified households. Buildings can take advantage of the synergies between energy efficiency and renewable energy by facilitating the use of on-site renewable energy to meet building energy loads.

Policies have been the main driver of energy efficiency improvements, with innovations in technology and finance also playing important roles. An increasing number of countries is setting energy efficiency targets; adopting new policies and standards, and updating existing ones; and introducing new financial incentives to channel additional funding towards energy efficiency. Many policies attempt to harness the synergy between energy efficiency and renewable energy.

8. FEATURE: DECONSTRUCTING BASELOAD

Dispelling the myths of traditional baseload power

Growth in variable renewable energy is changing how traditional, established power systems are planned, designed and operated for greater flexibility. Traditional baseload generators such as coal and nuclear power plants are beginning to lose their economic advantage and may no longer be the first to dispatch energy. In areas where demand is growing (notably in developing economies), there is an opportunity for new and less-developed power systems to grow in concert with higher shares of renewable generation as more-flexible systems are developed.

A number of countries and regions – including Denmark, Germany, Uruguay and Cabo Verde – have integrated high shares (20-40%) of variable renewable energy, demonstrating the potential to shift away from the traditional baseload paradigm. Improved resource forecasting, electricity storage, demand response, and co-ordination and trade of electricity supply across larger balancing areas are among the flexibility options that can be employed to integrate variable renewables; decisions regarding which options are most appropriate and cost-effective vary according to different institutional, technological and economic contexts. The ease of grid integration also varies from country to country.

A range of planning, operational and institutional changes to the power system can be pursued to promote overall least-cost operation and investment strategies while preserving reliability. As variable renewable energy resources and other enabling technologies continue to achieve more favourable cost and performance characteristics, the incentive to deploy them will continue to increase, moving new and existing systems further from the baseload paradigm.

01

FORECASTING of electricity production and demand is essential for operating power systems. A number of tools are used to forecast generation in solar PV and wind plants, ranging from a few minutes to several days in advance. Today, these have a high level of reliability, enabling system operation to adapt efficiently to upcoming changes.

LiDAR buoy for offshore wind and sea measurement – Germany

01 GLOBAL OVERVIEW

The year 2016 saw several developments and ongoing trends that all have a bearing on renewable energy, including the continuation of comparatively low global fossil fuel prices; dramatic price reductions of several renewable energy technologies (especially solar PV and wind power); and a continued increase in attention to energy storage.

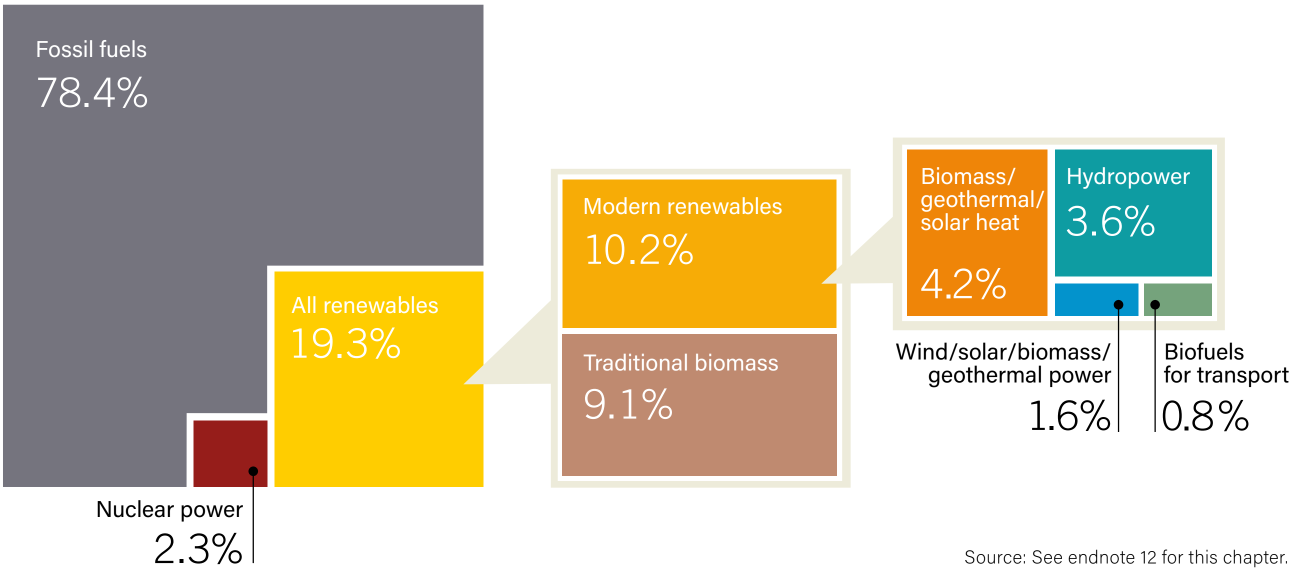
World primary energy demand has grown by an annual average of around 1.8% since 2011, although the pace of growth has slowed in the past few years, with wide variations by country.[1] Growth in primary energy demand has occurred largely in developing countries, whereas in developed countries it has slowed or even declined.[2]

For the third consecutive year, global energy-related carbon dioxide (CO_2) emissions from fossil fuels and industry were nearly flat in 2016, rising only an estimated 0.2%, continuing to break away from the trend of 2.2% average growth during the previous decade.[3] This slowing of emissions growth was due largely to declining coal use worldwide but also to improvements in energy efficiency and to increasing power generation from renewable energy sources.[4] Globally, coal production declined for the second year in a row.[5] In 2016, additional countries committed to moving away from or phasing out coal for electricity generation (e.g., Canada, Finland, France, the Netherlands and the US state of Oregon) or to no longer financing coal use (e.g., Brazil's development bank).[6] Countering this trend, however, a number of countries announced plans to expand coal production and use.[7]

Despite the overall decline in coal production, relatively low global prices for oil and natural gas during much of the year continued to challenge renewable energy markets, especially in the heating and transport sectors.[8] Fossil fuel subsidies, which remained significantly higher than subsidies for renewables, also continued to affect renewable energy growth.[9] Building on international commitments to phase out fossil fuel subsidies – such as the 2009 commitments by the Group of Twenty (G20) and by Asia-Pacific Economic Cooperation (APEC) – by the end of 2016 more than 50 countries had committed to phasing out fossil fuel subsidies.[10] Subsidy reforms were instituted during 2016 in Angola, Brazil, the Dominican Republic, Egypt, Gabon, India, Iran, Kuwait, Nigeria, Qatar, Saudi Arabia, Sierra Leone, Sudan, Thailand, Trinidad and Tobago, Tunisia, Ukraine, Venezuela and Zambia.[11]

Endnotes: see full version online at www.ren21.net/gsr

Figure 1. Estimated Renewable Energy Share of Total Final Energy Consumption, 2015



Source: See endnote 12 for this chapter.

As of 2015, renewable energy provided an estimated 19.3%[i] of global final energy consumption. Of this total share, traditional biomass, used primarily for cooking and heating in remote and rural areas of developing countries, accounted for about 9.1%, and modern renewables (not including traditional biomass) increased their share relative to 2014 to approximately 10.2%. In 2015, hydropower accounted for an estimated 3.6% of total final energy consumption, other renewable power sources comprised 1.6%, renewable heat energy accounted for approximately 4.2%, and transport biofuels provided about 0.8%.[12] *(→ See Figure 1.)*

The overall share of renewable energy in total final energy consumption has increased only modestly in recent history, despite tremendous growth in the renewable energy sector, particularly for solar PV and wind power. A primary reason for this is the persistently strong growth in overall energy demand (with the exception of a momentary pull-back in 2009 following the onset of a global economic recession), which counteracts the strong forward momentum for modern renewable energy technologies. In addition, the use of traditional biomass for heat, which makes up nearly half of all renewable energy use, has increased, but at a rate that has not kept up with growth in total demand.[13] *(→ See Figure 2.)*

In 2016, the power sector experienced the greatest increases in renewable energy capacity, whereas the growth of renewables in the heating and cooling and transport sectors was comparatively slow. ***(→ See Reference Table R1.)*** As in 2015, most growth in renewable energy capacity was in solar PV (which led by a wide margin) and in wind power; hydropower continued to represent the majority of renewable power capacity and generation. Bioenergy (including traditional biomass) remained the leader by far in the heat (buildings and industry) and transport sectors.

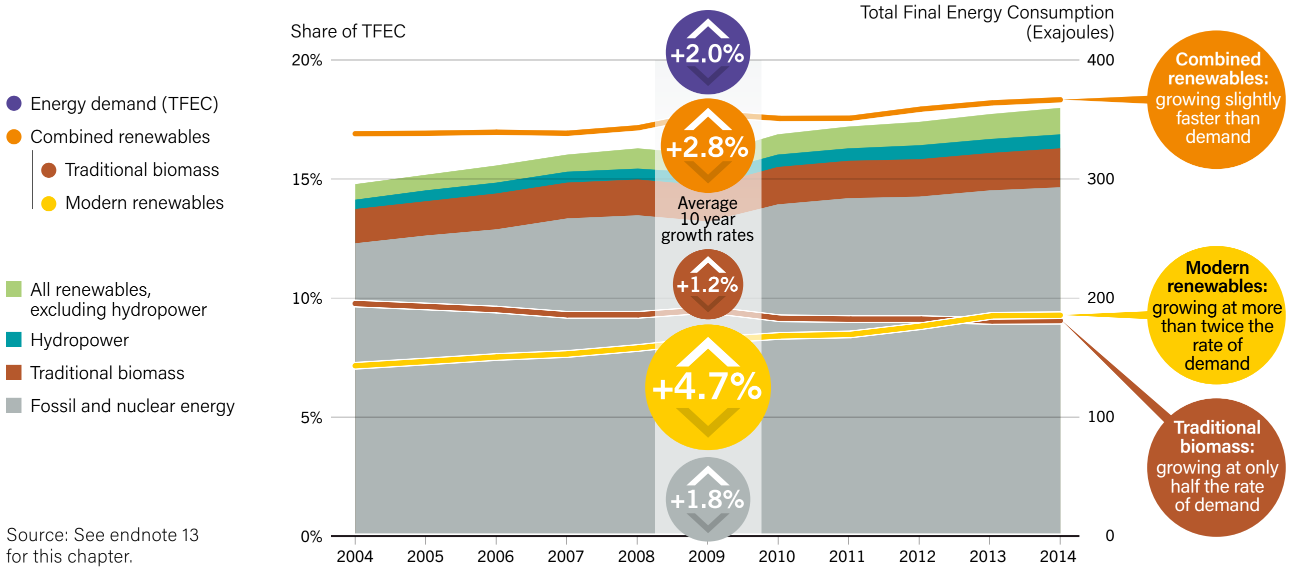
Growth rates of renewable energy capacity vary substantially across regions and nations, with most new capacity being installed in developing countries, and primarily in China.[14] China has been the single largest developer of renewable power and heat for the past eight years.[15] In 2016, an ever-growing number of developing countries continued to expand their renewable energy capacities, and some are rapidly becoming important markets. Emerging economies are quickly transforming their energy industries by benefiting from lower-cost, more efficient renewable technologies and more reliable resource forecasting, making countries such as Argentina, Chile, China, India and Mexico attractive markets for investment.[16] Nonetheless, some unique challenges remained in developing countries during the year, including a lack of infrastructure and of power sector planning, as well as off-taker risks.[17]

At the national, state and local levels, government policy continued to play an important role in renewable energy developments, although uncertainty in the policy arena also created challenges.[18] The number of countries with renewable energy targets and support policies increased again in 2016; targets were in place in 176 countries (up from 173 in 2015), and several jurisdictions made their existing targets more ambitious. *(→ See Policy Landscape chapter.)* Despite the significance of the heat and transport sectors to energy demand and global emissions, policy makers continued to focus predominantly on the power sector.[19]

At the global level, the 2015 Paris Agreement of the United Nations Framework Convention on Climate Change (UNFCCC) formally entered into force at the 22nd Conference of the Parties (COP22) in Marrakesh, Morocco in November 2016.[20] Renewable energy figured prominently in a large portion of the Nationally Determined Contributions (NDCs) that countries submitted in the lead-up to November.[21] Renewable energy markets were affected only indirectly by these developments during 2016; more concrete policy developments resulting from commitments to the Paris Agreement and new announcements had not yet been enacted and/or implemented in most countries.[22]

i The methodology for calculating the renewable share of total final energy consumption has been modified from earlier versions of the Renewables Global Status Report (GSR). Based on the previous methodology, the estimated share for 2015 is about 19.6%. For details, see endnote 12 for this chapter.

Figure 2. Growth in Global Renewable Energy Compared to Total Final Energy Consumption, 2004-2014



Source: See endnote 13 for this chapter.

Other international efforts of note also took place during the year. At COP22, leaders of the 48 nations that constitute the Climate Vulnerable Forum jointly committed to work towards achieving 100% renewable energy in their respective nations.[23] Cities around the world echoed this pledge as they continued to advance commitments to 100% renewable energy, with some already having achieved their goals. *(→ See Policy Landscape chapter.)*

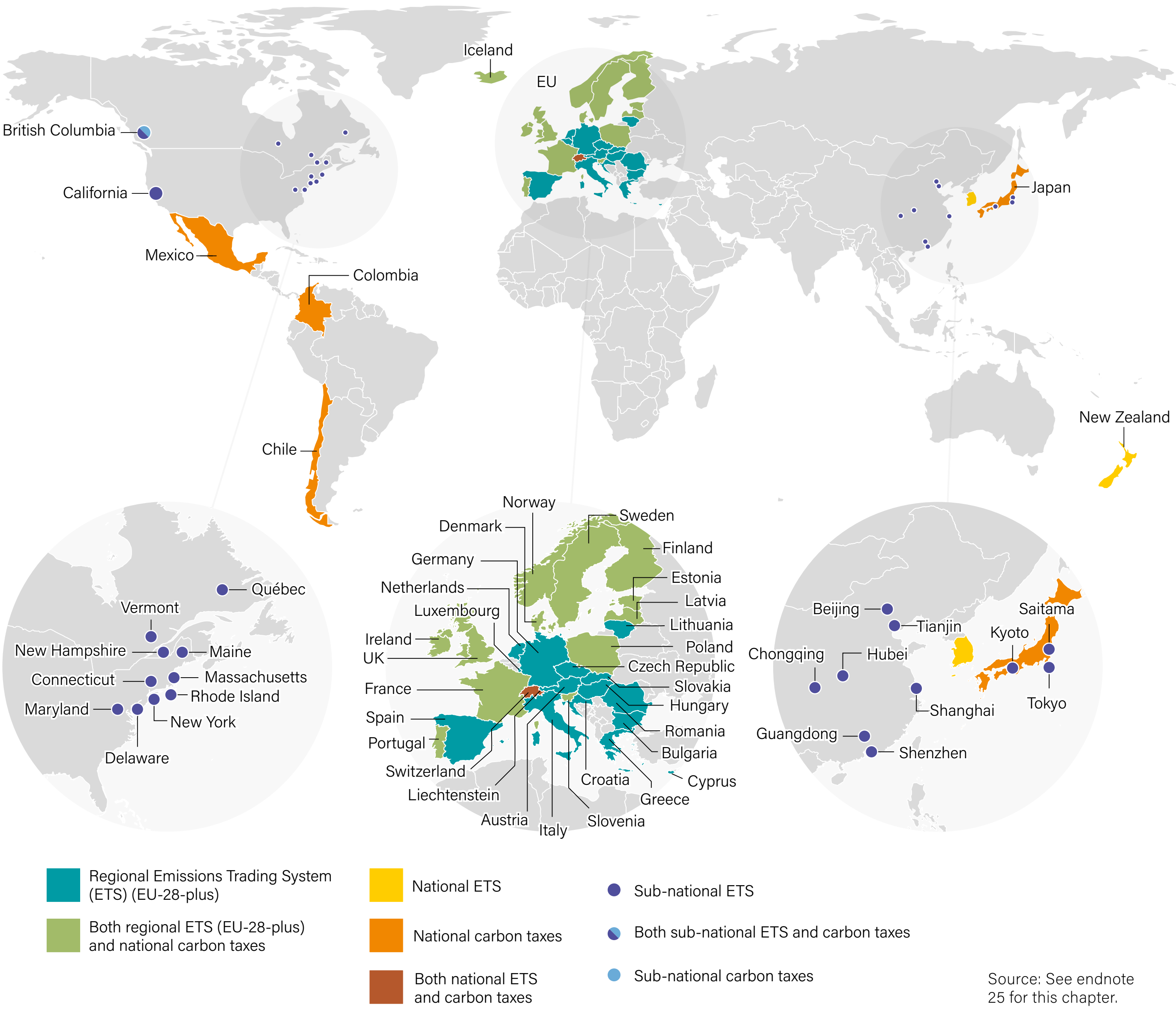
The World Trade Organization continued negotiations on the Environmental Goods Agreement, which seeks to eliminate tariffs on a number of products including renewable energy technologies, although discussions stalled in December.[24]

Carbon pricing policies (either carbon taxes or emissions trading systems) were in place in a number of jurisdictions worldwide in 2016.[25] *(→ See Figure 3.)* If well designed, carbon pricing policies may incentivise the development and deployment of renewable energy technologies by increasing the comparative costs of higher-emission fuels and technologies. However, some uncertainty exists as to whether these mechanisms alone are sufficient to drive deployment of renewable energy, even if well-designed, due to other factors at play, including the structure of power markets and regulations governing market access.[26]

In parallel with growth in renewable energy markets, renewable energy employment expanded during 2016. The number of jobs in renewables rose again, reaching an estimated 9.8 million jobs worldwide – a majority of which were in Asia.[27] *(→ See Sidebar 1.)*

The year also saw continued advances in renewable energy technologies, including innovations in solar PV manufacturing and installation and in cell and module efficiency and performance; improvements in wind turbine materials and design as well as in operation and maintenance (O&M), which further reduced costs and raised capacity factors; advances in thermal energy storage for concentrating solar thermal power (CSP); new advanced control technologies for electric grids that facilitate increased integration of renewable energy; and improvements in the production of advanced biofuels.[28]

Figure 3. Carbon Pricing Policies, 2016



Source: See endnote 25 for this chapter.

Note: This figure includes only policies that were implemented as of end-2016. Carbon pricing policies that were enacted or announced but not yet implemented by year's end do not appear. These include national emissions trading systems (ETS) in China and Ukraine; a national carbon pricing plan in Canada; a national carbon tax in Chile and in South Africa; a provincial carbon tax in Alberta (Canada); and a provincial ETS in Manitoba and in Ontario (Canada). Additional countries and states/provinces not listed here also may have plans to implement carbon pricing policies.

Ongoing advances in energy efficiency are reducing the cost of providing energy services with renewable energy, whether on-grid or off-grid. *(→ See Sidebar 3 and Energy Efficiency chapter.)* As penetrations of variable renewable energy continued to increase in 2016, there also was increased attention to energy storage, particularly in the power sector.[29] Electric vehicles, valued for their contribution to improving local air quality, gained attention in some markets for their ability to help integrate variable renewable electricity generation. *(→ See Enabling Technologies chapter.)*

Modern renewable energy is being used increasingly in power generation, heating and cooling, and transport. The following sections discuss 2016 developments and trends in these sectors.

POWER

Renewable power generating capacity saw its largest annual increase ever in 2016, with an estimated 161 gigawatts (GW) of capacity added.[30] Total global renewable power capacity was up almost 9% compared to 2015, to nearly 2,017 GW at year's end.[31] Solar PV saw record additions and, for the first time, accounted for more additional power capacity (net of decommissioned capacity) than any other generating technology.[32] Solar PV represented about 47% of newly installed renewable power capacity in 2016, and wind and hydropower accounted for most of the remainder, contributing about 34% and 15.5%, respectively.[33] *(→ See **Reference Table R1.**)*

The world now adds more renewable power capacity annually than it adds (net) capacity from all fossil fuels combined.[34] In 2016, renewables accounted for an estimated nearly 62% of net additions to global power generating capacity and represented far higher shares of capacity added in several countries around the world.[35] By year's end, renewables comprised an estimated 30% of the world's power generating capacity – enough to supply an estimated 24.5% of global electricity, with hydropower providing about 16.6%.[36] *(→ See Figure 4.)*

By the end of 2016, the top countries for total installed renewable electric capacity continued to be China, the United States, Brazil, Germany and Canada.[37] China was home to more than one-quarter of the world's renewable power capacity – totalling approximately 564 GW, including about 305 GW of hydropower.[38]

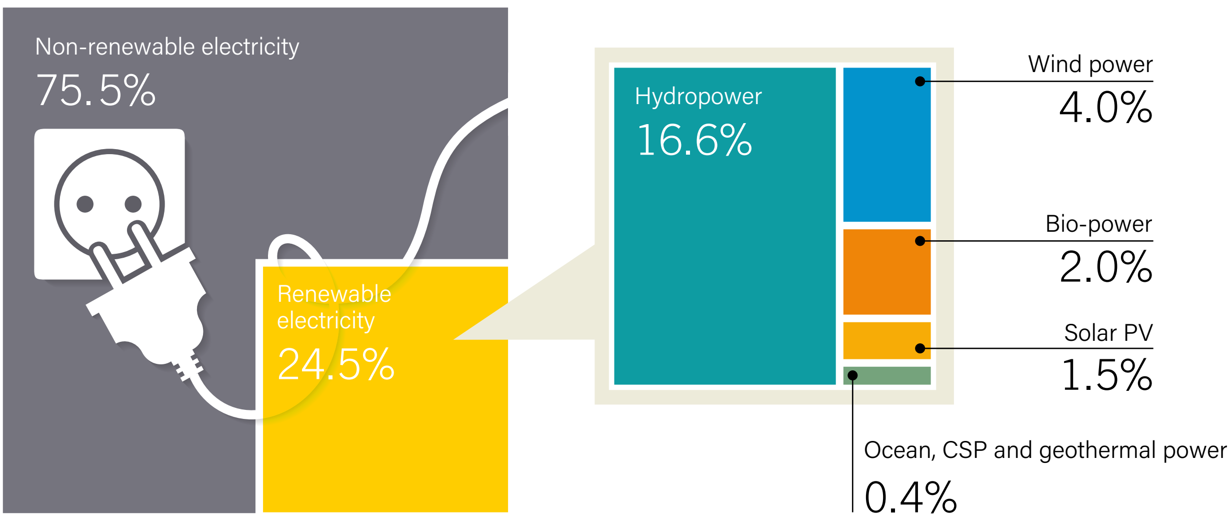
Considering only non-hydro[i] capacity, the top countries were China, the United States and Germany; they were followed by Japan, India and Italy, and by Spain and the United Kingdom (with about equal amounts of capacity by year's end).[39] *(→ See Figure 5 and **Reference Table R2.**)* The world's top countries for non-hydro renewable power capacity per inhabitant were Iceland, Denmark, Sweden and Germany.[40]

Throughout 2016, variable renewables achieved high penetration levels in several countries: for example, wind power met 37.6% of electricity demand in Denmark, 27% in Ireland, 24% in Portugal, 19.7% in Cyprus and 10.5% in Costa Rica; and solar PV accounted for 9.8% of electricity demand in Honduras, 7.3% in Italy, 7.2% in Greece and 6.4% in Germany.[41] Higher penetration levels of variable renewable energy have been met with curtailments in some countries, particularly in China.[42] However, for short periods of time, some countries and regions managed to integrate very high levels of variable renewable energy as shares of total demand, for example in Denmark (140%) and Scotland (106%).[43]

The ongoing growth and geographical expansion of renewable energy was driven by the continued decline in prices for renewable energy technologies (in particular, for solar PV and wind power), by rising power demand in some countries and

i The distinction of non-hydropower capacity is made because hydropower remains the largest single component by far of renewable power capacity and output, and thus can mask trends in other renewable energy technologies if always presented together.

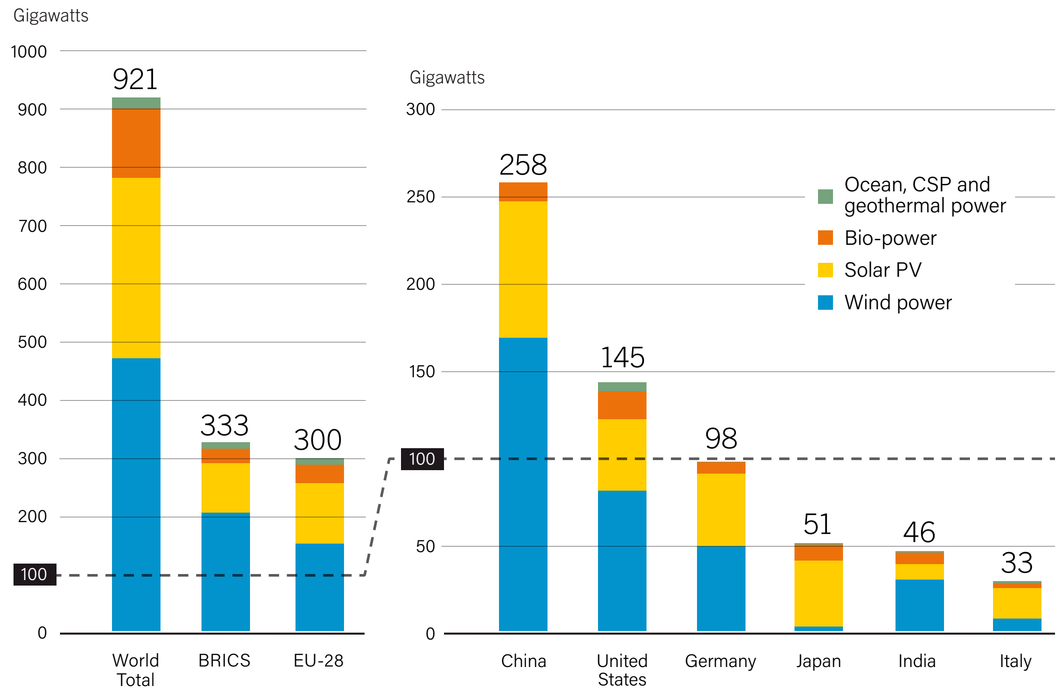
Figure 4. Estimated Renewable Energy Share of Global Electricity Production, End-2016



Source: See endnote 36 for this chapter.

Note: Based on renewable generating capacity at year-end 2016

Figure 5. Renewable Power Capacities in World, BRICS, EU-28 and Top 6 Countries, 2016



Note: Not including hydropower. Distinction is made because hydropower remains the largest single component by far of renewable power capacity, and thus can mask developments in other renewable energy technologies if included. ***(→ See Reference Table R2 for data including hydropower.)*** The five BRICS countries are Brazil, the Russian Federation, India, China and South Africa.

by targeted renewable energy support mechanisms.[44] Solar PV and onshore wind power are now competitive with new fossil fuel generation in an increasing number of locations due in part to declines in system component prices and to improvements in generation efficiency.[45] Bid prices for offshore wind power also dropped significantly in Europe during 2016.[46] *(→ See Market and Industry Trends chapter and Sidebar 2.)*

Such declines are particularly important in developing and emerging economies and in isolated electric systems (such as islands or isolated rural communities) where electricity prices tend to be high (if they are not heavily subsidised), where there is a shortage of generation and where renewable energy resources are particularly plentiful, making renewable electricity more competitive relative to other options.[47] Many developing countries are racing to bring new power generating capacity online to meet rapidly rising electricity demand, often turning to renewable technologies (that may be grid-connected or off-grid) through policies such as tendering or feed-in tariffs (FITs) to achieve this desired growth quickly.[48]

Throughout 2016, there were noteworthy renewable energy developments in the power sector in most regions of the world.

- **Asia:** China leads the world in installed capacities of hydropower, wind power and solar PV.[49] The country saw record installations of solar PV, raising the country's total capacity by 45%.[50] Curtailment rates of wind and solar power increased in 2016, reflecting ongoing integration challenges.[51] Outside of China, most of the renewable power generated in Asia is from hydropower, but its share is decreasing relative to other renewable power technologies, especially solar PV and wind power.[52] In India, wind power and solar PV capacity increased substantially, and bio-power generation was up 8% relative to 2015.[53] Indonesia and Turkey led the world in new geothermal power installations in 2016.[54]

- **Europe:** Continuing an ongoing trend, renewable energy accounted for a large majority (86%) of all new power installations in the EU, dominated by wind power and solar PV.[55] Nonetheless, legislative proposals by the European Commission during the year, known collectively as the "Clean Energy for All Europeans Package", caused some concern for the renewables sector (including manufacturers, project developers, investors and financing institutions). Concerns stemmed from proposals to remove priority access and dispatch for renewable energy, from the level of 2030 targets for renewable energy and energy efficiency, from the absence of binding national targets or indicative benchmarks, and from the planned mandatory replacement of FITs by tendering.[56]

- **North America:** In the United States, renewable energy accounted for over 15% of total electricity generation, up from 13.7% in 2015.[57] Bio-power generation was down in 2016, but electricity generated by wind energy and solar PV increased substantially.[58] More solar PV capacity was installed in the United States in 2016 than any other power source.[59] Operation of the country's first offshore wind farm also began during the year.[60] In Canada, hydropower continued to be a dominant source of power generation, although wind power has been the largest source of new generation for the past 11 years.[61]

- **Latin America:** Countries across the region achieved high shares of electricity generation with variable renewable energy. For example, Honduras supplied 9.8% of its electricity with solar PV, and in Uruguay wind power supplied 22.8% of electricity consumption in 2016.[62] In addition, a number of Caribbean islands (e.g., Aruba, Curaçao, Bonaire and St. Eustatius) reached renewable energy shares of over 10% in the total power mix.[63] In Brazil, the cancellation of the renewable power auctions during the year, motivated in part by declining electricity demand and the recent economic downturn, created uncertainty in renewable technology markets, which affected manufacturers; however, substantial hydropower capacity was commissioned in 2016.[64]
- **Africa:** Egypt, followed by Morocco, leads the region in installed renewable power capacity; both countries have significant hydropower capacity.[65] In South Africa – which (together with Ethiopia) leads sub-Saharan Africa in total installed renewable power capacity – renewable energy reached 5% of total electricity generating capacity in 2016.[66] South Africa and several countries in northern Africa (Algeria, Egypt and particularly Morocco) are becoming important markets for CSP as well as centres of industrial activity for solar PV modules and wind turbine components.[67] Several countries, including Ghana, Senegal and Uganda, commissioned solar PV plants during the year, and Kenya was one of the few countries worldwide to bring additional geothermal capacity online.[68] Several large hydropower projects also are under development on the continent.[69]
- **Oceania:** In Australia, which leads the region in renewable electricity capacity, the majority of capacity is hydropower (59%) and wind power (32%), although solar PV capacity is growing quickly.[70]
- **Middle East:** Capacities of solar PV, wind power and CSP are comparatively small, but a number of countries were building new wind power and solar PV projects and developing domestic manufacturing capacity during 2016. Projects exceeding 200 megawatts (MW) were either under construction or planned in Jordan, Oman, the State of Palestine and the United Arab Emirates (UAE).[71] Jordan, Saudi Arabia and Abu Dhabi and Dubai (UAE) all held solar PV tenders during the year.[72]

Globally, renewable electricity production in 2016 continued to be dominated by plants owned by utilities or large investors, and the scale of plants (solar PV, wind power and CSP) and of some generator equipment (such as wind turbines) continued to grow.[73] Utilities in China, Denmark, Germany, India, Sweden and the United States continued to invest in large-scale renewable energy projects, especially in solar PV and wind power, and in some cases they also invested in renewable energy technology companies.[74] Companies that traditionally have focused on fossil fuel extraction or nuclear power technology manufacturing also continued to move into renewable energy during the year.[75]

Major corporations and institutions around the world also made large commitments to purchase renewable electricity. In 2016, 34 businesses joined RE 100, a global initiative of businesses committed to 100% renewable electricity; new members included companies in China and India, as well as companies engaged in heavy industry. By year's end, 87 companies worldwide were participating in the initiative.[76] Most big companies that invest in renewable energy focus on wind energy (accounting for 54% of power purchased) and solar PV (21%), procuring the renewable electricity through renewable energy certificates (RECs) and, increasingly, through power purchase agreements (PPAs) or direct ownership.[77] An increasing number of large corporations committed in 2016 to PPAs of unprecedented size, many of which are contracts directly with renewable energy generators rather than with utilities.[78] The overall volume of PPAs in 2016, at 4.3 GW, was the second highest on record, although it was down 20% from 2015.[79]

The development of community renewable energy[i] projects continued in some countries in 2016.[80] Canada saw its first community wind farm begin operation, and Chile, which implemented a dedicated policy for community energy in late 2015, registered 12 new communities to receive funds for renewable energy projects in 2016.[81] However, growth in community energy projects is declining in several countries, particularly where policies are shifting from FITs towards tendering (as in parts of

i See Glossary for definitions of this and other terms used in this report.

Europe, for example in Germany and the United Kingdom, but also in Japan).[82] In the United Kingdom, following policy changes that reduced tax benefits and FIT rates, 44 community energy projects stalled, and the number of new projects that were initiated declined dramatically relative to 2015.[83] In Japan, policy amendments that removed priority access for renewable energy meant that many community power projects no longer were able to connect to electric grids.[84]

Although community energy projects have focused historically on the production of power, they have begun to expand into energy retailing (supply), storage and demand-side management.[85] This trend of diversifying community involvement, most prominent in OECD countries, is being met with varying degrees of success due largely to policy constraints.[86]

Many energy markets are changing to integrate larger shares of variable renewable energy – by becoming more flexible, managing shorter trading times and integrating demand response on both the supply and demand sides.[87] New market participants – often small and medium-sized enterprises and decentralised independent energy producers – are playing an increasingly important role. Some existing participants (e.g., electric utilities) are developing new business models that focus on decentralised renewable energy rather than on centralised conventional fossil fuels or nuclear power; examples of energy companies undergoing such transitions include RWE and E.ON in Europe.[88] In response to the conceptual shift away from centralised electricity generation, utilities have shown increased interest in virtual power plants: networks of decentralised renewable energy generation, energy-efficient buildings, and battery storage connected to and remotely controlled by software and data systems.[89]

Innovations in renewable energy retailing continued to emerge in 2016. For example, preliminary test runs of peer-to-peer trading models – in which a direct contract is made between the energy generator and the energy user – took place in New York City.[90] Trading platforms for such peer-to-peer models also have emerged in Germany, the Netherlands and the United Kingdom.[91] In addition, a new model of pooling residential storage systems (which often are paired with distributed systems) to provide services to the grid was approved in Switzerland; similar models were implemented in Vermont (United States) and tested in Germany.[92] Such systems allow prosumers to play an active role in balancing power for the first time.

Renewable energy hybrid projects – which combine two or more renewable power technologies – are being built or developed in several countries, including Australia, China, India, Morocco and the United States.[93] Wind power-solar PV projects are becoming more common, in large part due to the natural synergies of the two resources: wind speeds often accelerate when solar irradiation drops.[94]

Several plans (some only in the early stages) to interconnect existing grids or to build "super-grids" were in place during 2016 (for example, in Africa, Asia and South America), many of which aim specifically to advance the integration of renewable energy.[95] Substantial investments also were made in upgrading national grids – for example, expanding transmission lines to transport renewably generated power in India, Jordan and China[i], which diverted significant investment in 2016 from renewable projects to grid improvements and to reforms in the power market to better utilise the country's existing renewable energy resources.[96]

For the more than 1 billion people worldwide without access to electricity (most of whom are in sub-Saharan Africa and Asia), renewable energy systems, especially those in rural areas far from the centralised grid, continued to offer important and often cost-effective options to provide such access.[97] *(→ See Distributed Renewable Energy chapter.)* The number of off-grid solar PV systems in particular has been increasing rapidly to this end.[98] Multilateral and bilateral financing institutions continued to provide funding to further develop and deploy renewable energy projects (notably solar PV and mini-grid systems) in 2016.

In developing and developed countries, the use of electric mini-grids continued to expand, driven in part by desires to improve the reliability of power supply in the face of extreme weather and other disruptions, but also for reasons including energy access and preferences for renewable energy supply.[99] Interconnections with regional/national grids and other mini-grids are increasing in some developed countries, particularly in the United States, which leads in global mini-grid capacity.[100] In a rising number of developing countries, renewables-based mini-grids are playing an important role in meeting energy access goals.

i In January 2017, the Chinese government announced plans to spend USD 360 billion on renewable energy through 2020 to reinforce its position as the world leader in renewable energy investments. See endnote 96 for this chapter.

HEATING AND COOLING

Energy use for heat (water and space heating, cooking and industrial processes) accounted for more than one-half of total world final energy consumption in 2016.[101] Energy demand for cooling is significantly lower, but it is increasing rapidly in many countries.

Renewable energy is used directly to meet heating and cooling demand by means of solar, geothermal or biomass (solid, liquid and gaseous) resources. Renewable electricity also can be used for heating and cooling. In 2016, renewable energy's share of final energy use in the heat sector remained stable at around 25%; of this share, more than two-thirds was traditional biomass, used predominantly in the developing world.[102]

Modern renewable energy[i] supplied the remaining one-third, or approximately 9% of total global heat production.[103] The use of modern renewable heat has increased at an average rate of 2.3% per year since 2007, accounting for a rising share of overall heat consumption.[104] Industrial users consume most (56%) of the heat generated by modern renewable technologies, followed by commercial district heating systems, which consume another 5%.[105] A significant amount also is used by households – for example, with modern biomass stoves and solar thermal heat systems.

Trends in the use of renewable energy for heating vary by technology, although the relative shares of the main renewable heat technologies have remained stable during the past few years. The use of traditional biomass has increased 9% since 2007, even as the share of traditional biomass in total global energy use has been declining.[106]

Focusing only on modern renewable energy, bioenergy accounts for almost 90% of renewable direct heat use, solar thermal represents around 8%, and geothermal accounts for 2%.[107] While additional capacities of modern bio-heat and solar thermal were installed in 2016, growth in both markets has continued to slow. Geothermal direct use also continued a gradual expansion during the year. *(→ See Biomass Energy, Solar Thermal Heating and Cooling, and Geothermal Power and Heat sections in Market and Industry Trends chapter.)*

Bioenergy accounts for around 7% of all industrial heat consumption.[108] In 2016, the use of solar process heat continued to increase in the food and beverage industry as well as in the mining industries, all of which have substantial demand for low-temperature heat. Solar process heat expanded into other industries as well; for example, in Oman construction continued on a 1 GW solar thermal plant for advanced oil recovery.[109]

Biomass is the primary renewable energy source used for district heating.[110] Increasingly, solar thermal is being incorporated into district heating systems at significant scales, with several large projects in some European countries. Denmark is in the lead and commissioned the world's largest solar thermal plant (110 megawatts-thermal (MW_{th})) in 2016.[111] Denmark's success has inspired project development elsewhere in Europe, especially in Germany and Poland, and solar district heating is attracting attention in China as well.[112] *(→ See Solar Thermal Heating and Cooling section in Market and Industry Trends chapter.)* Several European countries have expanded their use of geothermal district heating plants in recent years; the region had more than 260 plants as of 2016.[113]

In countries where district heating is more mature – such as Denmark, Finland and Sweden – so-called fourth-generation systems have begun to move beyond conceptualisation and towards design and eventual implementation. These advanced systems are integrated with a mix of smart electric grids, large-scale heat pumps, natural gas and thermal grids, long-term infrastructure planning processes, and energy-efficient buildings, all with the aim of incorporating increased shares of renewable energy.[114]

Electricity accounts for only an estimated 1.5% of the total renewable heat production in buildings and industry, but electrification of heat received increasing attention in 2016.[115] As FITs and net metering are phased out in many countries, there is growing interest in the potential to store electricity generated by small-scale renewable energy systems (especially solar PV) in batteries for self-consumption, or to use it to produce hot water.[116] In addition, the use of heat pumps continues to rise, particularly in new, efficient single-family homes with a low heat load.[117] *(→ See Heat Pumps section in Enabling Technologies chapter.)*

Interest also is expanding in the use of district heating to provide flexibility to power systems, by converting renewable electricity into heat.[118] Although still at a very limited scale, seasonal heat storage (both inter-seasonal and short-term storage) is being combined increasingly with the electric grid, using excess electricity for a power-to-heat process.[119] Seasonal storage systems for heat generated by renewable energy-based district heating systems were used in a number of European countries in 2016.[120]

The number of hybrid systems for heat (combining multiple technologies) continued to increase in 2016.[121] In such systems, solar thermal often is coupled with different technologies – depending on country-specific circumstances – to help ensure a secure supply of heat.[122] For example, in Germany solar thermal systems are more likely to be combined with natural gas burners, whereas in China they are more likely to be combined with

i Modern renewable energy for heat includes modern bioenergy combustion *(→ see Biomass Energy section in Market and Industry Trends chapter)*, solar thermal generation and geothermal direct use, and in this case also heat provided by renewably generated electricity.

electric heat.[123] Hybrid systems that rely exclusively on the use of renewable energy technologies (such as solar thermal coupled with biomass boilers) also are possible, although for cost reasons they are less common than systems paired with fossil fuels.[124] In the United Kingdom, a demonstration hybrid district heating project that combines solar thermal, heat pumps and energy storage began supplying heat and hot water to homes in 2016.[125]

Space cooling accounts for about 2% of total world final energy consumption; most of the demand is met by means of electrical appliances.[126] Rising demand for space cooling, especially in developing countries, has led to a dramatic increase in peak electricity demand in a number of countries.[127] It also has helped to spur interest in solar cooling, particularly in sun-rich countries, and some notable projects began operation in 2016.[128] In general, however, markets for renewable-based cooling technologies (non-electric) have not kept pace with the rising demand for cooling, due largely to the installation flexibility and cost-competitiveness of electricity-based cooling.[129] Some field tests and demonstration projects of combined cooling systems with solar PV panels and heat pumps were in progress during 2016.[130]

There are important differences across regions in demand for heating and cooling as well as in the use of renewable energy to provide these services:

- **Asia:** China, the world's largest consumer of heat, supplies only around 1.8% of its demand with renewable heat.[131] Due in part to the slowing rates of residential construction, investment in solar thermal installations declined for the third consecutive year.[132] At the same time, district heating has grown substantially, offering new opportunities for incorporating renewable heat.[133] In India, around 10% of heat demand is met by modern renewables, mostly in the form of bioenergy (bagasse, rice husks, straw and cotton stalks) used in industry.[134] A number of solar thermal systems for process heat also were installed during the year in India, supported by international programmes of the United Nations Environment Programme (UNEP) and UNIDO.[135] Across China, India and the rest of developing Asia, around 50% of the population relies on traditional biomass for cooking.[136]
- **Europe:** The EU continued to produce more heat from renewable energy than did any other region in 2016; most (about 61%) of this heat was consumed in buildings.[137] An estimated 18.6% of the region's total heating and cooling consumption is met by renewable sources, primarily solid biomass, up from 14.9% in 2010.[138] In Germany, Europe's largest consumer of heat, the share of renewables in heating and cooling (most of which is bioenergy) remained stable in 2016, although the country's total generation of renewable heat increased 6%.[139] In Sweden, which has the region's highest share of renewables in its heating and cooling mix, biomass accounted for 60% of the heat provided to district heating systems.[140] In Denmark, a majority of the heat supplied to district heating systems was generated from biomass and waste in 2016, although the country also has made significant strides in incorporating solar thermal into its district heating systems.[141]
- **North America:** The region was the world's second largest producer of renewable heat, with renewables meeting around 10% of heat demand.[142] The US market for woody biomass and pellet boilers did not grow in 2016, due in part to low oil prices, but interest in wood chips for district heating or small commercial boilers continued to increase.[143] Some electric utilities and some companies in the fossil fuel delivery industry (e.g., oil and propane suppliers) have begun to diversify their portfolios by launching programmes to lease air-source heat pumps for both heating and cooling purposes.[144] In Canada, renewables provide around 22% of industrial heat demand, mostly using bioenergy residues from the pulp and paper industry.[145]
- **Latin America:** Across Latin America, renewable energy supplies 35% of heat demand, nearly one-quarter of which is met with traditional biomass (concentrated mainly in Bolivia, Colombia, El Salvador, Guatemala, Honduras, Nicaragua, Paraguay and Peru), with significant variations across countries.[146] A few countries in the region rely heavily on renewable sources for industrial heat (largely solid biomass fuels such as bagasse and charcoal), including Paraguay (90% renewable), Uruguay (80%), Costa Rica (63%) and Brazil (54%).[147] Solar thermal use in industry is growing rapidly

in Mexico, where a total of 95 process heat plants had been installed by the end of 2016.[148]

- **Africa:** Approximately 2.7 billion people in Africa, or 69% of the continent's population, use traditional solid biomass for cooking.[149] ***(→ See Reference Table R11.)*** However, access to modern renewable heat is increasing in some countries. South Africa and Tunisia led the continent in newly installed solar thermal heat capacity in 2016.[150] In South Africa, deployment of solar thermal systems for water heating has been driven by the need to reduce peak electricity demand in supply-constrained markets, whereas in Tunisia deployment has been driven by a desire to reduce fossil fuel imports.[151] In Egypt, the country's first demonstration solar thermal cooling plant was installed during the year.[152]
- **Middle East:** In general, interest in solar thermal energy for both domestic water heating as well as commercial and industrial heat is on the rise across the region, with large projects under development in Kuwait, Qatar, Oman and the UAE in 2016.[153] In the UAE, the 2012 solar thermal obligation in Dubai continued to have a positive effect on the solar thermal market.[154] In Jordan, about 15% of all households are equipped with solar water heating systems.[155]

In 2016, continued improvements in the sector – including in the efficiency of industrial processes, building materials, and heating and cooling systems – facilitated increased use of renewable energy for heating and cooling. In general, however, deployment of renewable technologies in these markets is constrained by several factors, including limited awareness of the technologies, the distributed nature of consumption and fragmentation of the markets, comparatively low fossil fuel prices, ongoing fossil fuel subsidies and a comparative lack of policy support. In developing countries, despite significant potential for solar thermal heating and cooling, the lack of installation know-how remains an important barrier, particularly for industrial-scale heat.[156]

Nevertheless, throughout 2016 there was evidence in international policy of increasing awareness and political support for renewable heating and cooling technologies. A number of the NDCs delivered to the UNFCCC for COP22 specifically mentioned goals to expand the use of renewable heating technologies, and the European Commission's proposal for a new Renewable Energy Directive to 2030, released in November 2016, includes a recommendation to increase the share of renewables in heating and cooling by 1% annually, while leaving specific implementation strategies to member states.[157] For the first time in EU policy discussions, the strategy also specifically highlighted the importance of renewable energy for district heating and cooling.[158]

TRANSPORT

Global energy demand in transport has increased by just under 2% annually on average since 2005; it accounts for about 28% of overall energy consumption and for 23% of energy-related greenhouse gas emissions.[159] Oil products account for around 93% of final energy consumption in transport.[160]

There are three main entry points for renewable energy in the transport sector: the use of 100% liquid biofuels or of biofuels blended with conventional fuels; natural gas vehicles and infrastructure that can be fuelled with gaseous biofuels; and the electrification of transport, which can use batteries or hydrogen produced by renewable electricity.

Biofuels (ethanol and biodiesel) represent the vast majority of the renewable share of global energy demand for transport. They provide around 4% of world road transport fuel.[161] In 2016, global ethanol production remained stable relative to 2015, with decreases across Europe and in Brazil offset by increases in the United States, China and India.[162] Global biodiesel production increased by around 9% compared with 2015, with substantial increases in the United States and Indonesia.[163] *(→ See Biomass Energy section in Market and Industry Trends chapter.)*

The technology for producing, purifying and upgrading biogas for use in transport is relatively mature, and vehicles and infrastructure based on natural gas are increasing slowly but steadily internationally.[164] However, several barriers remain to broader biogas penetration in the transport sector, including the lack of regulations regarding access to natural gas grids, the lack of natural gas infrastructure, the decentralised nature of biogas feedstock and comparatively high economic costs.[165] Most biogas production for transport purposes is concentrated in Europe and the United States.[166]

Electrification of the transport sector increased during the year, expanding the potential for greater integration of renewable energy in the form of electricity for trains, light rail, trams, and two- and four-wheeled electric vehicles (EVs). Further electrification of the transport sector has the potential to create a new market for renewable energy and to ease the integration of variable renewable energy using the possibility of storage offered by EVs. *(→ See Electric Vehicles section in Enabling Technologies chapter.)*

Although direct links between renewable energy and EVs remain limited, as the share of renewables in grid power increases, so does the share of renewables in electrified transport. Some EV service providers, such as car sharing companies in the United Kingdom and the Netherlands, have begun offering a provision for charging vehicles with renewable electricity.[167] On a very limited scale, companies in several countries are developing prototypes that use solar PV directly, for example on passenger cars in China and Japan and a solar-powered bus in Uganda.[168]

Barriers to electrification in the transport sector continued to include relatively high EV purchase costs, perceived limits to range and battery life, and a lack of charging infrastructure.[169] In most developing countries, additional barriers relate to the lack of a robust electricity supply, which reduces the attractiveness of using electricity for transport.[170]

Road transport accounts for 75% of transport energy use.[171] Each region has a unique mix of renewable fuels, vehicle types and fuelling infrastructure. Regional trends in road transport during 2016 include:

- **North America:** The United States continued to be the largest producer of biofuels, with use of these fuels supported by agricultural policy and by the federal renewable fuel standard.[172] Production of both ethanol (at a similar pace as 2015) and biodiesel (reversing the decline witnessed in 2015) increased in 2016. The United States is one of the five largest producers of biogas for vehicle fuel worldwide (all others are in Europe).[173] Renewable gas accounts for 20-35% of natural gas used in transport, and 37 new renewable natural gas projects ongoing in 2016 indicate growing interest.[174] EV sales also increased (by 38%) in the United States during the year, and the country accounts for 28% of passenger EV sales in the global market.[175] In Canada, ethanol production decreased, while biodiesel production increased, and EV sales were up 56% from 2015.[176]

- **Latin America:** Brazil, the second largest producer of biofuels (after the United States), saw declines in both ethanol and biodiesel production in 2016, reversing the increase in 2015.[177] Colombia and Peru also saw decreases in both ethanol and biodiesel production during the year.[178] Countering this decline, production of both biofuels increased in Argentina, while in Mexico ethanol production increased from near zero in previous years to 20 million litres.[179] The EV market in Latin America is still in its infancy but is seeing early developments, particularly in Costa Rica and Colombia.[180] Argentina, Brazil and Colombia all have a developed natural gas infrastructure into which biogas could be incorporated, but this has not yet seen much if any deployment.[181]

- **Europe:** Policy and public support for first-generation biofuels continued to wane due in part to sustainability concerns, but also because of the increasing interest in electric mobility; as a result, investment in new biofuels production capacity declined in 2016.[182] Regional production of both ethanol and biodiesel was down, although increases occurred in some individual countries (such as for ethanol production in Hungary, Poland, Sweden and the United Kingdom).[183] Countering the decline in biofuels, biomethane continued to gain share of the transport fuels mix, particularly in Sweden, which provided record shares (over 70%) of biomethane in its supply of compressed natural gas (CNG) for transport.[184] Europe is home to four of the world's five largest producers of biogas for vehicle fuel: Germany, Sweden, Switzerland and the United Kingdom.[185]

  Regional sales of EVs also increased (by 14%) in 2016.[186] Europe accounts for 29% of global sales of passenger EVs; Norway leads the region in total sales, followed by the Netherlands, the United Kingdom and France.[187] In 2016, installation of what is reportedly the world's first solar controlled, bi-directional charging station for EVs was completed in the Netherlands.[188] *(→ See Electric Vehicles section in Enabling Technologies chapter.)*

- **Asia:** Growth in ethanol production in Asia continued to slow; China, India and Thailand led the region in production. Biodiesel production continued to rise, particularly in Indonesia where the significant increase in 2016 countered the decline in 2015. Both China and India have an established natural gas infrastructure into which biogas could be incorporated.[189] Movement in this direction during the year included the start of operation of India's first biomethane-fuelled bus, with more stations, buses and routes planned.[190] EV sales increased in China, the largest market for passenger EVs worldwide.[191] China also is the global leader in sales of electric two-wheelers.[192] Japan, which accounted for 8% of the global market for passenger EVs in 2016, saw sales decline (-12%) for the second year in a row.[193]

- **Africa:** Production of fuel ethanol increased 11% (from comparatively low levels) in 2016, albeit well below the 30% growth in 2015.[194] Some early EV sales have been seen in South Africa and Morocco.[195] Biomethane road transport pilot projects also have been launched in South Africa in recent years.[196]

Aviation accounts for around 11% of the total energy used in transport.[197] In October 2016, the International Civil Aviation Organization announced a landmark agreement by 66 nations accounting for 86% of aviation activity to mitigate greenhouse gas emissions in the sector; the first phase of the agreement is expected to begin in 2021.[198] Alongside technical and operational improvements, the agreement will support the production and use of sustainable aviation fuels, specifically drop-in fuels produced from biomass and different types of waste.[199] In aviation, biofuel use moved from a concept to business-as-usual for a few airlines in 2016.[200] A number of significant agreements for provision of aviation biofuels were signed during the year, including a few worth over USD 1 billion.[201] There also was ongoing development work on prototypes for short-range electric flights.[202]

Shipping consumes around 7% of the total energy used in transport.[203] Ships can incorporate wind and solar energy directly, and for propulsion they can use biofuels or other renewable-based fuels (e.g., hydrogen).[204] However, the integration of renewable energy into shipping continued to stagnate in 2016.[205] Late in the year the International Maritime Organization agreed to a 0.5% sulphur cap by 2020, which will have implications for the burning of heavy fuel oil and therefore also may increase interest in liquefied natural gas (LNG) and renewable fuels.[206] Developments associated with gaseous fuels — including a new action plan in China and some deployment of LNG-fuelled ships (e.g., in Australia) – may offer opportunities for the incorporation of biogas.[207] Active research and prototype development of wind energy-assist technologies also continued during the year.[208]

Rail accounts for around 2% of the total energy used in the transport sector; it can incorporate biofuels in fleets fuelled by oil products (around 57% of the total) and renewable power in fleets powered by electricity (around 36% of the total).[209] The renewable electricity share in the total energy mix of the world's railways increased from 3.4% in 1990 to around 9% in 2013, with some countries reaching much higher penetrations by 2016.[210] As of early 2017, for example, all electric trains in the Netherlands were powered 100% by wind power, one year ahead of schedule.[211]

A few railways implemented new projects in 2016 to generate their own electricity from renewables (e.g., wind turbines on railway land and solar panels on railway stations), notably in India and Morocco.[212] Also in 2016, Chile announced that new construction of solar PV and wind farms will help power the Santiago subway.[213] Ongoing tests of smart energy management in both intercity and urban trains (such as onboard energy management and dynamic response) also occurred during the year to help manage and store variable renewable energy.[214]

Motivated in part by the need to manage local air pollution, some countries (for example, Germany, India, the Netherlands and Norway) began discussing for the first time a phase-out of internal combustion engines, a step that would have implications for both biofuels and renewable electricity in transport.[215]

Following the historic climate agreement in Paris in December 2015, the international community focused increased attention on decarbonisation of the transport sector, although only 22 of the NDCs submitted refer specifically to renewable energy in the transport sector, and only two (Niue and New Zealand) link EVs to renewable energy.[216] During 2016, some governments, mostly in Europe, began looking at medium- to long-term strategies to decarbonise the sector, often involving long-term structural changes; many also considered or developed strategies to more closely link the transport and electricity sectors.[217] For example, Germany's climate action plan, developed in 2016, aims to reduce emissions in the sector 40-42% by 2030, with a longer-term objective to fully decarbonise the sector.[218] However, much of the focus of international decarbonisation discussions was on the electrification of transport, with very little attention focused on ensuring a renewable electricity supply.[219]

SIDEBAR 1. Jobs in Renewable Energy

The renewable energy sector employed 9.8 million people in 2016 – a 1.1% increase over 2015[i]. Jobs in renewables, excluding large-scale hydropower, increased 2.8% to 8.3 million in 2016. In some major markets, job losses followed policy changes, a decrease in investment and rising automation. Even so, global employment numbers continued to rise due to record deployment of renewables, driven by falling prices and supportive policies in several markets. Solar PV was the largest employer, followed by biofuels, large-scale hydropower, wind energy and solar heating and cooling. *(→ See Table 1.)*

Global employment in solar PV increased 12% in 2016, to 3.1 million jobs. In China, solar PV employment was up 19%, with growth mostly in construction and installation. In the United States and India, strong growth in annual installations boosted employment by 17% and 24%, respectively. By contrast, solar PV-related employment declined in Japan and the EU (in 2015) [ii] due to market contraction.

Biofuels employment increased around 3% to an estimated 1.7 million, even though mechanisation reduced labour needs in the feedstock supply chain in the two largest producers: the United States and Brazil. Indonesia's palm oil-based biodiesel sector saw employment increase by around 60% to 154,000 jobs. Biofuel production also rose in South-Eastern Asia, including in Thailand, Malaysia and the Philippines, which together employed close to 192,000 people in 2016. Colombia's labour-intensive biofuels sector supported around 85,000 jobs.

Some 1.2 million people worked in the wind power industry in 2016, a 7% increase over 2015. In China, jobs in wind energy edged up slightly to 509,000, accounting for close to half of the global total. Germany, the United States, India, Turkey, the United Kingdom and Brazil followed.

The number of solar heating and cooling related jobs declined by an estimated 12%. In China, the dominant market, employment fell yet again as annual installations continued to decline. Other significant employers included Brazil, Turkey, India, the United States and Germany.

Jobs in small-scale hydropower remained steady in 2016, whereas jobs in large-scale hydropower decreased 7%. China, India and Brazil were the leading employers for large-scale hydropower. Most of the jobs were in operation and maintenance, followed by construction and installation.

Overall, renewable energy-related employment (not including large-scale hydropower) continued to shift towards Asia, which accounted for 62% of jobs, compared to 51% in 2013. Across all renewable energy technologies, not considering large-scale hydro (omitted from the remaining discussion[iii]), the leading employers continued to be China, Brazil, the United States, India, Japan and Germany.

China remained the leader with 3.6 million jobs, up 3% relative to 2015; solar PV was China's main source of job creation. Contraction in solar thermal heating and small-scale hydropower resulted in job losses, while reduced production combined with rising labour productivity lowered the number of jobs in bio-power and biofuels.

Employment in Brazil's biofuel sector fell 5%, driven primarily by an 8% drop in ethanol jobs due to increased mechanisation. The slowdown in new installations reduced employment in the wind power (down 21%) and solar water heater industries.

In the United States, expanded jobs numbers were due primarily to employment increases in the solar PV and wind power (up 16%) industries, buoyed by the extension of federal tax credits in late 2015. Biodiesel job gains compensated for cuts in ethanol-related jobs, keeping total biofuel employment stable.

In India, tenders for utility-scale solar plants and capital subsidies for distributed generation pushed up solar PV employment by 17% in 2016, with most of the gains in project development and installation. The number of wind power jobs rose 26% due to a significant increase in new capacity.

In Japan, new solar PV installations declined due to tariff cuts and to difficulties in securing grid connections. As a result, solar PV employment declined 20% relative to the 2014 estimate.

The number of renewable energy jobs in the EU fell slightly in 2015 to 1.16 million. Reductions in solar PV installations and module manufacturing resulted in a 22% decrease in solar PV jobs in 2015. At the same time, employment increased in geothermal, wind and solid biomass power.

Germany continued to lead Europe in renewable energy employment, even as the number of jobs declined about 6% in 2015. Offshore wind power and small-scale biomass heating (primarily household and other solid fuel systems) were the country's only industries to create additional jobs; although employment in the offshore sector rose 10% (to 20,500 jobs), total wind power jobs declined 4% due to reduced onshore activity. Solar PV-related employment slipped to less than one-third of Germany's 2011 peak. France, the second largest European employer, saw renewable energy jobs fall 5%. In the United Kingdom, close to 110,000 people were employed in 2015, a 2% decline relative to 2014. Employment in Spain stabilised in 2015 at 75,500 jobs, following six years of job cuts resulting from policy changes and the national economic crisis.

Renewable energy employment increased during 2016 in several other countries, particularly in Asia. In Bangladesh, the number of jobs in solar PV rose 10%, due primarily to growth in deployment of mini-grids and solar water pumps. Malaysia's role as a solar PV manufacturing hub for export markets continued to expand, with employment up 46% (to about 27,900). Considering all renewable energy technologies, employment in Malaysia reached 95,500 jobs in 2016.

i This sidebar is drawn from *Renewable Energy and Jobs – Annual Review 2017*. Data are principally for 2015-2016, with dates varying by country and technology, including some instances where only earlier information is available.

ii The most recent EU data available are for 2015, with some exceptions *(→ See Table 1 notes)*.

iii National and regional employment trends exclude jobs in large-scale hydropower, given differences in the methodology used for estimating large-scale hydro employment and uncertainties in underlying data. IRENA estimates large-scale hydro numbers using an employment factor approach and includes only direct jobs; numbers for most other renewables are based primarily on data from primary and secondary sources and include direct and indirect jobs. Uncertainties in large-scale hydro estimates exist due to a lack of reliable data on variables such as construction time and employment factors.

JOBS IN RENEWABLE ENERGY

Table 1. Estimated Direct and Indirect Jobs in Renewable Energy, by Country and Technology

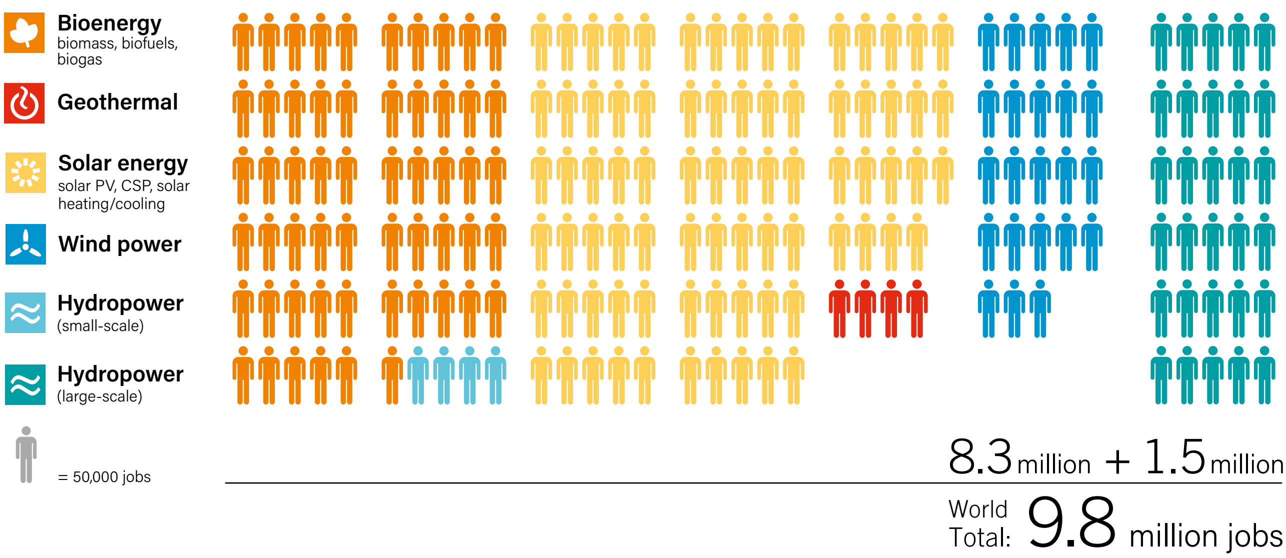
	World	China	Brazil	United States	India	Japan	Bang-ladesh	European Union[i] Germany	France	Rest of EU
	THOUSAND JOBS									
Solar PV	**3,095**	1,962	4	241.9	121	302	140	31.6	16	67
Liquid biofuels	**1,724**	51	783[c]	283.7[f]	35	3		22.8	22	48
Wind power	**1,155**	509	32.4	102.5	60.5	5	0.33	142.9	22	165
Solar heating/ cooling	**828**	690	43.4[d]	13	13.8	0.7		9.9	5.5	20
Solid biomass[a, g]	**723**	180		79.7[e]	58			45.4	50	238
Biogas	**333**	145		7	85		15	45	4.4	15
Hydropower (small-scale)[b]	**211**	95	11.5	9.3[l]	12		5	6.7	4	35
Geothermal energy[a]	**182**			35		2		17.3	37.5	62
CSP	**23**	11		5.2				0.7		3
Total	**8,305[h]**	**3,643**	**875.9**	**777.3**	**385**	**313**	**162.3**	**334[j]**	**162**	**667[k]**
Hydropower (large-scale)[b]	**1,519**	312	183	28	236	18		6	9	46
Total (including large-scale hydropower)	**9,824**	**3,955**	**1,058**	**806**	**621**	**330**	**162**	**340**	**171**	**714**

Note: Figures provided in the table are the result of a comprehensive review of primary (national entities such as ministries, statistical agencies, etc.) and secondary (regional and global studies) data sources and represent an ongoing effort to update and refine available knowledge. Totals may not add up due to rounding.

[a] Power and heat applications (in the case of geothermal energy in the EU, 110,000 jobs in heat pumps also are included). [b] Although 10 MW is often used as a threshold, definitions are inconsistent across countries. [c] About 238,300 jobs in sugar cane and 174,600 in ethanol processing in 2015; also includes rough estimate of 200,000 indirect jobs in equipment manufacturing in 2015, and 169,900 jobs in biodiesel in 2016. [d] Equipment manufacturing and installation jobs. [e] Based on employment factor calculations for biomass power and CHP. [f] Includes 222,500 jobs for ethanol and about 61,100 jobs for biodiesel in 2016. [g] Traditional biomass is not included. [h] The total for 'World' is calculated by adding the individual totals of the technologies, with 4,870 jobs in ocean energy, 16,400 jobs in renewable municipal and industrial waste and 14,500 jobs in miscellaneous which are not broken down by technology. [i] All EU data are from 2015, except for wind energy jobs data for Finland and Netherlands, which was available for 2016. The two major EU countries are represented individually. [j] Includes 7,700 jobs in publicly funded R&D and administration, not broken down by technology. [k] Includes 13,550 jobs in renewable municipal and industrial waste and 1,000 jobs in ocean energy. [l] Direct jobs only.

Source: IRENA

Figure 6. Jobs in Renewable Energy



02

Relatively inflexible baseload generators, such as coal and nuclear power plants, have always been complemented by **FLEXIBLE GENERATION** to adapt the electricity supply to time-variable demand. Hydropower and other dispatchable renewables such as bio-power, and concentrating solar thermal power (CSP) with thermal storage offer flexible renewable energy generation options.

Väo Biomass Power Plant – Capacity:
25 MW power, 49 MW heat – Tallinn, Estonia

02 MARKET AND INDUSTRY TRENDS

BIOMASS ENERGY

There are many pathways by which biomass feedstocks can be converted into useful renewable energy. A broad range of wastes, residues and crops grown for energy purposes can be used directly as fuels for heating and cooling or for electricity production, or they can be converted into gaseous or liquid fuels for transport or as replacements for petrochemicals.[1] *(→ See Figure 6 in GSR 2015.)* Many bioenergy technologies and conversion processes are now well-established and fully commercial.[2] A further set of conversion processes – in particular for the production of advanced liquid fuels – is maturing rapidly.[3]

In 2016, local and global environmental concerns, rising energy demand and energy security continued to drive increasing production and use of bioenergy. Bioenergy consumption and investment in new capacity are supported by policy in many countries. *(→ See Policy Landscape chapter.)* However, in some countries, low fossil fuel prices during 2016 discouraged investment in bioenergy-based heating; unlike transport use of biofuels, bio-heat is not sheltered by blending mandates from changes in fossil fuel prices. Increased competition from other low-cost renewable sources of electricity acted as a barrier to bio-power production during the year.[4] The continuing discussion about the sustainability of some forms of bioenergy has led to regulatory and policy uncertainty in some markets, and has made for a more difficult investment climate.[5]

BIOENERGY MARKETS

Bioenergy (in traditional[i] and modern uses) is the largest contributor to global renewable energy supply.[6] Total primary energy supplied from biomass in 2016 was approximately 62.5 exajoules (EJ).[7] The supply of biomass for energy has been growing at around 2.5% per year since 2010.[8] The bioenergy share in total global primary energy consumption has remained relatively steady since 2005, at around 10.5%, despite a 21% increase in overall global energy demand over the last 10 years.[9]

The contribution of bioenergy to final energy demand for heat in buildings and industry far outweighs its use for electricity and transport combined.[10] *(→ See Figure 7.)*

i Traditional use of biomass refers to the use of fuelwood, animal dung and agricultural residues in simple stoves with very low combustion efficiency. There are no precise universally accepted definitions for what comprises traditional use of biomass. The definition adopted by the IEA (see endnote 7) is "the use of solid biomass in the residential sector of non-OECD member countries, excluding countries in non-OECD Europe and Eurasia". This, however, fails to take into account the inefficient use of biomass in many industrial and commercial applications in these countries, the efficient use of biomass in developing countries and the inefficient use within residential heating in some OECD, European and Eurasian countries. A discussion on this and other methodological issues associated with biomass can be found in Sustainable Energy for All, *Sustainable Energy for All 2015: Progress Toward Sustainable Energy* (Washington, DC: June 2015), http://www.se4all.org/sites/default/files/GTF-2105-Full-Report.pdf.

Bio-Heat Markets

Biomass in many forms – as solids, liquids or gases – can be used to produce heat. Solid biomass is burned directly using traditional stoves and more modern appliances to provide heat for cooking and for space and water heating in the residential sector. It also can be used at a larger scale to provide heat for institutional and commercial premises and in industry, where it can provide either low-temperature heat for heating and drying applications or high-temperature process heat. The heat also can be co-generated with electricity via combined heat and power (CHP) systems, and distributed from larger production facilities by district energy systems to provide heating (and in some cases cooling) to residential, commercial and industrial customers.

The traditional use of biomass for heat involves the burning of woody biomass or charcoal as well as dung and other agricultural residues in simple and inefficient devices. Given the informal nature of the supply, it is difficult to acquire accurate data on the use of these biomass materials.[11] However, the traditional use of biomass in 2016 is estimated at 33 EJ; although there is growth in absolute terms, the share of traditional bioenergy in total global energy consumption has been falling gradually.[12] *(→ See Figure 2 in Global Overview chapter.)*

Consumption of fuelwood for traditional energy uses has remained stable since 2010, at an estimated 1.9 billion cubic metres (m^3), equivalent to around 15 EJ.[13] The largest shares of fuelwood (as well as other fuels such as dung and agricultural residues) are consumed in Asia, South America and Africa.[14] The production of fuel charcoal for cooking (which is most common in urban areas) has increased by an average of around 2% a year since 2010, although the rate of growth has slowed in the last few years. Production decreased slightly in 2015, to 52 million tonnes, and a similar quantity is estimated to have been produced in 2016.[15]

Growth in the use of modern bioenergy for heating also has slowed in recent years, to around 1% per year. In 2016, modern bioenergy applications provided an estimated 13.9 EJ of heat, of which 9.1 EJ was for industrial uses and 4.8 EJ was consumed in the residential and commercial sectors, where it was used principally for space heating in buildings and for cooking.[16] Based on these production data, modern biomass heat capacity in 2016 increased to an estimated 311 GW_{th}.[17]

Bioenergy (mostly from solid biomass) accounts for around 7% of all industrial heat consumption, and its use in industry has not increased in recent years.[18] This use is concentrated in bio-based industries such as the pulp and paper sector, timber, and the food and tobacco sectors. The cement industry also used larger volumes of waste fuels (estimated at 0.5 petajoules (PJ)) in 2016 relative to previous years.[19]

The principal regions for industrial bio-heat are Asia (e.g., bagasse[i], rice husks, straw and cotton stalks in India) and South America (particularly Brazil, where bioenergy from agricultural and wood residues is used to produce heat in the food, tobacco, and pulp and paper industries, and bioenergy from bagasse is used in the sugar and alcohol industries).[20] North America is the next largest user: in Canada, 22% of industrial heat was provided by bioenergy in 2016, mostly in the pulp and paper industry.[21] There are signs of reduced use of bioenergy in North America, with stronger growth in Asia, reflecting changes in production patterns in key industry sectors, especially pulp and paper.[22]

In the buildings sector, the United States is the largest consumer of modern biomass for heat. Despite low oil prices, the US market for woody biomass and pellet boilers remained stable in 2016.[23]

Europe is the largest consumer of bio-heat by region. EU member states have promoted renewable heat in order to meet mandatory national targets under the Renewable Energy Directive.[24] Germany, France, Sweden, Italy and Finland and Poland were the largest producers and users in Europe in 2016.[25] In Eastern Europe, the market for bioenergy in district heating continued to grow; in Lithuania, wood chips have overtaken natural gas as the major fuel in district heating schemes.[26]

The market for wood pellets for heating grew only slowly in 2016 as the mild winter in Europe – the world's largest market – reduced demand.[27] Nonetheless, Europe accounted for some 70% of global demand for pellets for heating, led by Italy, Germany, Sweden and France.[28]

Biogas also is used in industrial and residential heating applications. In Europe, it is used increasingly to provide heat for buildings (space) and industry (processes), often in conjunction with electricity production via CHP.[29] Asia leads the world in the use of small-scale biogas digesters to produce gas for cooking and water and space heating. For example, around 4.9 million household and village-scale biogas plants are now present in India, fuelled mostly by cattle dung and agricultural wastes.[30]

Bio-Power Markets

Global bio-power capacity increased an estimated 6% in 2016, to 112 GW.[31] Generation rose 6% to 504 terawatt-hours (TWh).[32] The leading country for electricity generation from biomass in 2016 was the United States (68 TWh), followed by China (54 TWh), Germany (52 TWh), Brazil (51 TWh), Japan (38 TWh), India and the United Kingdom (both 30 TWh).[33] *(→ See Figure 8.)*

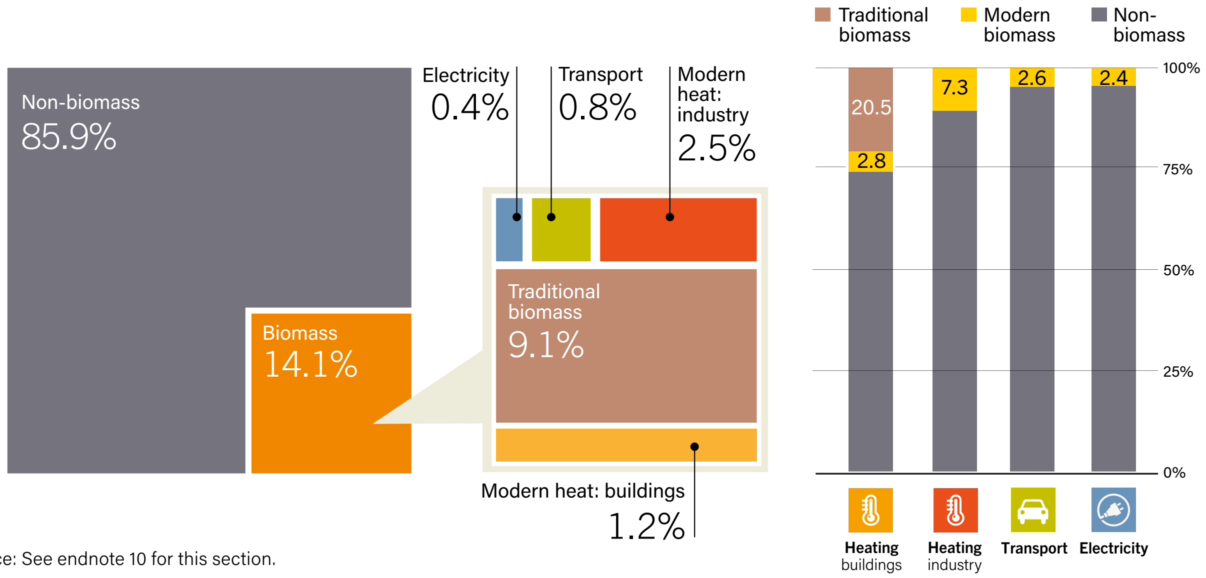
Although the United States remained the largest producer of electricity from biomass sources, generation fell 2% in 2016 to 68 TWh, down from 2015 levels of 69 TWh, as existing capacity faced increasing price competition from alternative renewable generation sources under the Renewable Portfolio Standards of a number of states.[34] However US bio-power capacity in operation reportedly increased by 197 MW (0.5%) to 16.8 GW through the installation of 51 small-scale generation plants.[35]

In Europe, growth in electricity generation from both solid biomass and biogas continued in 2016, driven by the Renewable Energy Directive.[36] In Germany, Europe's largest producer of electricity from biomass, total bio-power capacity increased 2%, to 7.6 GW, and generation was up 2.5% to 52 TWh.[37] Elsewhere in Europe, the United Kingdom's bio-power capacity increased 6% to 5.6 GW, due mainly to large-scale generation and to continuing growth in biogas production for electricity; however, generation was up only 1% because increases in output from solid biomass and anaerobic digestion were offset by reductions in generation from landfill gas.[38] In Poland, the capacity auction schemes with dedicated tranches for municipal solid waste (MSW) plants and

i Bagasse is the fibrous matter that remains after extraction of sugar from sugar cane.

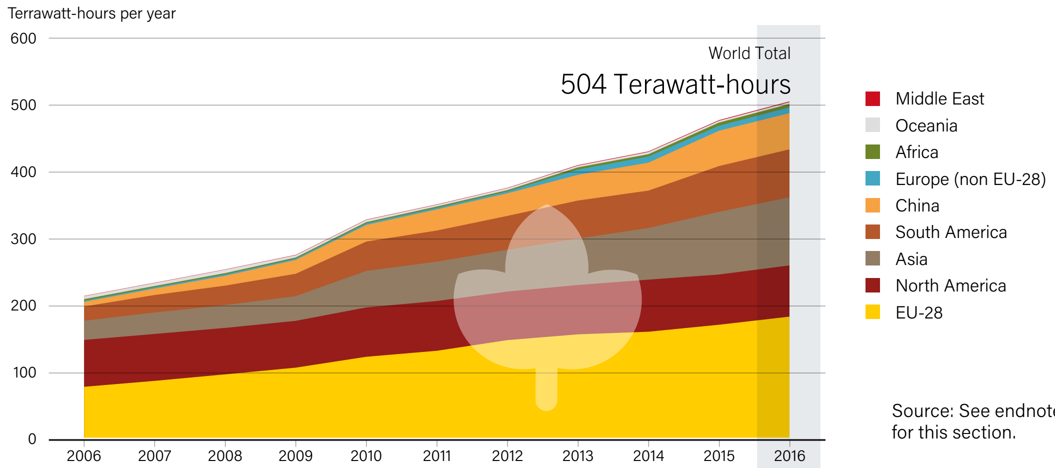
BIOMASS ENERGY

Figure 7. Shares of Biomass in Total Final Energy Consumption and in Final Energy Consumption, by End-use Sector, 2015



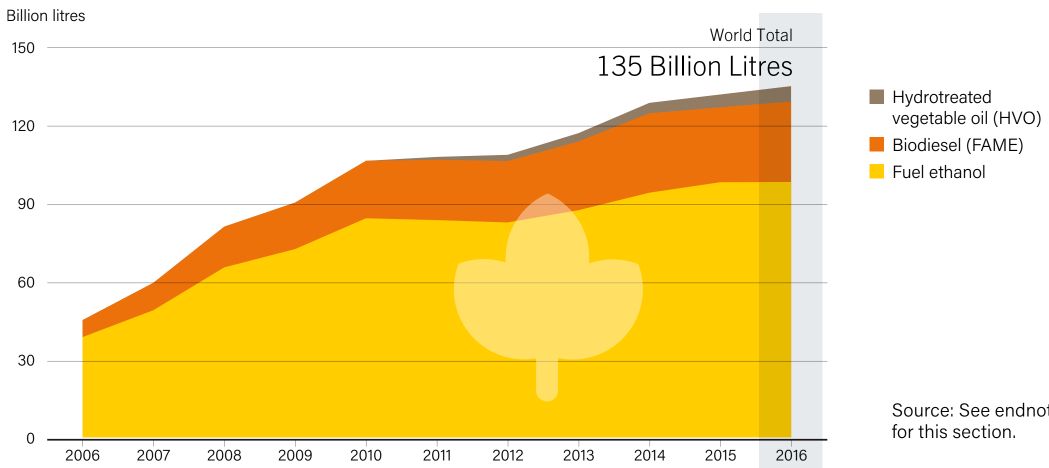
Source: See endnote 10 for this section.

Figure 8. Global Bio-Power Generation, by Region, 2006-2016



Source: See endnote 33 for this section.

Figure 9. Global Trends in Ethanol, Biodiesel and HVO Production, 2006-2016



Source: See endnote 50 for this section.

for biogas-based generation stimulated the deployment of new bio-power capacity. As a result, bio-power capacity grew from 1.27 GW to 1.34 GW, and generation increased 50% (from 10 TWh to 15 TWh) in 2016.[39]

In China, in response to revised objectives in the 13th Five-Year Plan, bio-power capacity rose by an estimated 13% in 2016, to 12 GW, and generation increased to an estimated 54 TWh.[40] The combustion of MSW and of agricultural wastes accounted for most of this generation.[41]

Elsewhere in Asia, capacity and generation rose strongly in Japan, with bioenergy featuring in the feed-in tariff scheme. Japan's imports of wood pellets for direct combustion and for use in co-firing installations has grown rapidly. The country's capacity for dedicated biomass plants reached a total of 4 GW in 2016, and generation totalled some 38 TWh, a 5% increase from 2015.[42] In the Republic of Korea, generation rose by 44% to 8 TWh, reflecting political efforts to reduce coal use in electricity generation by co-firing with biomass.[43] India's bio-power capacity increased as well, with on-grid capacity up by 164 MW (up 0.3%) to 8.3 GW, and off-grid capacity up by 18.9 MW (up 2%) to 330 MW; generation rose 8% relative to 2015, to 30 TWh.[44]

Brazil is the largest overall consumer of electricity and bio-power in Latin America. The country's capacity, which grew rapidly in 2015, rose 5% in 2016, to 13.9 GW.[45] Generation also rose 5%, to 51 TWh.[46] Over 80% of the biomass-based electricity generation in Brazil is fuelled by bagasse, which is produced in large quantities in sugar production.[47]

Transport Biofuel Markets

In 2016, global biofuels production, which closely tracks demand, increased around 2% compared to 2015, reaching 135 billion litres.[48] This increase was due largely to a rebound in biodiesel production after a decline in 2015. The United States and Brazil remained the largest biofuels producers by far, accounting for 70% of all biofuels between them, followed by Germany, Argentina, China and Indonesia.[49] An estimated 72% of biofuel production (in energy terms) was fuel ethanol, 23% was biodiesel, and 4% was hydrotreated vegetable oil (HVO).[50] *(→ See Figure 9.)*

Global production of fuel ethanol was almost unchanged between 2015 and 2016 at approximately 99 billion litres.[51] The United States and Brazil maintained their leading roles in ethanol production with 59% and 27%, respectively, of global production in 2016.[52] China, Canada and Thailand were the next largest producers.[53]

US ethanol production rose 3.5% to 58 billion litres during the year.[54] Domestic demand was supported by the annual volume requirements under the US Environmental Production Agency's (US EPA) final Renewable Fuel Standard (RFS2) allocations. Ethanol production in Brazil fell slightly, to 27 billion litres.[55] In Canada, which ranked fourth globally in 2015, production declined 3% in 2016, to 1.7 billion litres.[56]

After North and South America, Asia is the third largest regional producer of ethanol, and China is the region's largest producer. Ranking third for ethanol production globally in 2016, China produced an estimated 3.2 billion litres, an increase of 5% over 2015.[57] About 99% of the ethanol produced annually in China is based on conventional starch-based feedstocks. All ethanol production and distribution is controlled by state-owned oil companies, and only state-approved companies can carry out blending and receive incentives and subsidies.

China's biofuels policies have focused mainly on ethanol production. An E10 mandate is in place in 4 provinces and 27 cities, but production has been constrained and, historically, no blending was allowed to take place outside of these areas.[58] This limitation was eased in 2016, however, and some stockpiled grain was released for ethanol production in line with plans to boost domestic ethanol production.[59]

Elsewhere in Asia, ethanol production increased 3.9% in Thailand to 1.2 billion litres, and in India it reached 0.9 billion litres, encouraged by stronger policy support in the form of mandates.[60]

In Europe, the next-largest producing region, ethanol production fell 6% to 4.8 billion litres in 2016.[61] Production fell sharply (by 14%) in France, one of Europe's largest producers, due to a poor grain harvest, but grew strongly in Hungary (38%) and the United Kingdom (23%).[62]

Biodiesel production is more geographically diverse than ethanol, with production spread among many countries. The leading countries for production of fatty acid methyl ester (FAME) biodiesel were the United States (18% of global production), Brazil (12%), and Indonesia, Germany and Argentina (each with 10%).[63] Following a significant decrease in 2015, when output was down 6.5% to 28.7 billion litres, global production rose 7.5% in 2016 to 30.8 billion litres.[64] The increase was due mainly to restored production levels in Indonesia and Argentina and to significant increases in North America; US biodiesel production rose 15% in 2016, reaching 5.5 billion litres in response to improved opportunities for diesel within the RFS2.[65] In Canada, production rose 19% to 0.4 billion litres.[66]

By contrast, biodiesel production in Brazil fell 3% to 3.8 billion litres, despite an increase in the blending mandate.[67] The reduction probably resulted from a decline in demand for diesel consumption linked to a reduced level of business activity.[68] In Argentina, biodiesel production recovered from a fall in 2015, rising 43% to 3.0 billion litres.[69] This expansion was stimulated by increased domestic demand (which accounts for around 45% of production) and improved market prospects in the United States and Peru.[70]

European biodiesel production declined 5% to 10.7 billion litres.[71] Germany was again the largest European producer (3.0 billion litres), followed by France (1.5 billion litres).[72] Production fell by 11% in both of these countries but increased in Spain (1.1 billion litres, up 1%) and Poland (0.9 billion litres, up 8%).[73]

In Asia, after a significant decline to 1.7 billion litres in 2015, Indonesian production rose 76% to 3.0 billion litres in 2016, boosted by a number of measures aimed at stimulating a domestic market and at making Indonesia the region's largest producer again.[74] China's biodiesel production fell an estimated 10%, to 0.3 billion litres, due to reduced diesel fuel use (linked to a slowdown in industrial activity) and an absence of widespread blending mandates.[75]

Global production of HVO grew some 22% from 4.9 billion litres to 5.9 billion litres.[76] Production was concentrated in the Netherlands, the United States, Singapore and Finland.[77]

The production and consumption of biomethane as a transport fuel also continued to increase during the year. In the United States, for example, consumption grew nearly six-fold between

2014 and 2016, when biomethane provided the equivalent of 188 million gallons (712 million litres) of ethanol equivalent (15.1 PJ).[78] Conversion of biomass to biomethane was stimulated by the 2014 EPA ruling on the RFS2, which increased incentives for biomethane by promoting it to an advanced cellulosic biofuels category.[79] As a result of this substantial growth, in 2016 the United States overtook the other significant markets for biomethane in transport – Sweden and Germany – which together consumed an estimated 6.4 PJ of biomethane fuel in transport.[80]

BIOENERGY INDUSTRY

The bioenergy industry includes feedstock suppliers and processors; firms that deliver biomass to end-users; manufacturers and distributors of specialist biomass harvesting, handling and storage equipment; and manufacturers of appliances and hardware components designed to convert biomass to useful energy carriers and energy services. Industry, with support from academia and governments, also is making progress in bringing new technologies and fuels to the market.

Solid Biomass Industry

A very diverse set of industries is involved in delivering, processing and using solid biomass to produce heat and electricity, ranging from the informal supply of traditional biomass, to the locally based supply of smaller-scale heating appliances, to regional and global players involved in large-scale district heating and power generation technology supply and operations.

In Europe, the trend to convert large-scale power station capacity from coal to wood pellets continued. For example, in Denmark, a 360 MW unit of a power station in Aarhus was converted from coal to run on wood pellets, which will supply biomass-based heat to more than 100,000 homes and electricity to about 230,000 homes.[81] In the United Kingdom, Drax received European Commission approval to convert a third unit of its coal-fired plant to run on wood pellets.[82]

In both Japan and the Republic of Korea, wood pellet imports rose during the year, reflecting the rapidly increasing use of bioenergy for co-firing with coal in power generation. Japan imports 300,000 tonnes per year of industrial pellets, 70% of which come from Canada, along with 600,000 tonnes of palm kernel shells from Vietnam and other South-Eastern Asian countries.[83]

The global market for wood pellets for industrial (mostly power station) use and heating use has continued to expand. Demand in the industrial sector reached some 13.8 million tonnes in 2016.[84] A similar quantity (around 14 million tonnes) of pellets went to heating markets (individual houses and district heating), notably in Italy, Germany and Sweden.[85] The wood pellet heating market has grown steadily at a rate of nearly 1 million tonnes per year over a 10-year period.[86]

The United States is the largest exporter of wood pellets. In 2016, US manufacturers produced approximately 6.9 million tonnes of wood pellets and exported 4.8 million tonnes.[87] During the first half of 2016, 85% of exported pellets were sold to the UK Drax plant.[88] Canadian exports also rose 47% in 2016 to 2.5 million tonnes.[89] Latvia, Europe's largest producer, exported 1.9 million tonnes mainly to Denmark and the United Kingdom, as well as to Sweden and Italy.[90]

Along with some large-scale plants designed to provide supply chain security to particular users (such as Drax), the pellet industry mostly comprises independent producers and is based around sawmill operations.[91] For example, 142 pellet plants are operational in the United States and 58 in Canada.[92] However, there are signs of industry consolidation. In the EU, for example, Graanul (Estonia) was the largest producer in 2016, with 11 pellet plants across Estonia, Latvia and Lithuania.[93]

The sustainability of bioenergy, and particularly of the large-scale use of pellets derived from wood, continues to be a controversial issue.[94] The European Commission, in its proposals for a new Renewable Energy Directive launched in November 2016, stated its intent to reinforce mandatory sustainability criteria for bioenergy by extending the scope to cover solid biomass and biogas for heating and cooling and electricity generation.[95] As of 2016, such mandatory criteria applied only to biofuels, although member states can introduce criteria for the heat and electricity sectors, as the United Kingdom and Denmark have done.[96]

The torrefaction of wood enables the production of pellets with a higher energy density and results in a product compatible with systems designed for coal. Although commercialisation of the technology has been slower than expected, some promising developments occurred in 2016.[97] For example, Airex Energy (Canada) started producing torrified pellets at its Bécancour plant in Canada, with a capacity of 15,000 tonnes per year.[98] Finnish company Biopower Oy invested USD 74-84 million (EUR 70-80 million) to build a bio-coal[i] plant in Mikkeli, Finland that will produce 200,000 tonnes of bio-coal pellets annually and is due to come online in 2017-18.[99]

Liquid Biofuels Industry

Liquid biofuel production is concentrated among a small number of large industrial players with dominant market shares. These include ethanol producers Archer Daniels Midland (ADM), POET and Valero in the United States, and Copersucar, Oderbrecht (ETH Bioenergia) and Raizen in Brazil.[100] A number of large-scale companies with fossil fuel backgrounds (such as Shell, Neste and Honeywell UOP) and from bio-based industries (such as UPM from the pulp and paper sector) are engaged in developing and producing new biomass-based fuels.[101]

New patterns of trade for ethanol are developing, particularly with the rise in both demand and production in China. In 2015, China became a major importer of ethanol from the United States; US exports to China rose 2.4-fold in 2016.[102] Indigenous Chinese production also increased, based on high stocks of grains. China recently introduced an import tax on ethanol to support domestic production, and as of 2016 the country was exporting ethanol to some Asian markets.[103]

Net imports of biodiesel to the United States more than doubled between 2015 and 2016 (from 1.0 billion to 2.3 billion litres).[104]

i The US Department of Agriculture (USDA) defines bio-coal as "A biomass fuel processed by torrefaction of agricultural wastes such as wood residues into a high density, energy-concentrated fuel product in the form of pellets or briquettes". USDA, National Agricultural Library, "Glossary: Biocoal", https://agclass.nal.usda.gov/mtwdk.exe?k=glossary&l=60&w=1439&n=1&s=5&t=2.

Argentina was a leading supplier of this increase: the country has significant biodiesel production capacity, and since 2010 it has been supplying markets in the EU as well as in the United States, Peru and other countries. Despite growing domestic demand, however, Argentina's biodiesel manufacturing capacity has been underutilised (at 40-55%) since 2013, when the EU imposed a heavy import tax on Argentinian biodiesel.[105]

In Africa, despite significant potential and attempts in some countries to design biofuels strategies, development of production has been slow, held back in part by problems in accessing appropriate technology.[106] Some promising developments have occurred, however; for example, Nigeria launched a national biofuels strategy in 2016.[107] The Nigeria National Petroleum Corporation (NNPC) announced plans to set up a biorefinery that will use agricultural products to produce ethanol and other products, and Union Dicon Salt has agreed to a joint project with Delta State (Nigeria) to plant 100,000 hectares of cassava and to build an ethanol processing plant that will produce 22,000 litres a day along with starch products.[108] Biofuels Nigeria also is planning to build a biodiesel plant in Kogi State using jatropha as feedstock.[109] In South Africa, Ethala Biofuels announced plans for a sweet sorghum biorefinery project that will produce ethanol and other products.[110]

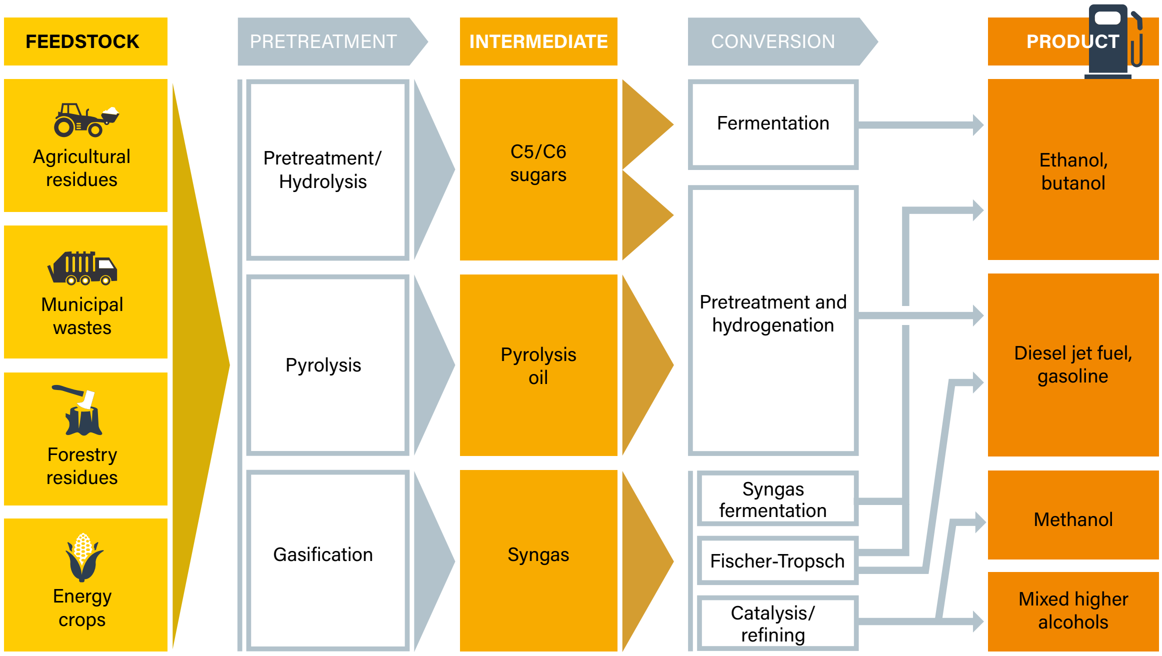
In 2016, worldwide efforts to demonstrate the production and use of advanced biofuels were expanded. The aim of developing and commercialising advanced biofuels is three-fold: first, to produce fuels that can provide more life-cycle carbon savings than some biofuels produced from sugar, starch and oils; second, to produce fuels with less impact on land use (e.g., from wastes and residues), thereby reducing indirect land-use change impacts and also reducing competition for food or for productive agricultural land; and finally, to produce biofuels with properties that enable them to directly replace fossil fuels in advanced transport systems such as aviation engines, or to be blended in high proportions with conventional fuels ("drop-in biofuels"). A number of routes are under development to produce advanced biofuels in the form of ethanol, butanol, diesel jet fuel, gasoline, methanol and mixed higher alcohols from an array of feedstocks.[111] *(→ See Figure 10.)*

The market for new biofuels in 2016 was led by HVO, followed by ethanol from cellulosic materials such as crop residues and by fuels from thermochemical processes including gasification and pyrolysis.[112] Production of fuels from HVO (including used cooking oil (UCO), tall oil[i] and others) increased greatly in 2016, mostly because capacity that had been announced or commissioned in 2015 came fully online and improvements were made in production efficiency.[113] For example Neste, which owns three large-scale renewable HVO diesel production facilities in Singapore, the Netherlands and Finland, announced plans to increase its production to 2.6 million tonnes (3.3 billion litres) by 2017 by improving productivity at these existing sites rather than adding new locations.[114] The US Renewable Energy Group, which has 14 production sites in the United States and Germany, announced that its cumulative biodiesel production had exceeded 2 billion gallons (7.6 billion litres) early in 2017.[115]

Plans were announced in 2016 for the construction of several additional cellulosic ethanol manufacturing plants, which will extend the geographical coverage of production outside the United States and Europe. Italy's Beta Renewables (which operates the Crescentino cellulosic ethanol plant in Italy) engaged in further joint-venture projects in the United States, Brazil, China and the Slovak Republic.[116] In Finland, North European BioTech Oy was

i Tall oil is a mixture of compounds found in pine trees and is obtained as a byproduct of the pulp and paper industry.

Figure 10. Some Conversion Pathways to Advanced Biofuels



Source: See endnote 111 for this section.

developing advanced ethanol production plants in Pietarsaari and Kajaani; once in operation, these plants will be able to produce 50 million litres each of advanced ethanol per year using softwood sawdust, recycled wood and other forestry wastes and residues.[117]

In Asia, DuPont (United States) signed a licensing agreement with New Tianlong Industry Company Ltd. (China) to begin construction of China's largest cellulosic ethanol manufacturing plant, to be located in Siping City.[118] India Glycols opened India's first cellulosic plant in Kashipur, which runs on wood chips, cotton stalk, cane bagasse, maize stover and bamboo.[119] Also in India, during 2016, memoranda of understanding relating to five additional cellulosic ethanol plants were finalised.[120] In Thailand, Toray and Mitsui (both of Japan) announced plans to build a large-scale plant to convert sugar bagasse to ethanol; the facility is expected to come online in August 2018.[121]

Commercialisation of thermal processes such as pyrolysis and gasification also advanced in 2016. Enerkem (Canada) commissioned a commercial-scale plant in Edmonton, Canada based on the gasification technology and ethanol synthesis technology demonstrated at the company's Westbury plant. The Edmonton plant uses 300 tonnes per day of sorted municipal waste to produce methanol, and a facility allowing ethanol production was being constructed as of 2016.[122] Also in 2016, the Altair Renewable Jet Fuel Project in the US city of Los Angeles began producing "drop-in" biofuels via Honeywell UOP's Renewable Jet Fuel Process in a retrofitted part of an existing oil refinery. The plant, which uses vegetable oils, animal fats and greases as feedstocks, is capable of producing 2,500 barrels (0.15 billion litres) per day of bio-jet fuel.[123]

Strong interest in the development of aviation biofuels continued in 2016, although quantities remained relatively small and mostly for demonstration use.[124] By the end of the year, the American Society for Testing and Materials (ASTM[i]) had certified two additional technology pathways to produce bio-jet fuels, bringing the total to five.[125] Several aircraft manufacturers have been instrumental in the development of bio-jet fuels, including Airbus and Boeing. In addition, a number of air carriers worldwide continued to use biofuels in 2016, including Aeromexico, Alaska Airlines, British Midland, FedEx, Finnair, Gol, KLM, Lufthansa, Qatar Airways, Scandinavian Airlines (SAS), Southwest Airlines and United Airlines.[126] Several voluntary initiatives at the local and regional levels have sought to establish bio-jet supply chains at specific airports, such as the supply of bio-jet fuel to Arlanda airport In Stockholm, Sweden by SkyNRG and Air BP.[127] The US Air Force also continued to actively develop bio-aviation fuels for defence purposes, working with a number of companies to establish production facilities, and the US Navy continued with its Great Green Fleet initiative during 2016.[128]

In the marine sector, an initiative was established In the Netherlands to develop sustainable drop-in biofuels (similar to UPM's wood-derived product) for marine applications.[129] The Maersk Group (Denmark) is testing biofuels and other alternatives in larger ships and has a dedicated container ship for the purpose of testing biofuels derived from a wide variety of sources.[130] In Italy, ENI provided biodiesel prepared using the company's Ecofining process for the Italian navy's offshore patrol vessel Foscari.[131]

Gaseous Biomass Industry

Most biogas production occurs in the United States, where it is based predominantly on the collection of landfill gas, and in Europe. Production in Europe is focused more on the anaerobic digestion of agricultural wastes, including animal manures, and increasingly on the digestion of recovered food wastes (for example, in Sweden and the United Kingdom).[132] Other regions, including Asia and Africa, were taking up the technologies as of 2016. Growth rates have been higher in these new regions, albeit from a low starting level.[133]

Expanding markets for biogas and biomethane are stimulating commercial activity worldwide. In response to the recent growth of biomethane as a transport fuel in the United States under RFS2, BP announced that it will buy the bio-methane business owned by Clean Energy Fuels for USD 155 million (EUR 147 million).[134] In Europe, waste management firm Suez bought a 22% stake in biogas producer Prodeval, which developed a high-performance membrane purification process for biomethane production.[135] Meanwhile, strong growth in the market for biogas facilities has led to Xergi, a supplier and builder of such systems, being named one of the fastest growing businesses in Denmark.[136]

In India, where biogas capacity is estimated at 300 MW, many industrial processes now produce biogas, driven by strong water-quality standards that limit the release of effluents into waterways.[137] In other parts of Asia, there is a similar trend to produce and use biogas obtained by treating liquid effluents and wastes. In late 2016, Green & Smart Holdings (Malaysia) announced the start of operations of its first biogas-based power plant (2 MW), which runs on palm oil mill effluent and will export electricity to the national grid.[138]

In Africa, biogas production has continued to expand, largely from municipal and agricultural wastes. In South Africa, renewable energy developer New Horizons teamed with gas firm Afrox to open an energy-from-waste biogas plant near Cape Town, at a cost of USD 29 million (ZAR 400 million).[139] In Kenya, the country's first biogas-powered grid-connected CHP plant commenced generation at a commercial farm, producing 2 MW of electricity and enough heat to cultivate 704 hectares of vegetables and flowers, with enough surplus power to supply 5,000 to 6,000 rural homes.[140]

i ASTM certification is required before commercial airlines can use a fuel for an international flight.

GEOTHERMAL POWER AND HEAT

GEOTHERMAL MARKETS

Geothermal resources provide electricity and thermal energy services (heating and cooling). In 2016, the estimated electricity and thermal output from geothermal sources was 567 PJ[i] (157 TWh), with each providing approximately equal shares.[1] Some geothermal plants produce both electricity and thermal output for various heat applications.

An estimated 0.4 GW of new *geothermal power* generating capacity came online in 2016, bringing the global total to an estimated 13.5 GW.[2] Indonesia and Turkey were in the lead for new installations. Kenya, Mexico and Japan also completed projects during the year, and several other countries had projects under development.[3] *(→ See Figure 11.)*

The countries with the largest amounts of geothermal power generating capacity at the end of 2016 were the United States (3.6 GW), the Philippines (1.9 GW), Indonesia (1.6 GW), New Zealand (1.0 GW), Mexico (0.9 GW), Italy (0.8 GW), Turkey (0.8 GW), Iceland (0.7 GW), Kenya (0.6 GW) and Japan (0.5 GW).[4] *(→ See Figure 12.)*

Indonesia added about 200 MW of new capacity in 2016, ending the year with 1.64 GW.[5] By early 2017, the country also had started commercial operations at the 110 MW Sarulla plant, one of the largest geothermal plants in the world. The plant is notable for being a combined-cycle operation, analogous to a Turkish plant coming online in 2017, where conventional flash turbines are supplemented with a binary system to extract additional energy from the post-flash turbine steam, maximising energy extraction and efficiency.[6]

Existing capacity in Indonesia is estimated to be less than 6% of the country's total geothermal power potential, and Indonesia aims for continued rapid development of these resources.[7] To facilitate progress, as of early 2017 the government had plans to mitigate the risks of exploration and development by mapping the country's geothermal resources, and was considering a feed-in tariff to provide a predictable fixed price for geothermal energy to further reduce risk to project developers.[8]

Following the opening of 10 plants in 2015, Turkey added at least another 10 new geothermal power plants in 2016, increasing capacity by about 200 MW for a total of 821 MW.[9] With so much additional capacity online, the country has seen continued rapid growth in electricity generated from geothermal energy; generation rose 25% in 2016 alone, to 4.21 TWh.[10] All the new plants were binary Organic Rankine Cycle (ORC[ii]) units, with capacity of up to 25 MW each.[11] Turkey also is developing projects with conventional flash turbine technology that is suitable for the country's remaining high-temperature resources. For example, the 70 MW Unit 2 of the Kizildere III plant, to be operational in 2017, will combine a 51 MW flash-steam turbine to harness high-pressure steam with a 19 MW binary-cycle unit to capture usable energy from the flash turbine's exhaust stream.[12]

Kenya completed a 29 MW addition at the Olkaria III complex in 2016, increasing the facility's capacity to 139 MW.[13] At year's end, Kenya's total operating capacity was about 630 MW.[14]

In Mexico, a 25 MW condensing flash unit was added to the Domo San Pedro plant, taking over from two 5 MW temporary wellhead units that were installed in 2015 to get production under way.[15] The net addition of 15 MW brought Mexico's total capacity to about 950 MW. This plant is the first private geothermal project in the country, but another was in the early stages of exploratory drilling as of early 2017.[16] Mexico awarded three additional exploration permits in 2016 to private Mexican companies under the country's new Geothermal Energy Law, which governs the exploration and use of geothermal resources.[17]

Japan's progress on geothermal development has been mixed, with competing desires for alternatives to fossil and nuclear fuels on one hand, and concerns about safety and potential unintended economic and environmental consequences on the other. A combination of a higher FIT and an exemption from environmental impact assessments for small plants (less than 7.5 MW) has encouraged interest in small-scale geothermal power projects in Japan.[18] A small geothermal facility in Tsuchiyu was completed in 2015, and at least one small ORC generator came online in 2016. However, as of early 2017 the country had no large-scale projects under development.[19]

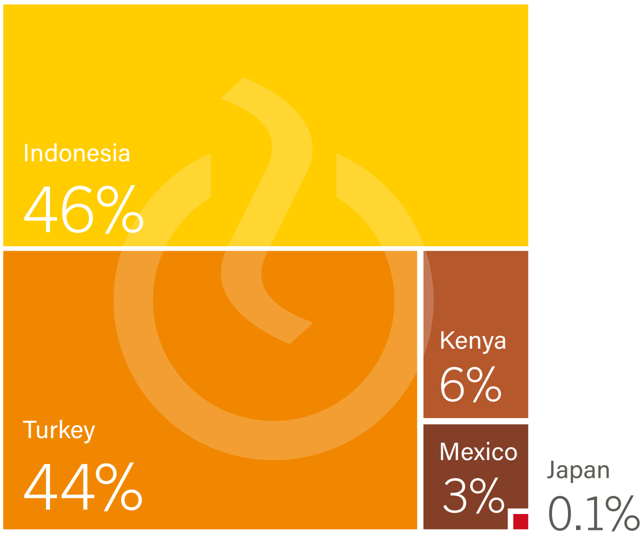
Another small project in Japan's Fukushima prefecture was in the planning stage during 2016, but not without apprehension from local business interests.[20] Many hot spring resort owners and local governments in Japan are concerned that development of geothermal power projects will put such businesses at risk.[21] To alleviate these concerns, in 2016 the national government established an expert advisory committee to provide information on geothermal energy development to local governments. The

i This does not include the renewable final energy output of ground-source heat pumps. *(→ See Enabling Technologies chapter.)*

ii In a binary plant, the geothermal fluid heats and vaporises a separate working fluid that has a lower boiling point than water; the fluid drives a turbine for power generation. Each fluid cycle is closed, and the geothermal fluid is re-injected into the heat reservoir. The binary cycle allows an effective and efficient extraction of heat for power generation from relatively low-temperature geothermal fluids. ORC binary geothermal plants use an organic working fluid, and the Kalina cycle uses a non-organic working fluid. In conventional geothermal power plants, geothermal steam is used directly to drive the turbine.

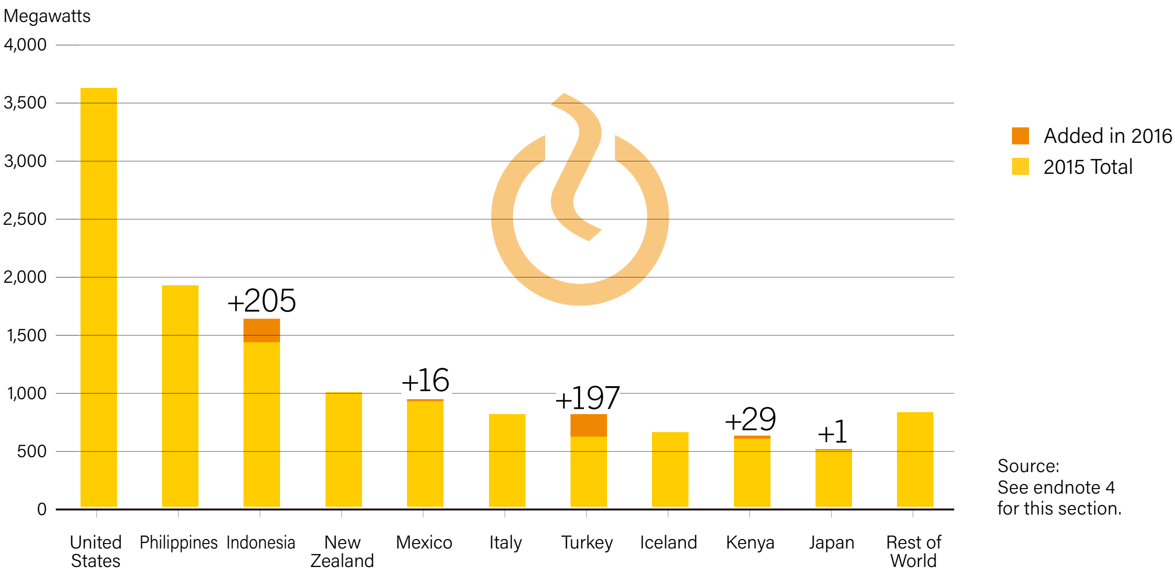
GEOTHERMAL POWER

Figure 11. Geothermal Power Capacity Additions, Share by Country, 2016



Source:
See endnote 3 for this section.

Figure 12. Geothermal Power Capacity and Additions, Top 10 Countries, 2016



Source:
See endnote 4 for this section.

INDONESIA and TURKEY led the way for NEW GEOTHERMAL POWER installations, and EUROPE remained an active market for GEOTHERMAL HEAT.

government also announced plans to cover some of the initial costs of exploratory drilling and data gathering to address development risk.[22]

Project development and other geothermal activities were under way in several other countries during 2016, including the United States. Although the country saw no net increase in geothermal capacity, leaving the total at 3.6 GW (2.5 GW_{net}), electricity generation increased by 9.4% relative to 2015, to 17.4 TWh.[23] The United States has about 0.8 GW of ongoing projects that are likely to be operational by 2020, and another 0.9 GW of projects that are under development with the potential to come online if small hurdles are overcome.[24] However, progress is reportedly constrained by an unfavourable regulatory environment and by competition from relatively low natural gas prices.[25]

The Philippines is second only to the United States for total geothermal power capacity in operation. No capacity was brought online in 2016, and the country's geothermal industry association called for FITs for geothermal power, similar to those granted to other renewables, to spur development of more-challenging low-temperature resources.[26] Low-temperature resources may require deeper drilling and the application of binary-cycle technology, which increases development risk and the ultimate cost of produced energy.[27] In early 2016, the Asian Development Bank (ADB) announced plans to back the first Climate Bond in Asia and Oceania, in the form of a 75% guarantee of principal and interest on a USD 225 million bond, specifically for the refurbishment of the Philippines' Tiwi and Mak-Ban geothermal facilities.[28]

In China, the central government plans to increase the sustainable use of geothermal energy in cities to reduce local air pollution and greenhouse gas emissions.[29] As of 2015, China had less than 30 MW of geothermal power capacity, mostly in Tibet, but the country's 13th Five-Year Plan for geothermal energy calls for an additional 500 MW by 2020.[30]

Unlike many of its Asian neighbours, Malaysia had no geothermal plants in operation by end-2016. This will change upon completion of a 30 MW plant under construction in the state of Sabah on the island of Borneo.[31] To support the nascent geothermal energy development in Malaysia, in 2016 the government was in the process of establishing a Geothermal Resource Centre to create a platform for collaboration with foreign institutions, to bring together stakeholders and specialists in geothermal energy and to offer training in related sciences.[32]

Croatia also initiated construction of its first-ever geothermal power project in 2016.[33] This 16 MW binary plant will utilise the 170°C geothermal brine and steam from the Pannonian basin, one of the key geothermal areas in Europe.[34]

Ethiopia shares the geothermal riches of the Great Rift Valley with Kenya, but limited development has occurred to date, with about 7 MW in place.[35] However, in 2015, the country pushed the agenda by signing a 500 MW PPA for the first phase of the Corbetti project, which is expected to be built in two stages within 8 to 10 years.[36] The International Finance Corporation has worked with Ethiopia to enact regulations to facilitate private

investor engagement in geothermal projects.[37] In 2016, Ethiopia reclassified geothermal resources as renewable energy, making geothermal energy use exempt from royalty payments that are exacted from extractive mineral resources under the country's mining laws.[38]

Many of the islands of the Caribbean are volcanic and have the potential to displace costly fuel imports with local geothermal energy. In 2016, the Abu Dhabi Fund for Development announced a new loan to St. Vincent and the Grenadines for the construction of a 15 MW geothermal power plant that is expected to reduce power costs, provide local jobs and improve the reliability of electricity service.[39] Later in the year, New Zealand signed a partnership agreement with the Commonwealth of Dominica, pledging to support the construction of a 7 MW geothermal plant on the island.[40] Plans also are under way to expand an existing 10 MW plant on the island of Guadeloupe.[41]

Geothermal direct use – direct thermal extraction for heating and cooling, excluding heat pumps[i] – was estimated to be 286 PJ (79 TWh) in 2016, based on historical growth rates for various geothermal heat applications, which suggests that an estimated 1.3 GW_{th} of capacity was added in 2016, for a global total of 23 GW_{th}.[42] Direct use capacity has grown by an annual average of 6% in recent years, while direct heat consumption has grown by an annual average of 3.5%.[43] The difference is explained in part by rapid growth in geothermal space heating (7.1% annually), which exhibits below-average capacity utilisation.[44]

i Direct use refers here to deep geothermal resources, irrespective of scale, as distinct from shallow geothermal resource utilisation, specifically by use of ground-source heat pumps. *(→ See Heat Pumps section in Enabling Technologies chapter.)*

The single largest direct use application is estimated to be swimming pools and other public baths, followed by space heating (including district heat networks).[45] These two broad markets command around 80% of both direct use capacity and consumption. The remaining 20% of direct use capacity and heat output is for applications that include domestic hot water supply, greenhouse heating, industrial process heat, aquaculture, snow melting and agricultural drying.[46]

China utilised the largest amount of direct geothermal heat (20.6 TWh) in 2015.[47] Other top users of direct geothermal heat are Turkey (12.5 TWh), Iceland (7.4 TWh), Japan (7.1 TWh), Hungary (2.7 TWh), the United States (2.6 TWh) and New Zealand (2.4 TWh).[48] These countries accounted for approximately 70% of direct geothermal use.[49] As of 2015, the countries with the largest geothermal direct use capacity were China (6.1 GW_{th}), Turkey (2.9 GW_{th}), Japan (2.1 GW_{th}), Iceland (2.0 GW_{th}), India (1.0 GW_{th}), Hungary (0.9 GW_{th}), Italy (0.8 GW_{th}) and the United States (0.6 GW_{th}).[50] Together, these eight countries accounted for about 80% of total global capacity.[51]

Several EU countries have added direct use capacity through the continued expansion of geothermal district heating. Between 2012 and 2016, 51 new or renovated geothermal district heating plants were completed in the EU, adding about 550 MW_{th} of capacity.[52] In 2016, Europe had more than 260 geothermal district heating systems, including co-generation systems, with a total installed capacity of approximately 4 GW_{th}. The main markets are France, the Netherlands, Germany and Hungary.[53] One of the projects that started operations during the year is a 20 MW_{th} plant for district heating in the city of Munich.[54] The plant is the latest of many small-scale geothermal facilities in Bavaria that use relatively low-temperature resources, often to produce both heat and power.[55]

In France, geothermal district heating is extending beyond the Paris metropolitan area, which has seen significant development of these systems in recent years. In early 2017, the city of Bordeaux issued a contract to develop geothermal resources to serve the bulk of the heating needs of about 28,000 homes.[56] In addition, the use of geothermal heat is spreading to the French industrial sector. In 2016, a 24 MW_{th} enhanced geothermal plant opened in Rittershoffen, in the Upper Rhine Valley.[57] The plant is reported to be the country's first high-temperature (greater than 150°C) geothermal facility supplying industrial process heat; the heat is extracted from a 170°C aquifer at a depth of 2.5-3.0 kilometres.[58] The Rittershoffen project benefited from lessons learned from the nearby pioneering enhanced geothermal system (EGS) power plant at Soultz-sous-Forêts. Chemical and hydraulic stimulations of the field did not result in notable induced seismic activity.[59]

Development of geothermal for heat also continued in China, where direct use of geothermal energy covered slightly more than 100 million square metres (m^2) of heated space as of 2015.[60] China's central government envisions a significant increase, in pursuit of the sustainable use of geothermal resources to reduce air pollution while also protecting water resources. Under the 13th Five-Year Plan, China aims to increase direct use of geothermal heat by another 400 million m^2 by 2020.[61]

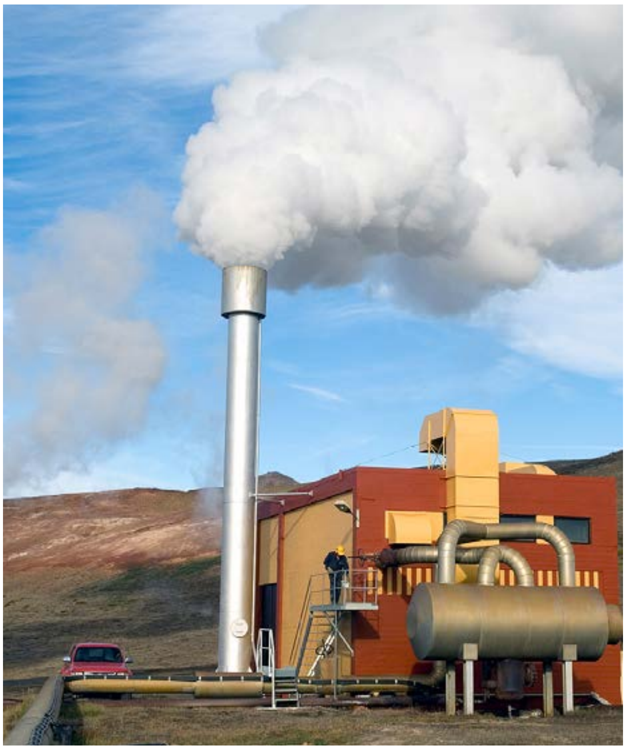
GEOTHERMAL INDUSTRY

The geothermal industry continued to face challenges in 2016, burdened by the inherent high risk of geothermal exploration and project development, the associated lack of risk mitigation, and the constraints of financing and competitive disadvantage relative to low-cost natural gas. Yet the industry made progress with new project development in key markets, and industry leaders cemented partnerships to tackle new opportunities.

Progress on the development of geothermal energy around the world has been constrained, in part, by a lack of clear resource assessment standards. To help address this challenge, in 2016 new geothermal specifications were completed under the UN Framework for Fossil Energy and Mineral Reserves and Resources. The framework's objective is to harmonise standards for reporting geothermal resources in a manner similar to other extractive industries worldwide, for the benefit of investors, regulators and the general public.[62]

The industry is sensitive to trends in oil and natural gas prices. Low oil and gas prices tend to reduce global demand for drilling rigs for oil and gas exploration, which can have a positive effect on the geothermal industry by reducing the associated costs of geothermal exploration and the development of new fields.[63] Conversely, low fossil fuel prices in general, and natural gas prices in particular, tend to reduce the competitiveness of geothermal heat and power.[64]

In late 2016, Chevron Corporation (United States), one of the world's largest operators of geothermal facilities, announced its intention to sell its geothermal assets in Indonesia and the Philippines. These include the Darajat and Salak fields in Indonesia and the Tiwi and Mak-Ban plants in the Philippines.[65] The purchase of the Indonesian plants (637 MW in total) by a consortium of holding companies in the Philippines and Indonesia was completed in April 2017, with the acquisition of the remaining assets (747 MW in total) pending regulatory approvals.[66]



Some top technology providers have formed partnerships in recent years to pursue projects jointly. In 2015, Ormat Technologies (United States) and Toshiba Corporation (Japan) reached a strategic agreement to join Ormat's binary technology and Toshiba's flash technology in a combined-cycle configuration.[67] In 2016, Mitsubishi Hitachi Power Systems Ltd., formed by the 2014 merger of the thermal power divisions of Mitsubishi (Japan; parent company of Turboden, Italy) and Hitachi (Japan), won an order for a 55 MW turbine in Costa Rica.[68] The company anticipated that Japan's International Cooperation Agency would pave the way for projects in all major geothermal power markets through low-interest loans for exploration and development.[69]

Technology advances continued during 2016 and into 2017. In early 2017, after 176 days of drilling, the Icelandic Deep Drilling Project achieved a significant milestone for the geothermal industry with the completion of its 4,659-metre-deep borehole on the Reykjanes Peninsula. The well successfully found supercritical fluid at a temperature of 427°C, with promising characteristics for energy production. The project aimed to investigate the feasibility of finding and utilising supercritical hydrothermal fluids, which modelling suggests could have 10 times the power output of a conventional geothermal well, potentially allowing for improved economics and reduced environmental impact per unit of energy produced.[70]

Also in Iceland, methods have been developed to reinject to the ground both carbon dioxide and hydrogen sulphide (H_2S) for sequestration in mineral form.[71] Together, CO_2 and H_2S comprise more than 80% of the off-gases at the country's geothermal plants.[72] In Iceland's CarbFix project, more than 95% of injected CO_2 has become bound as carbonate minerals within a period of two years, faster than was predicted.[73] Alternatively, once separated from other gases, the CO_2 can be made available to local commercial interests, such as greenhouses and algae producers.[74]

Because the CO_2 concentrations in geothermal gases can be significant, some experts are concerned about the potential greenhouse gas impact of open-loop geothermal power generation, although emission rates depend on local geology and operating conditions. In California, CO_2 emissions from geothermal power plants are significantly lower per kilowatt-hour (kWh) than those from coal- or natural gas-fired plants – emissions have been estimated at less than 0.2 kilograms per kWh from flash steam geothermal plants and about 0.03 kilograms per kWh for dry steam geothermal plants (all open-loop)[i],[75]

In Turkey, by contrast, studies have found that a "typical" open-loop 50 MW geothermal plant emits 1 kilogram of CO_2 per kWh, or approximately 1,200 tonnes per day, probably due to high levels of dissolved calcite in the country's geothermal reservoirs.[76] In some instances, CO_2 emissions from geothermal power generation in Turkey may be double those from coal-fired power plants.[77] It has been postulated that this might place future projects in Turkey at odds with the environmental criteria of development agencies, including the developing criteria for green bonds.[78] Efforts are under way to study means to capture the CO_2 from Turkey's geothermal plants for commercial use.[79]

Some technology advances have promised to expand the application of geothermal power. In the US state of Utah, the world's first geothermal-hydro plant hybridisation was realised when Enel S.p.A. (Italy) started operating a hydro-generator in a geothermal injection well during 2016. As a result, the 25 MW Cove Fort plant captures the energy of the geothermal brine flowing back into the earth, increasing plant efficiency.[80] In North Dakota, a first-of-its-kind geothermal power project was launched during the year, utilising hot water that flows naturally from petroleum production wells to co-produce electricity. The sheer number of oil- and gas-producing wells at the site means that the energy production potential is significant.[81]

Research continued in the field of enhanced (or engineered) geothermal systems (EGS) during 2016, particularly in the United States, where government-funded research has aimed to realise commercial, cost-competitive power production.[82] The common feature among all the most productive geothermal regions of the world is naturally occurring hydrothermal activity, defined by the presence of high heat, geothermal fluid and permeability. To achieve economical geothermal production elsewhere, or to enhance production at existing locations, fracturing of sub-surface rock formations can create the needed permeability to form a productive geothermal reservoir, which is known as EGS.[83] In other instances, adequate permeability may exist in hot sedimentary aquifers, but fracturing may be needed to ensure adequate well productivity.[84]

An example of an EGS project is the Rittershoffen project in France, mentioned above; this facility is a thermal application, but such systems also can be used to generate electricity with the use of binary-loop technology. EGS has been identified as a key to expanding the potential of geothermal heat and power production worldwide.[85]

i Stand-alone closed-loop binary cycle power plants can avoid significant venting of CO_2 and other pollutants from the geothermal fluid.

HYDROPOWER

HYDROPOWER MARKETS

Global hydropower capacity additions in 2016 are estimated to be at least 25 GW, with total capacity reaching approximately 1,096 GW[i].[1] The top countries for hydropower capacity are China, Brazil, the United States, Canada, the Russian Federation, India and Norway, which together accounted for about 62% of installed capacity at the end of 2016.[2] *(→ See Figure 13 and **Reference Table 5.**)* Global hydropower generation was estimated to be 4,102 TWh in 2016, up about 3.2% over 2015.[3] Global pumped storage capacity (which is counted separately) was an estimated 150 GW[ii] at year's end, with about 6.4 GW added in 2016.[4]

More than one-third of new hydropower capacity was commissioned in China. After China, the countries adding the most capacity in 2016 were Brazil, Ecuador, Ethiopia, Vietnam, Peru, Turkey, Lao PDR, Malaysia and India.[5] *(→ See Figure 14.)* China also was the leading installer of pumped storage capability during the year, followed by South Africa, Switzerland, Portugal and the Russian Federation.[6]

China added 8.9 GW of hydropower capacity in 2016 for a year-end total of 305 GW.[7] In addition, 3.7 GW of pumped storage capacity was completed for a total of 27 GW.[8] Hydropower generation in China continued its upwards trend, rising about 6% to 1,193 TWh, due in part to improving hydrological conditions.[9] Projects completed in 2016 represent an investment of USD 8.8 billion (CNY 61.2 billion), down 22.4% from 2015; as such, 2016 marked the fourth consecutive year of decline.[10] China's 13th Five-Year Plan for Hydropower Development envisions significant additional deployment of hydropower capacity (rising to 340 GW by 2020), as well as pumped storage (rising to 40 GW) to support the country's overall power infrastructure.[11]

In Brazil, hydropower capacity increased by 5.3 GW (5.8%), including 5.0 GW of large-scale[iii] (greater than 30 MW) capacity, for a year-end total of 96.9 GW.[12] Brazil's hydropower output increased 7.4% over 2015, to 410 TWh, thanks to improved hydrological conditions in 2016 following several years of drought-induced decline. The improved hydropower production, combined with a significant increase in wind power generation, allowed the country to reduce output from thermal power plants by 30% relative to the previous year.[13]

The final three units (totalling 1,092 MW) of Brazil's 1.82 GW Teles Pires plant came online in August.[14] In addition, about one-sixth of the 11.2 GW Belo Monte plant was completed, with three of the larger 611 MW turbines installed during the year; the remainder of the facility is expected to be finished by 2019.[15] Among other notable projects commissioned was the 3.75 GW Jirau plant, with the 10 remaining units (75 MW each) installed in 2016.[16]

Ecuador ranked third for newly installed hydropower capacity. Two large projects started operations, nearly doubling the country's hydropower capacity.[17] The 1.5 GW Coca Codo facility and the 487 MW Sopladora plant are expected to meet nearly half of the country's electricity needs and could allow Ecuador to export electricity to neighbouring Colombia.[18] To the south, Peru also brought online two significant projects in 2016. The 525 MW Cherro del Águila facility and the 456 MW Chaglla plant expanded Peru's hydropower capacity by almost one-quarter, to 5.2 GW.[19]

In Africa, Ethiopia reached a significant milestone in 2016. The remaining 1.5 GW of Ethiopia's Gibe III came online, marking the completion of this 1.87 GW plant.[20] The plant nearly doubles the power generating capacity of the country and is expected to serve about half its output to neighbouring countries Kenya, Sudan and Djibouti.[21] To accommodate power exports, Ethiopia also is building a transmission interconnection with Kenya to be completed in 2018, along with internal transmission upgrades to improve poor grid reliability at home.[22]

Several other countries, all in Asia, added significant hydropower capacity – including Vietnam, Lao PDR, Malaysia, Turkey and India. Vietnam ranked fifth worldwide for additions, commissioning a total of 1.1 GW, for a cumulative 16.3 GW of capacity in operation.[23] The two remaining units of the 1.2 GW Lai Chau plant were connected to the grid, following the first unit coming online in 2015. In addition to generating hydropower, this plant is expected to regulate flows for flood protection and water supply during the dry season.[24] Also online in 2016 was

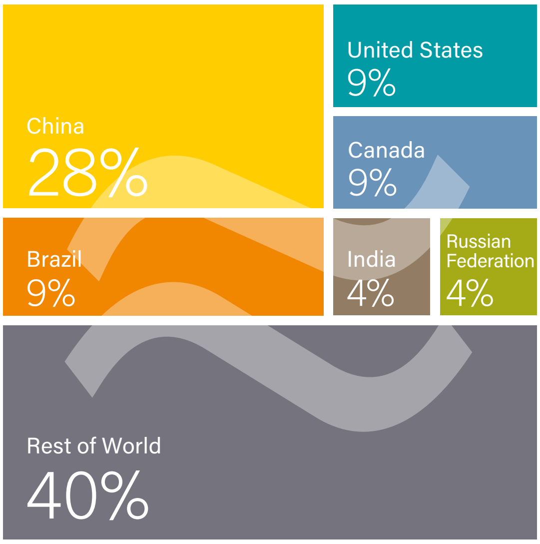
i Unless otherwise specified, all capacity numbers exclude pure pumped storage capacity if possible. Pure pumped hydro plants are not energy sources but means of energy storage. As such, they involve conversion losses and are powered by renewable and/or non-renewable electricity. Pumped storage plays an important role in balancing power, in particular for variable renewable resources.

ii This total may include some "mixed" plants that incorporate pumping capability alongside net incremental generation from natural inflows (open loop) and, as such, can be counted as hydropower capacity. The global capacity of mixed plants in 2016 was estimated at about 38 GW, corresponding to global pure pumped storage capacity of 122 GW for a total of nearly 160 GW of pumping capability. International Renewable Energy Agency, Abu Dhabi, UAE, personal communication with REN21, May 2017.

iii Brazil reports hydropower capacity separately by size category, describing all facilities smaller than 30 MW as "small". India reports hydropower above a threshold of 25 MW, with smaller units reported as "renewable energy".

HYDROPOWER

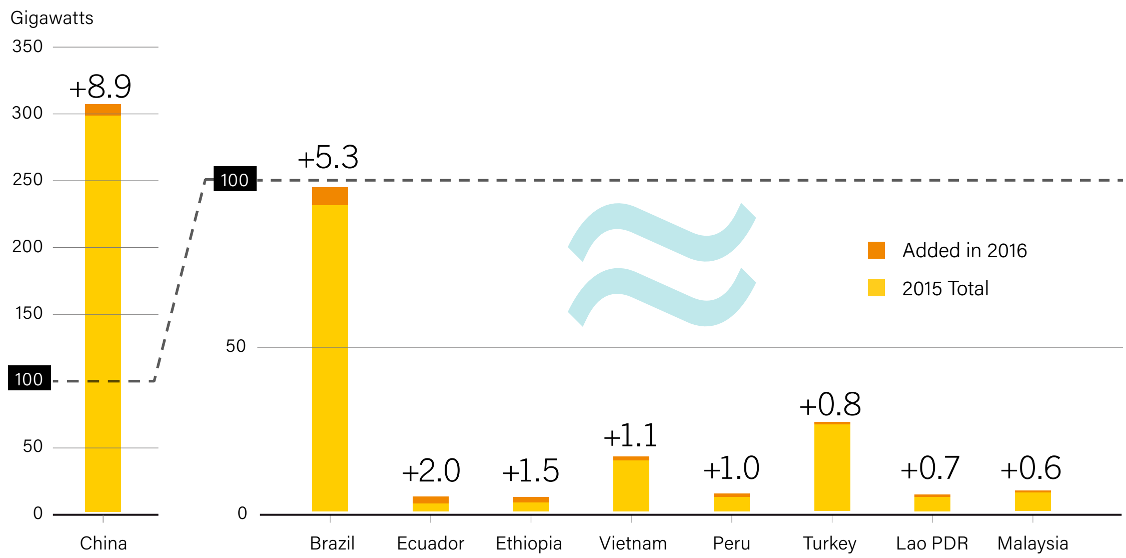
Figure 13. Hydropower Global Capacity, Shares of Top 6 Countries and Rest of World, 2016



Source: See endnote 2 for this section.

At least 25 GW of HYDROPOWER CAPACITY was commissioned, and PUMPED STORAGE grew by more than 6 GW.

Figure 14. Hydropower Capacity and Additions, Top 9 Countries for Capacity Added, 2016



Source: See endnote 5 for this section.

the second 260 MW generating unit of Vietnam's Huoi Quang plant and the 30 MW Coc San facility.[25] Neighbouring Lao PDR finished two stages (420 MW) of its project on the Nam Ou River, which is the largest tributary of the Mekong River in northern Lao PDR.[26] Malaysia continued rapid expansion of its hydropower capacity with the completion of the 372 MW Ulu Jelai project, and two new dams added 265 MW at Tasik Kenyir, the largest manmade lake in South-Eastern Asia.[27]

Turkey's reported hydropower capacity expanded by 0.8 GW in 2016, bringing total installed capacity to 26.7 GW.[28] Following a sharp recovery in production in 2015, hydropower output remained virtually unchanged in 2016, at 66.9 TWh.[29]

India brought online approximately 0.6 GW of new hydropower capacity, all in units of 65 MW or smaller.[30] At year's end, the country had a total of 47.5 GW of hydropower capacity.[31] India's hydropower facilities generated 129 TWh during 2016, similar to total output in the previous year.[32]

The United States continued to rank third globally for installed hydropower capacity, adding a net of 380 MW, for a year-end total of 80 GW.[33] Output increased 6.7% relative to 2015, with 266 TWh generated.[34] The state of California saw its hydropower output more than double, from 13.8 TWh in 2015 to 28.9 TWh in 2016, thanks to high levels of precipitation after several years of persistent drought conditions.[35] Following erosion damage to spillways at California's Oroville Dam, the state announced a plan in early 2017 to bolster dam safety and flood protection. The plan will require the state to allocate additional funds for flood control and emergency response capability, to enhance its existing dam inspection programme and to seek federal action to further improve dam safety.[36]

The Russian Federation remained one of the top countries for total capacity. During 2016, the country's stated hydropower capacity increased by about 230 MW for a total of 48.1 GW.[37] Two new facilities were finalised late in the year in the northern Caucasus. The 30 MW Zaragizhskaya facility in Kabardino-Balkaria completes a three-plant cascade and was built without a dam, and the 140 MW (160 MW in pump mode) Zelenchukskaya is a mixed pumped storage plant that incorporates two reversible turbines to combine conventional hydropower generation with pumped storage capability.[38] Both plants are expected to boost local power generation and to contribute to system reliability. The Russian Federation also completed modernisation projects at several hydropower facilities in order to improve their reliability, safety and efficiency.[39] Hydropower generation (178 TWh) increased by a significant 11.3% in 2016, following a drop in 2015, due to improved hydrological conditions.[40] For example, inflows to reservoirs in the far east of Russia were 30-60% above the long-run average.[41]

The World Bank remains committed to continuing its support for well-designed and well-implemented hydropower projects of all sizes for both local development and climate mitigation, while noting that resettlement of communities, flooding of large areas of land and significant changes to river ecosystems must be carefully considered and mitigated.[42] Under the Africa Climate Business Plan, launched at the Paris climate conference in late 2015, the Bank highlighted the importance of deploying hydropower (and associated water regulation), along with other renewable power technologies, as a key component in its efforts to accelerate climate-resilient and low-carbon development in sub-Saharan Africa.[43]

The Bank aims to increase the share of hydropower in sub-Saharan Africa's energy mix from 24% in 2016; progress during the year included advancement of the Lom Pangar project in Cameroon, which is expected to ensure all-season water flows in addition to providing needed electricity.[44] Also in 2016, the World Bank suspended financing for the 4.8 MW Inga-3 Basse Chute project in the Democratic Republic of the Congo following the country's decision to deviate from a previously agreed strategic direction.[45] However, the Bank said it would continue dialogue with the government, with the goal of ensuring that the project follows international good practice.[46]

Growing shares of variable renewable energy have given extra impetus to the deployment of additional electricity storage capacity.[47] *(→ See Feature and Enabling Technologies chapters.)* Pumped storage is the dominant source of large-scale energy storage, and new projects are under development. Global pumped storage capacity rose by more than 6 GW in 2016, with new capacity installed in China, South Africa and Europe.[48]

South Africa completed the installation of three turbines (333 MW each) of the 1.3 GW Ingula pumped storage plant in 2016; the fourth and final turbine became operational in January 2017.[49] Peak flow through the plant's turbines is reported to equal the volume of eight Olympic-sized swimming pools every minute.[50]

In Europe, Switzerland's 1 GW Limmern pumped storage plant was partially completed in 2016 as two of four reversible pump turbines were synchronised with the grid. The two remaining turbines were expected to begin operation in 2017.[51] Portugal started operating the 189 MW Baixo Sabor pumped storage plant and completed construction of the 780 MW Frades II station (also known as Venda Nova III), with the latter entering service in early 2017.[52] Both are open-loop storage plants, using reversible pumps to supplement generation from natural flow with pumping capability.[53] During several days in May 2016, Portugal met all of its electricity demand with domestic renewable power, due in part to the country's ability to use pumped storage to balance demand and supply.[54]

On a smaller scale, pumped storage is being pursued to supplement mini-grids and to help integrate variable renewable energy. For example, a 200 MW pumped storage facility is being implemented in the Canary Islands as part of a larger programme to improve grid stability and to accommodate variable generation.[55] In Gaildorf, Germany, a hybrid wind power and pumped storage pilot project is under way; the upper reservoirs are being integrated into the towers and bases of the wind turbines, creating the added benefit of taller hub heights and thus greater potential wind power generation.[56]

HYDROPOWER INDUSTRY

As the vast stock of hydropower facilities around the world ages, modernisation and retrofitting of existing facilities continues to be a significant part of industry operations, with the potential to increase greatly the performance of existing plants. For example, as part of a comprehensive modernisation programme of RusHydro (Russian Federation), completion of the Kamskaya plant retrofitting in 2016 increased the plant's capacity by 14%, and modernisation was expected to improve reliability and safety as well.[57]

In addition to ongoing improvements to mechanical equipment such as turbines, plant operators also continued to implement advanced control technologies and data analytics for digitally enhanced power generation. It is expected that these steps will help to optimise plant management for greater reliability, efficiency and lower cost, while also allowing for more flexible integration with other grid resources, including variable renewable energy.[58] With improved system integration, hydropower plants can better enhance their added value within larger power systems – for instance, by shifting generation from baseload duty to cycling duty, as system conditions may dictate. *(→ See Feature and Enabling Technologies chapters.)*

Climate risk is a pressing concern for the hydropower industry. On one hand, freshwater reservoirs emit greenhouse gases, and there is a significant risk that hydropower may be excluded from some "green" investment mechanisms due to its perceived carbon footprint. On the other hand, the impacts of climate change may positively or negatively affect the hydropower sector in the future.[59] The relative resilience of hydropower projects in the face of climate variability – including increased glacial run-off and variability of rainfall – is both a planning and operational consideration going forward, and a further risk in the context of securing project financing. To address these concerns, in 2016 an international research initiative developed a tool for estimating net greenhouse gas emissions from planned and existing reservoirs to provide a more consistent estimate of hydropower's greenhouse gas footprint.[60] Also in 2016, the Climate Bond Initiative launched a working group with the aim of developing criteria to identify hydropower-related investments that deliver climate mitigation benefits and/or incorporate climate resilience and adaptation.[61]

The most significant providers of hydroelectric equipment in 2016 included GE (United States), Andritz Hydro (Austria), Voith Hydro (Germany), Harbin (China), Dongfang (China) and Power Machines (Russian Federation).[62]

As hydropower development at home has slowed, Chinese-based corporations have been expanding their involvement in hydropower projects elsewhere, including construction, the supply of hydroelectric equipment, and plant operations, with particular focus on developing countries.[63] For example, Dongfang was the equipment supplier for the 1.87 GW Gibe III plant in Ethiopia, and Harbin (with Andritz) supplied hydroelectric equipment for the 1.5 GW Coca Codo plant in Ecuador.[64]

GE's renewable energy segment reported increased revenues during the year, in part due to higher hydropower-related sales following the acquisition of Alstom hydropower operations in 2015.[65] Andritz Hydro reported unchanged, difficult market conditions with a continued decline in new orders (-13%) and sales (-5%) for 2016, and announced the launch of structural reorganisation of operations.[66] Voith Hydro also was affected by weakness in the global market during 2016. Although the company managed to increase sales by 6%, new orders were down slightly (-1%).[67]

Despite the value of pumped storage to grid stability and integration of renewable energy in general, the European regulatory environment is characterised as unfavourable for pumped storage facilities.[68] For example, seven years on since the initial project approval for the Limmern plant in Switzerland, the plant owner has questioned its short- to medium-term profitability due to low wholesale electricity prices and to the small price differential between peak and off-peak power.[69] Yet, with an eye to growing shares of variable generation and the plant's 80-year investment horizon, the long-term prognosis is considered to be favourable.[70]

OCEAN ENERGY

OCEAN ENERGY MARKETS

Ocean energy refers to any energy harnessed from the ocean by means of ocean waves, tidal range (rise and fall), tidal streams, ocean (permanent) currents, temperature gradients and salinity gradients.[1] Very few commercial ocean energy facilities have been built to date. Of the approximately 536 MW of operating capacity at the end of 2016, more than 90% was represented by two tidal barrage facilities: the 254 MW Sihwa plant in the Republic of Korea (completed in 2011) and the 240 MW La Rance tidal power station in France (built in 1966).[2]

Aside from tidal range facilities such as Sihwa and La Rance, which use established in-stream turbine technology, ocean energy technologies are still largely in pre-commercial development stages. Tidal current technologies are the furthest along, with the first tidal turbine arrays nearing commercial deployment. Wave energy converters are advancing to the pre-commercial demonstration stage, and some pilot projects have been developed utilising ocean thermal energy conversion and salinity gradient technologies.[3] Since most of the advancement in the industry is tied to pre-commercial testing and development, the global ocean energy sector continues to rely on backing from national and regional governments in the form of funding and infrastructure support.[4]

A potentially significant commercial tidal range project, the 320 MW Swansea Bay Tidal Lagoon in Wales, was awaiting final government approval at the end of 2016.[5] An independent review into the feasibility and practicality of tidal lagoon energy in the United Kingdom, completed late in the year, found a strong case for a pioneering project on a scale comparable to Swansea Bay based on economic and decarbonisation benefits, among others, but it also noted the need for monitoring for potential impacts on marine life.[6]

A great number of research and development (R&D) projects is under way in a growing number of countries, with several new deployments of ocean energy devices in 2016. Most of the projects focus on tidal stream and wave energy, but some active projects also exist in the areas of thermal and salinity gradients. To accommodate R&D, ocean energy test centres are proliferating around the world, often with the active support of local governments.[7] As of late 2016, projects were under way in Canada, Chile, China, the Republic of Korea, the United States and several countries in Europe.

OCEAN ENERGY INDUSTRY

The character of 2016 was similar to the previous year for the ocean energy industry, with a growing number of companies around the world advancing their technologies and deploying new and improved devices. However, commercial success for ocean energy technologies remained in check due to perennial challenges. These include financing obstacles in an industry characterised by relatively high risk and high upfront costs and the need for improved planning, consenting and licensing procedures.[8] As in 2015, at least one ocean energy technology developer succumbed to the economic headwinds.[9]

The tidal industry was again very active in 2016 and celebrated notable achievements, with several deployments in Scotland as well as in France and Canada. In Scotland, Nova Innovation (United Kingdom), with Belgian partner ELSA, claimed the distinction of operating the world's first grid-connected tidal array with two 100 kilowatt (kW) M100 direct-drive turbines deployed in Shetland's Bluemull Sound; a third turbine was installed in early 2017.[10] Scotrenewables Tidal Power (United Kingdom) installed its 2 MW SR2000 turbine for the first time at the European Marine Energy Centre (EMEC) in Orkney, Scotland.[11] Claimed to be the world's largest tidal turbine, the SR2000 is an integrated tidal energy generator with two horizontal-axis turbines mounted on a floating hull platform.[12]

Also in Scotland, the Meygen tidal energy project reached a significant milestone in late 2016 with the first 1.5 MW tidal turbine installed and delivering power to the grid. The Andritz Hydro Hammerfest (United Kingdom) turbine fully met its expected power specifications.[13] By early 2017, all three Andritz turbines were in place, and the first Lockheed Martin-designed (United States) 1.5 MW AR1500 turbine was deployed at the site, completing the first project phase.[14] The project, which is to reach 400 MW over several years, is owned by Tidal Power Scotland – of which Atlantis Resources (United Kingdom) is a majority stakeholder – and by Scottish Enterprise.[15]

Tidal stream technology developer Sabella SAS (France) completed one year of testing of its full-scale, grid-connected 1 MW D10 tidal turbine off the coast of Brittany, in the Fromveur Strait, where it had supplied electricity to Ushant Island.[16] Also in French waters, OpenHydro (a subsidiary of DCNS, France) installed two open-centre tidal turbines at EDF's (France) tidal array at Paimpol-Bréhat.[17] Another OpenHydro turbine hit the water across the Atlantic, where Cape Sharp Tidal (Canada) installed its first 2 MW tidal turbine at the Fundy Ocean Research Center for Energy (FORCE) development facility in the Bay of Fundy, supplying electricity to the Nova Scotia power grid.[18] The project, which plans to install a second turbine in 2017, is a joint venture between OpenHydro and Emera Inc. (Canada).[19] As of early 2017, several other tidal technology developers were planning for deployment at FORCE in the coming years.[20]

Wave energy also continued to progress in 2016 with several pilot and demonstration projects around the world, including in Spain, Sweden, the United States, the Republic of Korea and China. Spain saw its first floating wave energy converter connected to the grid at the Biscay Marine Energy Platform (BiMEP), in the form of a 30 kW prototype by Oceantec (Spain).[21] Spain is home to the Mutriku multi-turbine wave power plant, the first such facility in the world. The plant has been in operation since 2011 and generates electricity by harnessing wave-driven compressed air (oscillating water column, OWC), similar to the new Oceantec device.[22] On the southern tip of the Iberian Peninsula, Eco Wave Power (Israel) connected a 100 kW array of its energy conversion devices to the power grid of Gibraltar in 2016, with plans to expand the array to 5 MW.[23]

Swedish wave energy companies also made progress. In early 2016, Waves4Power deployed its WaveEL wave energy buoy in Norwegian waters, and Seabased connected its 1 MW Sotenäs Wave Power array to the grid.[24] The Sotenäs plant couples linear generators on the sea floor to surface buoys (a technology known as point absorbers) and is said to be the world's first array of multiple wave energy converters in operation.[25]

In the Pacific, the Bolt Lifesaver device by Fred Olsen (Norway) was deployed for one year of testing at the US Navy's Wave Energy Test Center (WETS) in Hawaii. The test was completed in March 2017 with the unit having produced power continuously over a span of six months.[26] Northwest Energy Innovations (United States) continued grid-connected testing of its half-scale 20 kW Azura wave energy device at WETS.[27] In addition, Columbia Power Technologies (United States) began land-based testing of its StingRAY wave energy converter at the National Wind Technology Center, due to its core similarities to direct-drive wind turbines, with open-water tests at WETS scheduled for 2017.[28]

Wave energy technologies are among the variety of ocean energy technologies being developed in the Republic of Korea. Among notable projects launched in 2016 was a study focused on integrating wave energy converters, such as OWC devices, with mini-grid connected energy storage on islands and other remote locations that have suitable breakwaters.[29] The construction of a 500 kW OWC pilot plant near Jeju Island was completed during the year.[30]

In 2016, electricity started flowing from the first two turbines of a seven-turbine, 3.4 MW wave energy demonstration project in Zhejiang Province, China.[31] China also installed a 10 kW ocean thermal energy conversion (OTEC) device; OTEC uses the temperature difference between cooler deep and warmer surface waters to produce energy.[32] At the start of 2017, the country released its 13th Five-Year Plan on Ocean Energy, which targets 50 MW of installed capacity by 2020.[33] The plan also envisions expanded testing and demonstration facilities and a research focus on tidal, wave and thermal energy conversion.[34]

Plans and roadmaps to support the industry advanced in other parts of the world as well, often through collaborations between government and industry. The core agenda of the European Commission's Ocean Energy Forum was completed in 2016 with the publication of the Ocean Energy Strategic Roadmap. Intended to establish a path towards a thriving European market for ocean energy, the Roadmap outlined four Action Plans designed to establish: a common technology development process to minimise project risk and waste; a European investment support fund for ocean energy farms; a European insurance and guarantee fund to underwrite project risk; and an integrated planning and consenting programme.[35]

Some examples of smaller-scale, cross-border co-ordination already exist in Europe. The FORESEA[i] project, launched in 2016, provides competitive funding opportunities to ocean energy technology companies to place their devices at test centres in the United Kingdom, Ireland, the Netherlands and France. With a total budget of USD 11.3 million (EUR 10.8 million), more than half of which is funded by the EU, a first round of awards was made in late 2016 and another in early 2017.[36]

Another example of active support from government came from Wave Energy Scotland (WES), formed in 2014 as a subsidiary of the Highlands and Islands Enterprise of the Scottish Government. By late 2016, WES had awarded nearly USD 14.5 million (GBP 11.8 million) to wave energy developers.[37] Another USD 3.7 million (GBP 3 million) was awarded to 10 wave energy projects in early 2017 to explore new materials and manufacturing processes.[38] The European Investment Bank committed up to USD 10.1 million (EUR 10 million) in loans for

i Funding Ocean Renewable Energy through Strategic European Action.

the Finnish wave energy technology developer AW-Energy. The funding was expected to keep the company on track towards commercialisation of its WaveRoller technology, with a 350 kW full-scale device pending installation in Portugal.[39]

Project de-risking by governments can come in the form of direct research funding and also through the establishment and operation of ocean energy test centres. In 2016, the US Department of Energy (DOE) awarded USD 40 million to the Northwest National Marine Renewable Energy Center in the state of Oregon to construct a full-scale, grid-connected facility to test wave energy technologies in open water. For the occasion, the DOE noted that the country's technically recoverable wave energy resources are in the vicinity of 1,000 TWh annually, which is about one-quarter of US net generation in 2016.[40]

Mexico also completed preparations for the Mexican Centre for Innovation in Ocean Energy (CEMIE-Ocean), which aims to foster collaboration between academia and industry for the advancement of ocean energy science and technologies. The Centre's activities were scheduled to commence in early 2017.[41] Far to the south, Chile's Marine Energy Research and Innovation Center (MERIC) started its work to establish a foundation for ocean energy development in the country. The centre was launched in 2015 with USD 20 million in funding for the first eight years of operation. Early research has focused on resource assessment, permitting and legal frameworks related to marine concessions, biofouling and marine corrosion.[42]

In a similar vein, two important reports examining ocean energy-related challenges were published in 2016. One report focused on the status of scientific knowledge on potential interactions between ocean energy devices and marine animals, such as the risk of animals colliding with moving components; various potential impacts of sound propagation from ocean energy devices; and any biological effect of electromagnetic fields generated from underwater cables.[43] Many of the concerns associated with such interactions are driven by uncertainty, due to lack of data, which continues to confound differentiation between real and perceived risks.[44]

The other report addressed the challenges of consenting processes for ocean energy development, where lack of clarity in the process may create potential barriers to the industry. The report's recommendations include the need to acknowledge and define the role of marine spatial planning; to clarify jurisdictions of different authorities; and to co-ordinate and streamline licensing and consenting processes.[45]

As in 2015, a UK ocean energy company was forced into administration mere months after deploying its device. In late 2015, Tidal Energy Ltd. had launched its 400 kW DeltaStream tidal demonstration device off the coast of Wales, but by October 2016 difficult economic tides forced the company to seek new ownership.[46]

SOLAR PHOTOVOLTAICS (PV)

SOLAR PV MARKETS

During 2016, at least 75 GWdc[i] of solar PV capacity was added worldwide – equivalent to the installation of more than 31,000 solar panels every hour.[1] More solar PV capacity was installed in 2016 (up 48% over 2015) than the cumulative world capacity five years earlier.[2] By year's end, global solar PV capacity totalled at least 303 GW.[3] *(→ See Figure 15.)*

For the fourth consecutive year, Asia eclipsed all other markets, accounting for about two-thirds of global additions.[4] The top five markets – China, United States, Japan, India and the United Kingdom – accounted for about 85% of additions; others in the top 10 for additions were Germany, the Republic of Korea, Australia, the Philippines and Chile.[5] For cumulative capacity, the top countries were China, Japan (which passed Germany) and the United States, with Italy a distant fifth.[6] *(→ See Figure 16.)* While China continued to dominate both the use and manufacturing of solar PV, emerging markets on all continents have begun to contribute significantly to global growth.[7] By end-2016, every continent had installed at least 1 GW, at least 24 countries had 1 GW or more of capacity, and at least 114 countries had more than 10 MW.[8] The leaders for solar PV capacity per inhabitant were Germany, Japan, Italy, Belgium and Australia.[9]

Market expansion was due largely to the increasing competitiveness of solar PV, as well as to rising demand for electricity and improving awareness of solar PV's potential as countries seek to alleviate pollution and reduce CO_2 emissions.[10] In many emerging markets solar PV now is considered a cost-competitive source for increasing electricity production and for providing energy access.[11] Nevertheless, markets in most locations continue to be driven largely by government incentives or regulations.[12]

In 2016, China added 34.5 GW (up 126% over 2015), increasing its total solar PV capacity 45% to 77.4 GW, far more than that of any other country.[13] *(→ See Figure 17 and* ***Reference Table R6****.)* The

i An effort is made to report all capacity data in direct current (DC). Where capacity is known to be in alternating current (AC), it is made explicit in the text and endnotes. *(→ See endnotes and Methodological Notes for further details.)*

record increase came despite a downwards adjustment in China's target for 2020, made in response to a slowdown in the growth of electricity demand.[14] A rush of installations (an estimated 20 GW) came online in advance of a mid-year cut-off date for approved projects to receive the 2015 FIT rate.[15] Following a brief dip, the market picked up again and continued strongly into 2017, in anticipation of the next cut-off deadline (June).[16]

Xinjiang province (3.3 GW) was the top market in China – followed by Shandong (3.2 GW) and Henan (2.4 GW) provinces – even though Xinjiang was a "no-go" development area due to high curtailment rates.[17] Although much of the new capacity was installed far from population centres, 15 provinces added more than 1 GW each, and 9 of those are in China's eastern regions.[18] Large-scale solar PV plants continued to represent most added capacity and more than 86% of the cumulative total at end-2016, despite the central government's effort to encourage smaller-scale distributed installations. Even so, the distributed market more than tripled relative to 2015.[19]

The rapid increase in solar PV capacity in China, up 11-fold since the end of 2012, has caused grid congestion problems and interconnection delays.[20] Curtailment started to become a serious challenge in 2015, and problems increased during 2016 due to inadequate transmission.[21] To address challenges related to curtailment, in 2016 China set minimum guaranteed utilisation hours (purchase requirements) for solar (and wind) power plants in affected areas and continued to build several ultra-high-voltage transmission lines to connect north-western provinces with coastal areas.[22] Against these challenges, solar PV generated 66.2 TWh of electricity during the year (up 69% over 2015), equivalent to 1% of China's annual generation.[23]

The United States was a distant second after China for new installations in 2016. For the first time, solar PV represented the country's leading source of new generating capacity.[24] More than 14.8 GW of capacity – almost double the installations in 2015 – was brought online, for a total of 40.9 GW.[25] Overall, 22 states installed more than 100 MW each, up from 13 states in 2015.[26] California again led for capacity added (5.1 GW), followed by Utah (1.2 GW) and Georgia (1 GW), which became the third largest state market even without additional mandates, subsidies or tax incentives beyond federal tax credits.[27]

Although all US sectors expanded, growth occurred primarily in the utility segment.[28] A record 10.6 GW of large-scale capacity came into operation, with a further 17.8 GW in the pipeline at year's end.[29] Renewable Portfolio Standards (RPS) accounted for the largest portion of projects in development in the United States, but new procurement was driven by other factors, such as cost-competitiveness with new natural gas plants in an increasing number of locations across the country.[30] Large corporate customers accounted for a record 10% of large-scale additions.[31]

The US non-residential (commercial and industrial) market increased 49%, to 1.6 GW, due primarily to looming regulatory deadlines in two key states and to an increase in community solar projects.[32] The residential sector experienced slower expansion (up 19%), after record growth in recent years, in part because some major markets are approaching saturation among early adopters.[33] The majority (70%) of new residential installations occurred in just five states; even so, additional states began to emerge as important markets.[34] The success of distributed solar PV and falling costs have led some US utilities to establish their own solar programmes and others to fight for revisions or elimination of supportive policies.[35] Net metering, which has driven most US customer-sited solar PV capacity, continued to be at the centre of regulatory disputes in several states during 2016.[36]

Japan's market was the world's third largest in 2016 – despite contracting 20% after the 2015 boom – and was enough to propel the country past Germany to rank second for cumulative solar PV capacity. An estimated 8.6 GW was installed, bringing the country's total to 42.8 GW.[37] Japan's slowdown was the result of several factors, including declining FIT payments as prices fall, ongoing land shortages and difficulties securing grid connections.[38]

Large-scale projects have driven most of Japan's solar PV expansion in recent years.[39] However, the country saw growing demand in the residential sector, which accounted for 11.8% of new installations.[40] There also was increased interest in residential solar-plus-storage options: as of early 2016, roughly 50,000 residential systems in Japan included storage.[41]

Since the introduction of a FIT in 2012, Japan has seen a rapid increase in renewable power capacity, with solar PV representing most of the total. The large volume of solar PV projects and their output has begun challenging Japan's fragmented electric power grid, leading the government to revise regulations and leading some utilities to refuse new interconnections and to curtail output from existing plants without compensation.[42] The first curtailment of solar PV occurred under the new regulations in early 2016.[43] Even so, solar PV's share of Japan's power mix increased to 4.4% in 2016 (from about 0.4% in 2012).[44]

The third largest market in Asia was India, which ranked fourth globally for additions and seventh for total capacity.[45] India added about 4.1 GW (up from 2 GW in 2015) for a total approaching 9.1 GW.[46] Tamil Nadu (with nearly 1.6 GW) overtook Rajasthan (1.3 GW), followed by Gujarat (1.1 GW) and Andhra Pradesh (1 GW) for cumulative capacity.[47] Much of Tamil Nadu's annual market was due to the commissioning of one 648 MW facility.[48] Demand for large-scale solar projects in India has been driven by rapidly falling prices combined with strong policy support in several states and at the national level since 2014.[49]

India's rooftop solar market has expanded significantly in recent years but accounted for only about 10% of the country's total solar PV capacity at the end of 2016.[50] Financial, regulatory and logistical challenges have hindered growth, and India remains a long way from its rooftop target of 40 GW by 2022.[51] But the most immediate challenges for India's solar sector are congestion in the grid and curtailment.[52] To help address these challenges, by year's end India was constructing eight "green energy corridors": transmission lines to carry power from solar-rich states to high-demand regions.[53]

The Republic of Korea followed India in the region, adding 0.9 GW to rank seventh for additions and to end 2016 with 4.4 GW.[54] The Philippines and Thailand both passed national targets, adding nearly 0.8 GW (total of 0.9 GW) and more than 0.7 GW (total of 2.15 GW) respectively, although a pause in Thai government procurement drove many developers to seek out new markets.[55] Pakistan and Vietnam both had several large plants under development by year's end, but policy uncertainties were delaying progress.[56]

The EU became the first region to pass the 100 GW milestone in 2016 (quickly surpassed by Asia); the region ended the year with an estimated 106 GW, more than 32 times its 2006 capacity.[57] Even so, as global additions increased 48% relative to 2015, EU demand fell by 24%.[58] The United Kingdom accounted for most of the market decline, with several other EU countries seeing capacity increases relative to 2015.[59]

Approximately 5.7 GW was added in 2016, mostly in the United Kingdom, Germany and France – which together installed about 70% of the region's new grid-connected capacity.[60] Others adding capacity included Belgium, Italy and the Netherlands.[61]

Europe has become a challenging market for several reasons. The region is transitioning from FIT incentives to tenders and feed-in premiums for large-scale systems, and to the use of solar PV for self-consumption in residential, commercial and industrial sectors.[62] Further, electricity demand is stagnating and conventional utilities are lobbying simply to maintain their position.[63] In Germany and elsewhere, the reaction from utilities is mixed – ranging from opposition to distributed solar PV deployment to participation.[64] Electricity market design and new business models are receiving increased attention.[65] *(→ See Feature chapter.)*

Despite the market contraction in 2016, the United Kingdom remained the region's top market, adding about 2 GW for a total of 11.7 GW.[66] The country's biggest month for additions was March, just before the Renewables Obligation closed to projects of 50 kW and larger.[67] Solar PV generated more electricity than coal from April through September, reflecting historic lows for coal-fired generation and the changing face of the UK electricity supply; solar PV represented about 3% of UK generation for the year.[68] Despite ranking third in Europe, France saw its lowest annual growth since 2009, adding 0.6 GW for a total of 7.1 GW.[69]

Germany's annual market remained at about 1.5 GW, well below the Renewable Energy Law (EEG) annual target of 2.5 GW, bringing total capacity to about 41.3 GW.[70] In October, Germany and Denmark opened the world's first cross-border auctions for solar PV, in which companies could bid for installations in either country.[71] All successful bids were awarded to projects to be sited in Denmark, due to differing conditions between the two countries (e.g., site restrictions in Germany but not Denmark).[72] Germany's solar-plus-storage market is growing rapidly as consumers shift from FITs to self-consumption.[73] The share of newly installed residential systems paired with storage rose from 14% in 2014 to 41% in 2015 and more than 50% in 2016, when Germany represented about 80% of Europe's home energy storage market.[74]

Utilities in Australia also are facing major impacts from solar PV. The country added nearly 0.9 GW in 2016, for a total approaching 5.8 GW.[75] Australia's market has been predominantly residential, although the commercial and large-scale sectors started to take hold in 2015 and 2016.[76] By late 2016, almost 1.6 million solar PV installations were operating in the country.[77] About 30% of dwellings in both Queensland and South Australia had solar PV installations, with high shares also in several other states and territories.[78]

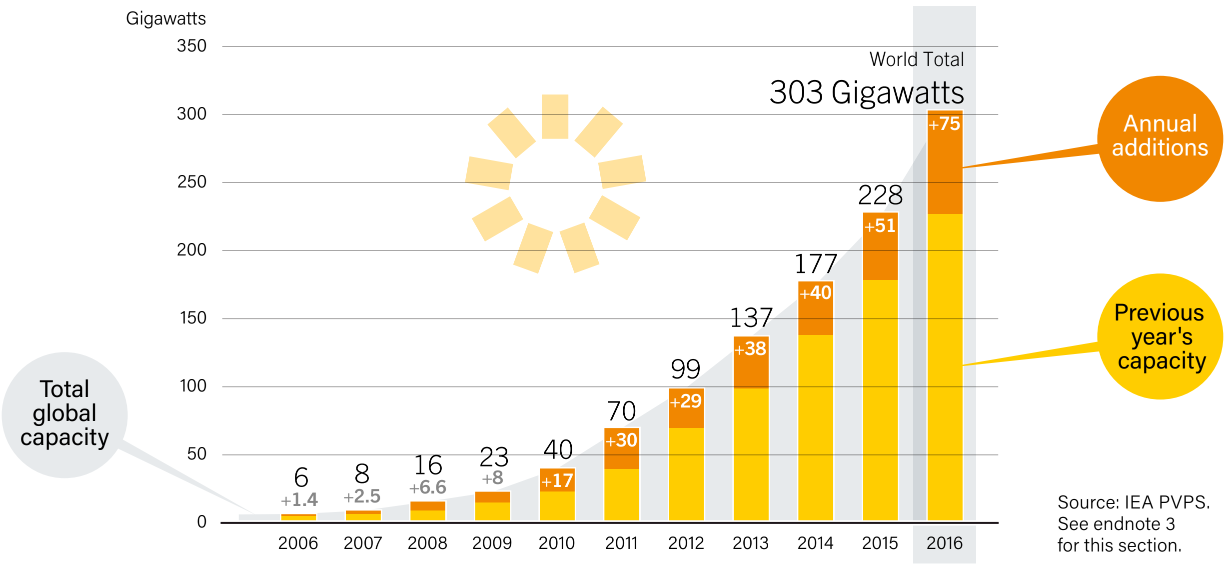
Australia's low wholesale electricity prices and high retail prices are encouraging consumers to shift to solar PV while providing them with little incentive to sell their generation into the grid.[79] Additionally, utilities have continued to lobby for further charges on self-consumption by solar PV system owners.[80] These factors have driven a small but rapidly growing market for residential storage.[81] The market for rooftop solar-plus-storage systems took off in 2016: an estimated 5% of new solar rooftop installations included storage, amounting to 6,750 battery installations (52 megawatt-hours (MWh)), up from 500 in 2015.[82]

In addition to Australia, Germany and Japan, interest in solar-plus-storage is picking up in other developed countries (e.g., France, Italy and the United Kingdom) for on- and off-grid applications, where incentives exist or economics align.[83] Markets also continue to expand in many developing countries (e.g., Bangladesh, India, Malawi, Peru), particularly in the off-grid sector.[84] *(→ See Distributed Renewable Energy chapter.)*

Solar PV is playing an important role in providing energy access in Latin America and the Caribbean, although the vast majority of capacity installed to date has been in large-scale projects.[85] Chile was the region's top installer and ranked tenth globally for

SOLAR PV

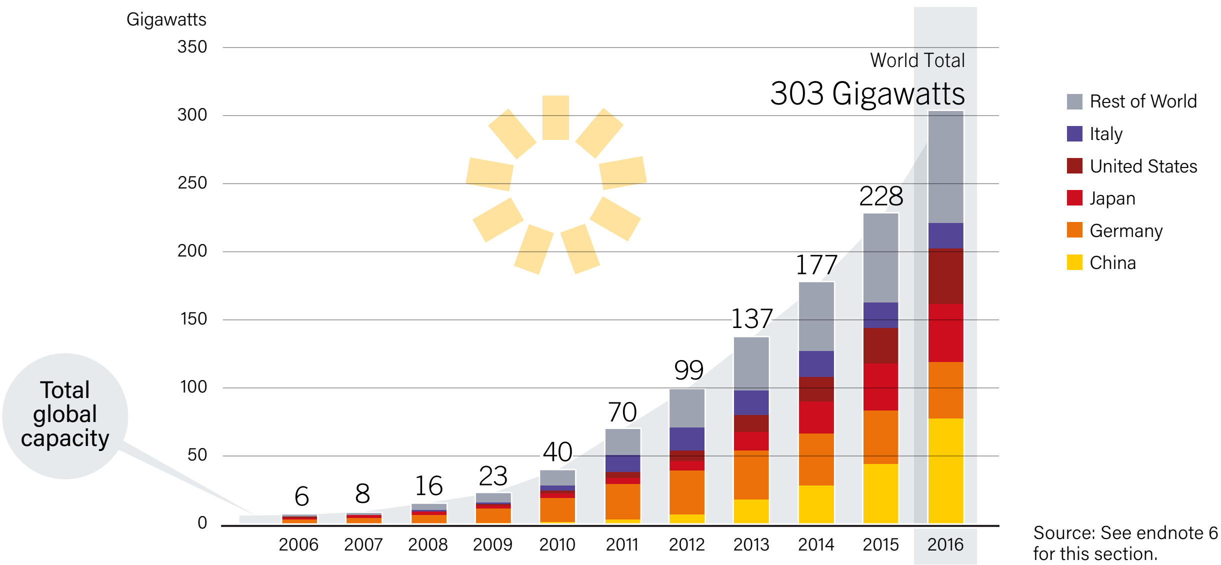
Figure 15. Solar PV Global Capacity and Annual Additions, 2006-2016



Source: IEA PVPS. See endnote 3 for this section.

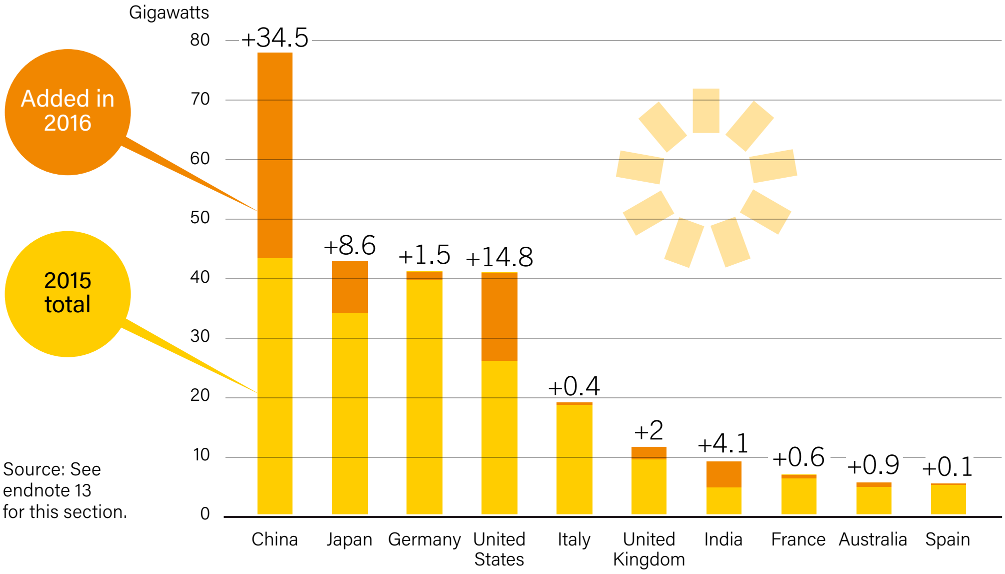
During 2016, at least **75 GW** of solar PV capacity was added worldwide – equivalent to the installation of more than **31,000 SOLAR PANELS EVERY HOUR.**

Figure 16. Solar PV Global Capacity, by Country and Region, 2006-2016



Source: See endnote 6 for this section.

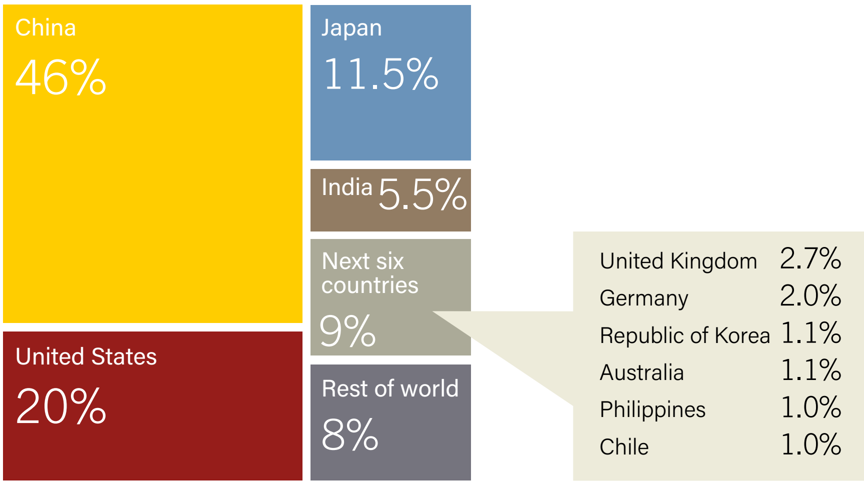
Figure 17. Solar PV Capacity and Additions, Top 10 Countries, 2016



Source: See endnote 13 for this section.

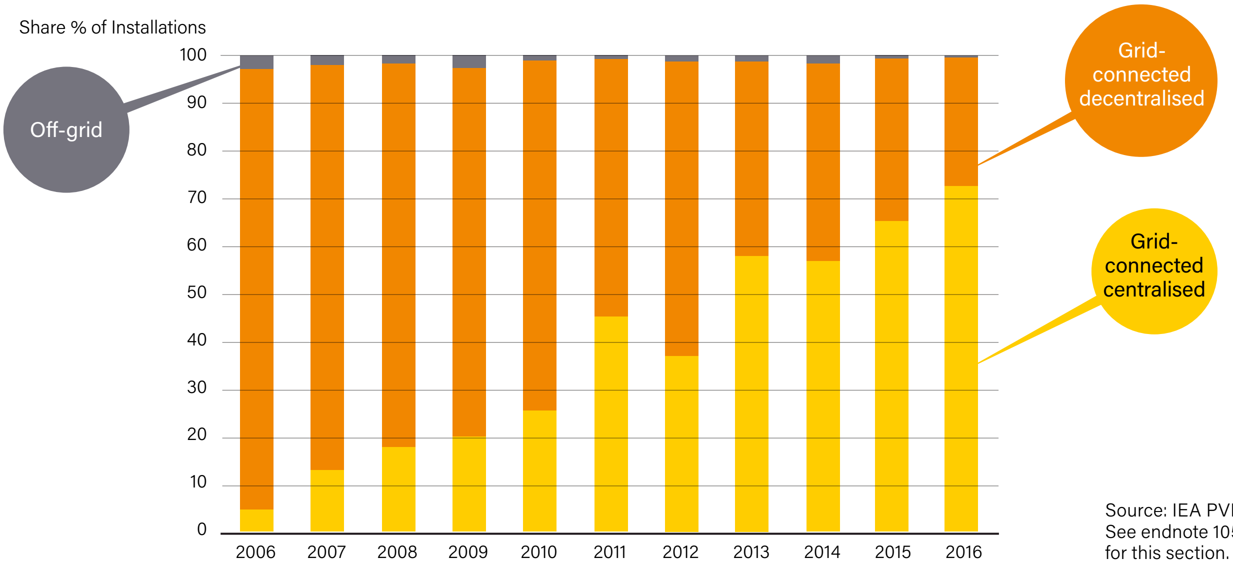
CHINA ACCOUNTED FOR **46%** OF NEW CAPACITY.

Figure 18. Solar PV Global Capacity Additions, Shares of Top 10 Countries and Rest of World, 2016



Source: See endnote 86 for this section.

Figure 19. Solar PV Global Additions, Shares of Grid-Connected and Off-Grid Installations, 2006-2016



Source: IEA PVPS. See endnote 105 for this section.

newly added capacity, thanks to a booming mining industry that has pushed rapid development in the north.[86] *(→ See Figure 18.)* The country added over 0.7 GW in 2016 for a year-end total of 1.6 GW.[87] Mexico followed, adding about 150 MW for a total of 0.3 GW.[88] The market was driven largely by the country's first tenders, although distributed systems accounted for at least one-third of additions in response to rising electric rates for large consumers combined with falling solar PV prices.[89] Argentina also held its first tender during the year.[90] In Brazil, the only renewable energy auction scheduled for 2016 was cancelled, and most projects awarded contracts in tenders through 2015 were stalled by a variety of factors, including high costs associated with local content rules and difficulty obtaining affordable financing.[91] Throughout the region, grid access, financing and administrative barriers remained challenges to growth.[92]

Although relatively little capacity was operating in the Middle East by the end of 2016, interest in solar PV has started to pick up. Countries without domestic fossil fuels have begun investing in solar power to diversify energy sources and economies, and oil producers are taking advantage of good solar resources, low land and labour costs, and favourable loan rates to preserve their fossil resources for export.[93] Israel remained the region's leading market, adding 0.1 GW for a total over 0.9 GW.[94] Jordan and Kuwait both brought large plants online during the year, and, in early 2017, Dubai inaugurated a 200 MW plant.[95] Jordan, Saudi Arabia and Abu Dhabi and Dubai (UAE) all held tenders, and Iran signed several agreements to deploy solar PV and build manufacturing facilities.[96]

Across Africa, countries are turning to solar PV to diversify their energy mix, meet rising electricity demand and provide energy access.[97] *(→ See Distributed Renewable Energy chapter for more on solar PV for energy access.)* Rapidly falling costs, new business models and a global certification scheme have combined to enable the emergence of projects of all sizes.[98] Leaders for new capacity in 2016 were South Africa (0.5 GW) and Algeria.[99] Due to a number of challenges – including lack of financing and clear policies, weak legal frameworks, poor transmission infrastructure and unclear land rights – numerous projects that began years ago still awaited construction at year's end.[100] However, several countries, including Ghana, Senegal and Uganda, brought plants online in 2016.[101] Tenders for projects (on- and off-grid) were launched or PPAs were signed in several countries across Africa, including Algeria, Egypt, Kenya, Morocco, Nigeria and Zambia, which set a new regional benchmark for low-cost solar PV power.[102]

While demand is expanding rapidly for off-grid solar PV, the capacity of grid-connected systems is rising more quickly and continues to account for the vast majority of solar PV installations worldwide.[103] Decentralised (residential, commercial and industrial rooftop systems) grid-connected applications have struggled to maintain a roughly stable global market (in terms of capacity added annually) since 2011, particularly with the transition from FITs and net metering to self-consumption.[104] Centralised large-scale projects, by contrast, have comprised a rising share of annual installations – particularly in emerging markets – despite grid connection challenges, and now represent the majority of annual installations.[105] *(→ See Figure 19.)* The drivers include increased use of tenders and availability of low-cost capital.[106] By one estimate, the average solar (mostly PV) project size in early 2016 ranged from 3 MW in Europe and 11 MW in North America, to 45 MW in Africa and 64 MW in South America.[107]

Around the world, the number and size of large-scale plants continued to grow in 2016. By year's end, at least 164 (up from 124 a year earlier) solar PV plants of 50 MW and larger

were operating in at least 26 countries, with Israel, Jordan, the Philippines and the United Kingdom joining the list during the year.[108] The cumulative capacity of plants of 50 MW and larger that came online in 2016 was more than 5.9 GW.[109] China's Yanchi project in Ningxia reportedly became the world's largest plant, at 1 GW.[110] Considering plants of 4 MW or larger, about 35 GW of projects was installed in 2016, bringing the world total to an estimated 96 GW.[111]

Several retailers and international corporations based in China, Europe, India, North America and elsewhere invested heavily in solar PV during the year.[112] Locally owned community solar also continued to expand, although the pace of growth slowed in some countries due to policy changes.[113] New projects came online in Australia, Europe and the United States.[114] Japan had an estimated 45 MW of community-owned[i] solar PV capacity by the end of 2016.[115] Increasingly in Australia and the United States, utilities and other energy companies are developing "community" projects to retain existing customers and attract new ones.[116]

Solar PV plays a substantial role in electricity generation in several countries. In 2016, solar PV accounted for 9.8% of net generation in Honduras and met 7.3% of electricity demand in Italy, 7.2% in Greece and 6.4% in Germany.[117] At least 17 countries (including Australia, Chile, Honduras, Israel, Japan and several in Europe) had enough solar PV capacity at end-2016 to meet 2% or more of their electricity demand.[118] At the end of 2016 there was enough solar PV capacity in operation to produce close to 375 TWh of electricity per year.[119]

SOLAR PV INDUSTRY

Despite tremendous demand growth in 2016, the year brought unprecedented price reductions for modules, inverters and structural balance of systems.[120] Due to even greater increases in production capacity, as well as to lower market expectations (particularly in China) for 2017, module prices plummeted.[121] Average module prices fell by an estimated 29%, to USD 0.41 per watt (W) between the fourth quarter of 2015 and a year later, dropping to historic lows.[122]

Downwards pressure on prices has challenged manufacturers, whose costs have not declined as quickly and who are seeing small, if any, margins.[123] By contrast, 2016 was a good year for developers.[124] Lower capital expenditures and improvements in equipment efficiency and capacity factors are helping to drive down costs; the cost of solar generation fell faster during the year than experts had expected, and continued downwards in early 2017.[125] Subsequently, solar PV is increasingly cost-competitive with traditional power sources, with large-scale solar PV outcompeting even new fossil fuel projects in some markets, especially in regions with low-cost financing.[126] However, challenges remain, with solar PV still vulnerable to policy changes or measures to protect fossil fuels in some countries.[127]

Countries around the world increasingly have been using tenders to raise their solar generating capacity *(→ see Policy Landscape chapter)*, and new record low bids were set again in 2016, with bidding in some markets below USD 0.03 per kWh.[128] Argentina, Chile, India, Jordan, Saudi Arabia, South Africa and the UAE all saw very low bids for solar PV in 2016 and early 2017.[129] The year also brought national record low bids for winning tenders in China (Inner Mongolia), Denmark and Germany, and a new low for Africa in Zambia.[130] In the United States, falling PPA prices[ii] have made solar PV more attractive than new natural gas capacity in many locations.[131]

Low bids were due at least in part to expectations that technology costs would continue to fall, as well as to relatively low weighted average cost of capital and expected low operating costs in some locations.[132] The cost of financing plays a major role in determining project costs, and depends heavily on operational and regulatory risk.[133] Yet low bids have spurred questions about whether the cheapest projects will be profitable, or even built.[134] There also is concern that low prices threaten product quality.[135]

A wide range in prices exists among different locations due to variations in soft (non-technology) costs and cost of capital, as well as in solar resource, market and regulatory conditions. Project scale also has a significant impact on price.[136] Distributed rooftop solar PV remains more expensive than large-scale solar PV but has followed similar price trajectories, and is competitive with (or cheaper than) retail prices in many locations.[137]

China dominated global shipments in 2016, for the eighth year running.[138] Asia accounted for 90% (and China 65%) of global module production; Europe's share continued to fall, to about 5% in 2016; and the US share remained at 2%.[139] The top 10 module

i Defined as having at least two of three criteria: most if not all of the project is locally owned; a community-based organisation controls voting; and the majority of the project's social and economic benefits are distributed locally.

ii US PPA prices reflect federal tax credits and other subsidies.

manufacturers[i] accounted for about 50% of shipments during the year, and the vast majority of manufacturing is China-based, with overseas plants in South-Eastern Asia.[140] They included JinkoSolar in the top spot, followed by Trina Solar and JA Solar (all China), as well as Canadian Solar (Canada) and Hanwha Q Cells (Republic of Korea); GCL (China), First Solar (United States), Yingli Green, Talesun and Risen (all China) rounded out the top 10.[141]

Locked in a race to build bigger, more advanced factories to produce panels faster and more cheaply than their competitors, companies announced expansions throughout the year.[142] The largest Chinese manufacturers continued expanding module assembly capacity in South-Eastern Asia, in response to ongoing trade disputes and to avoid US and EU import duties.[143] Chinese giants GCL-Poly and Longi Silicon Materials both announced plans for new production lines.[144] Expansions elsewhere included: the first module manufacturing plant in Ghana opened to serve the West African market; Canadian Solar commenced module production at a new facility in Brazil; Japanese thin film module producer Solar Frontier began commercial production at a new plant; a new facility opened in Kosovo; and, in early 2017, Solarion (Germany) announced plans to expand its Leipzig facility to supply projects in Turkey.[145]

However, some manufacturers and other solar companies scaled back expansion plans, closed facilities, changed strategies or restructured to adjust to changing landscapes.[146] Although some new production capacity opened in Europe, the region's overall module manufacturing output declined by 16%, to 2.7 GW.[147] Companies including Panasonic (Japan), Enel (Italy) and Mainstream Renewable Power (Ireland) sought new markets abroad as incentives and markets dried up at home.[148] Dow Chemical (United States) halted production of its solar shingle line, and some big US manufacturers announced plans to refocus at home (e.g., from large plants to rooftops) and to expand into emerging markets abroad.[149]

On balance, global production of crystalline silicon cells and modules rose significantly in 2016. Estimates of cell and module production, as well as of production capacity, vary widely; increasing outsourcing and rebranding render the counting of production and shipments more complex every year.[150] Preliminary estimates of 2016 production capacity exceeded 80 GW for cells (up 29% year-over-year) and 83 GW for modules (up 33% year-over-year).[151] Thin film production increased by an estimated 11%, accounting for 6% of total global PV production (down from 8% in 2015).[152]

Consolidation continued as downwards pressure on prices and slim margins made 2016 a challenging year for even the most competitive producers, and led manufacturers in and outside of China to lay off workers and some companies to fail.[153] In Japan, the number of bankruptcies in solar-related companies reportedly reached a record high (65), due to fierce competition in a shrinking market.[154] The highest-profile insolvency case was that of US-based project developer SunEdison which, after rapid growth and substantial debt accumulation, filed for bankruptcy protection in April and liquidated assets throughout 2016.[155]

Mergers and acquisitions, as well as new partnerships, continued as companies aimed to capture value in project development or to move into new markets (locations or applications).[156] For example, solar PV inverter specialist Ingeteam (Spain) purchased Bonfiglioli's (Italy) solar PV business to strengthen its position internationally for sales and for operation and maintenance (O&M).[157] Longi, Trina Solar and Tongwei (all China) partnered to build a 5 GW monocrystalline silicon ingot pulling production plant in China, and China National Building Materials Group partnered with UK solar developers WElink Energy and British Solar Renewables to develop solar energy projects and zero-carbon homes in the United Kingdom.[158] Numerous projects around the world changed hands; rapidly declining prices have created high demand for projects won under tenders and not yet built.[159]

Falling prices and expanding markets for solar PV have lured new players to the industry.[160] In 2016, Apple supplier Foxconn (Taipei) purchased financially troubled Sharp (Japan), which started making solar PV cells in the 1960s; and US electric vehicle manufacturer Tesla partnered with Panasonic (Japan) and acquired US installer SolarCity with plans to make an integrated solar PV-storage-EV product.[161] Four of the world's top wind turbine companies – GE, Gamesa, Goldwind and Mingyang – had entered the solar industry by year's end.[162] Electric utilities became more active in the sector, serving the distributed market and constructing and operating large-scale solar PV plants.[163] For example, Tata Power Company acquired a 1.1 GW solar and wind power portfolio from Welspun Renewable Energy in India's largest clean energy deal; RWE subsidiary Innogy acquired developer Belectric Solar & Battery (both Germany) to further its transition to renewable energy; and EDF (France) acquired installer Global Research Options to expand its US presence.[164]

Fossil fuel producers also moved further into solar energy in 2016. For example, Bangchak Petroleum (Thailand) bought SunEdison's solar PV plants in Japan; Coal India Limited, Thai state-owned oil and gas company PTT and Wärtsilä (Finland) all entered into solar

i The solar PV value chain also includes manufacturers upstream (e.g., polysilicon, wafers, solar glass, chemicals, backsheets, and balance of systems components) as well as downstream actors, including engineering, procurement and construction (EPC) companies, project developers, and O&M providers.

PV project development, as did oil and gas operator Eni (Italy) and Africa's largest oil and gas company Sonatrach (Algeria), which agreed to develop projects jointly in Algeria.[165] Statoil (Norway) invested in the UK technology company Oxford PV.[166]

Banks, pension funds and mutual funds also are investing in large-scale solar PV (and wind power) projects and partnering with solar companies, providing new pools of funding.[167] For example, APG Asset Management, the Netherlands' largest pension fund, committed to investing in solar companies in India, and the largest US public pension fund invested in solar farms in California.[168] Crowdfunding also continued to be an important means for financing projects as well as technology innovations, with new platforms launched in 2016.[169]

Innovations and advances continued during the year in manufacturing, product efficiency and performance, installation and O&M.[170] They were driven largely by rapid price reductions, which have forced companies to move forward their roadmaps to decrease costs and differentiate themselves, as well as by growing customer demands for increased functionality and a rising number of grid requirements in some countries.[171] SolarWorld (Germany) and REC Solar (Norway) were among the big players that upgraded production lines to Passivated Emitter Rear Cell (PERC) technology[i], a trend that continued into 2017.[172] Module manufacturers continued increasing the number of busbars[ii] to reduce internal electrical resistance, as well as reducing barren spaces on modules to enhance light trapping.[173] Perovskites[iii] achieved further improvements in efficiency and stabilisation through ongoing R&D, and Oxford PV purchased a former Bosch Solar facility to ramp up production of its perovskite technology.[174]

Efficiency gains from such advances have reduced the number of modules required for a given capacity, lowering soft costs.[175] Labour and other soft costs of large-scale projects also are falling thanks to customised design testing, pre-assembly of systems and advances in racking.[176] The year also saw an increased interest in hybrid projects that locally integrate solar PV with other renewables and energy storage technologies, an innovation that can strengthen a plant's generation profile and enable sharing of resources for construction and maintenance.[177]

As component and installation costs fall and as markets mature, attention is focused increasingly on O&M.[178] Significant challenges remain in many developed markets where O&M is exposed to rising price pressures and where there are significant inconsistencies in scope and quality of service, as well as in emerging markets that lack O&M skills and local capacity for manufacturing solar components.[179] However, O&M costs have fallen rapidly in some countries due to clustering of projects and economies of scale, improved performance and reliability of inverters, evolution in plant and tracker designs, and robotic cleaning systems.[180]

Inverters also are becoming more sophisticated and making a growing contribution to grid management, and manufacturers are working to improve long-term reliability and system-prediction methods.[181] During 2016, key areas of focus included advancing both materials and self-regulating technologies in order to build higher-voltage central inverters and thereby reduce balance of systems costs and the levelised cost of electricity (LCOE), as well as improving performance and software to reduce O&M costs.[182] As with solar PV production, inverter manufacturing is shifting to Asia (and Asia-based companies), and, in 2016, large US and European manufacturers were fighting to maintain market share.[183] As the market matures, the industry is becoming more concentrated, and the top 10 vendors accounted for 80% of global shipments in the first half of 2016.[184] The top companies globally for shipments during the full year were Huawei (China), Sungrow (China) and SMA (Germany).[185]

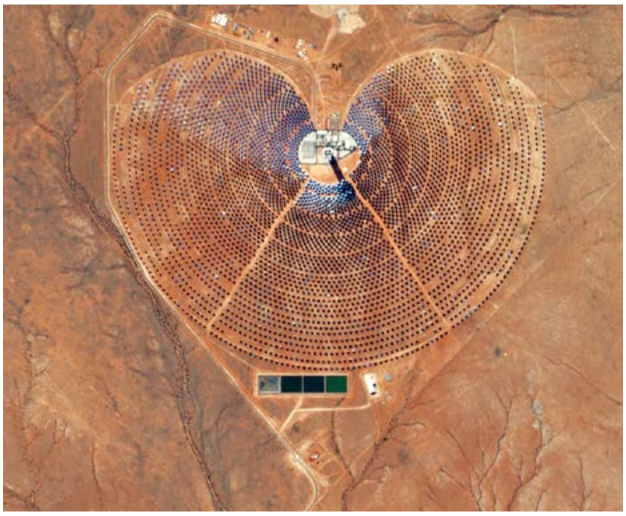
The concentrating PV (CPV) industry had another challenging year. Despite record efficiencies and declining system prices, CPV has been unable to compete with conventional solar PV.[186] A handful of companies remains; most are based in North America, and many are relatively new to the industry.[187] In 2016, heavily indebted Semprius (United States) was working with partners to improve conversion efficiency in previously uneconomical locations.[188] Saint-Augustin Canada Electric acquired Soitec's (France) CPV technology to increase its presence in the renewable energy sector, with plans to open its first production line in 2017.[189] Also in 2016, Korea Electric Power Corp (Kepco) acquired the Alamosa (Colorado) project from Cogentrix Solar Holdings to move into the US power market.[190]

Efforts to advance recycling processes continued, although there was relatively small demand for recycling of waste and solar panels (at end-of-life, or damaged or defective panels) as of 2016.[191] In addition to recycling's potential environmental benefits, the process can yield materials to be sold in global commodity markets or can be used for the production of new solar panels.[192] In 2016, Australia's Reclaim PV teamed with major manufacturers to refine its processes; a US industry programme was launched with the goal of making the national industry landfill-free; Japanese companies NPC and Hamada established a joint venture with the aim of recycling 80% of panel materials and reusing the rest; and the Japanese government issued recycling guidelines.[193] The EU has regulated solar PV-related waste since 2014.[194]

i PERC is a technique that reflects solar rays back to the rear of the solar cell (rather than being absorbed into the module), thereby ensuring increased efficiency as well as improved performance in low-light environments.

ii Busbars are the thin strips of copper or aluminium between cells that conduct electricity. The size of the busbar determines the maximum amount of current that it can carry safely.

iii Perovskite solar cells include perovskite (crystal) structured compounds that are simple to manufacture and are expected to be relatively inexpensive to produce. They have experienced a steep rate of efficiency improvement in laboratories over the past several years.



CONCENTRATING SOLAR THERMAL POWER (CSP)

CSP MARKETS

Concentrating solar thermal power (CSP), also known as solar thermal electricity (STE), saw 110 MW of capacity come online in 2016, bringing global capacity to more than 4.8 GW by year's end.[1] *(→ See Figure 20 and* ***Reference Table R7****.)* This was the lowest annual increase in total global capacity in 10 years, at just over 2%.[2] Even so, CSP remains on a strong growth trajectory, with as much as 900 MW expected to enter operation during the course of 2017.[3]

South Africa led the market in new additions in 2016, becoming the second developing country to do so after Morocco in 2015.[4] South Africa was followed by China, where the first of numerous new CSP plants came online in 2016.[5] CSP market growth continued to be driven outside of the traditional markets of Spain and the United States, and, by year's end, facilities were under construction in several countries representing nearly all regions.[6]

For the second year in a row, all new facilities that came online incorporated thermal energy storage (TES).[7] Most new CSP plants are being developed with TES, and 2016 marked a decade since the first commercial CSP system with TES was deployed.[8] *(→ See Figure 21.)* TES continues to be viewed as central to the competitiveness of CSP by providing the flexibility of dispatchability.[9]

Parabolic trough and tower technologies continued to dominate the market, with parabolic trough systems representing the bulk of capacity that became operational in 2016 as well as most of the capacity expected to come online during 2017.[10] Fresnel and parabolic dish technologies are still largely overshadowed, apart from some smaller plants in the development and construction phases.[11]

Spain remained the global leader in existing CSP capacity, with 2.3 GW at year's end, followed by the United States with just over 1.7 GW.[12] These two countries still accounted for over 80% of global installed capacity.[13] However, no capacity has entered commercial operation in Spain since 2013, and no new facilities were under construction in either country at end-2016.[14]

South Africa brought its first commercial tower plant online with the launch of the 50 MW (with 2.5 hours of TES; 465 MWh[i]) Khi Solar One facility in early 2016, followed shortly thereafter by the 50 MW (9.3 hours; 100 MWh) Bokpoort parabolic trough plant.[15] These two plants brought total installed capacity in the country to 200 MW.[16] At year's end, a further 300 MW was under construction and was expected to come online during the course of 2017, 2018 and 2019.[17] Several additional CSP projects under development faced uncertainty after the state-owned utility, Eskom, delayed the signing of PPAs under the Department of Energy's Renewable Energy Independent Power Producer Procurement Program (REIPPPP).[18]

China brought its first 10 MW of capacity online in 2016.[19] China's aggressive CSP programme, which aims to have 1.4 GW of CSP installed by 2018, started to bear fruit in 2016 with the addition of the 10 MW (15 hours; 150 MWh) Shouhang Dunhuang facility.[20] As much as 650 MW of trough, tower and Fresnel capacity was at varying phases of construction by year's end.[21]

Around the world, several projects that are being built are expected to come online over the next three years. CSP continued its push into developing countries that have high direct normal irradiance (DNI) levels and specific strategic and/or economic alignment with the benefits of CSP technology. In this respect, CSP is receiving increased policy support in countries with limited oil and gas reserves, constrained power networks, a need for energy storage, or strong industrialisation and job creation agendas.[22]

Apart from China, India was the only Asian country with CSP facilities under construction by the end of 2016. India's projects included the 25 MW Gujarat Solar 1 plant (9 hours; 225 MWh) and the 14 MW National Thermal Power Corporation's Dadri Integrated Solar Combined-Cycle (ISCC)[ii] plant.[23]

While Morocco did not bring new capacity online in 2016, it continued to be a key driver of CSP expansion. Both the 200 MW Noor II parabolic trough (7 hours; 1,400 MWh) and the 150 MW Noor III tower (7 hours; 1,200 MWh) facilities are expected to enter commercial operation during 2017.[24] These follow the 160 MW Noor I facility, commissioned in 2015, and will bring Morocco's total capacity to over 0.5 GW.[25]

Elsewhere in the Middle East and North Africa (MENA) region, construction continued on Israel's 121 MW Ashalim Plot B tower facility, which aims to achieve commercial operation in 2017.[26] The 110 MW Ashalim Plot A parabolic trough facility also was under construction in 2016, with operation expected to begin in 2018.[27]

In Saudi Arabia, two ISCC plants were under construction during the year. The 42 MW Duba 1 facility and the 50 MW Waad al

i For CSP plants that incorporate thermal energy storage (TES), the hours of thermal storage and capacity are provided, in parentheses, in hours and in MWh. Where thermal storage capacity has been reported in hours, it is assumed that these are full load hours (i.e., hours of storage at full plant discharge capacity). This section has converted capacity to MWh by multiplying peak plant capacity by full load hours.

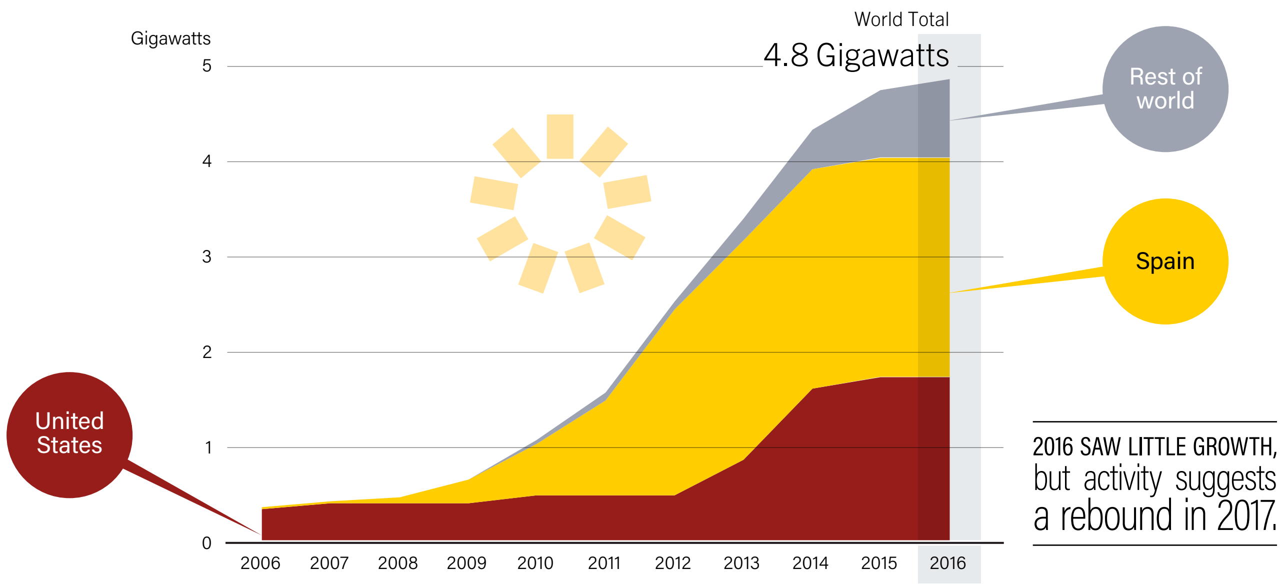
ii Integrated solar combined-cycle facilities are hybrid gas and solar power plants that utilise both solar energy and natural gas for the production of electricity.

Shamal plants are expected to enter operation in 2017 and 2019, respectively.[28] Construction continued on Kuwait's 50 MW (10 hours; 500 MWh) Shagaya plant, which is planned for operation in 2017.[29] In the UAE, the Dubai Electricity and Water Authority received a strong response to its request for proposals, released in early 2017, for a 200 MW CSP facility at the Mohammed bin Rashid Al Maktoum Solar Park.[30]

In Latin America, construction was halted at Chile's 110 MW (17.5 hours; 1,925 MWh) Atacama 1 (Planta Solar Cerro Dominador) plant due to financial challenges faced by Abengoa (the initial developer and owner of the facility, now involved only as a contractor).[31] Construction is expected to resume in 2017, with operations commencing in 2019.[32] The 12 MW Agua Prieta II plant in Mexico is scheduled for commissioning in 2017.[33]

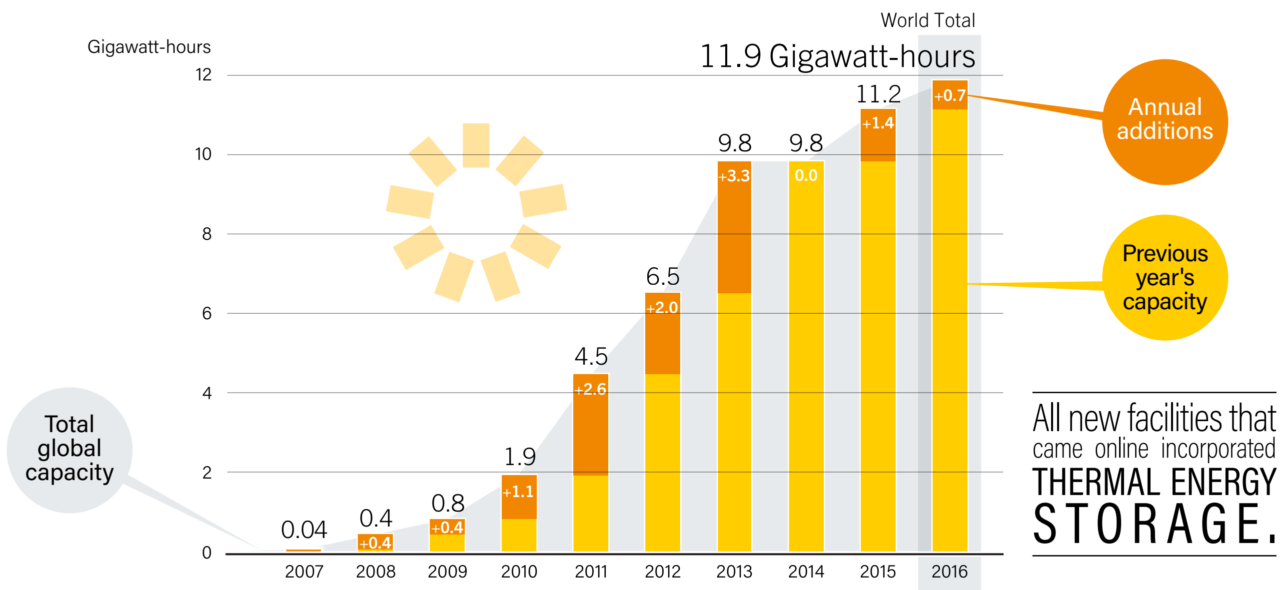
Some CSP activity continued in Europe during 2016. In France a 9 MW Fresnel facility was under construction in the Pyrenees-Orientales district.[34] In Denmark, a hybrid biomass-CSP facility that will incorporate 17 MW of CSP was under construction.[35] As a CHP plant, the facility will generate both electricity and low-temperature heat for district heating, representing an important potential application for CSP in colder climates.[36]

Figure 20. Concentrating Solar Thermal Power Global Capacity, by Country and Region, 2006-2016



Source: See endnote 1 for this section.

Figure 21. CSP Thermal Energy Storage Global Capacity and Annual Additions, 2007-2016



Source: See endnote 8 for this section.

CSP INDUSTRY

CSP activity saw a significant shift from Spain and the United States to developing countries in 2015, and this trend continued in 2016. The ongoing stagnation of the Spanish market, along with a long-predicted slowdown in the United States, resulted in ongoing growth of industrial activity and increased partnerships in new markets, including South Africa, the MENA region and particularly China.[37]

Recognising CSP's potential for local manufacturing, engineering and skills development, many countries – including Morocco, Saudi Arabia, South Africa and the UAE – continued to promote or enforce local content requirements in their CSP programmes during 2016.[38]

Abengoa (Spain), the industry's largest developer and builder, avoided the threat of insolvency that emerged early in 2016 when it reached a USD 1.2 billion (EUR 1.14 billion) restructuring deal with its creditors.[39] The company undertook significant changes, including the restructuring of ownership and the disposal of non-core solar PV and wind power assets.[40] Abengoa's rising debt was partially a result of Spanish energy reforms enacted in 2013, which reduced FITs for CSP facilities.[41]

With the exception of the fundamental restructuring that took place at Abengoa, 2016 was a relatively quiet year for CSP companies in terms of mergers, acquisitions and closures, with no major reports of significant corporate shifts.[42] Abengoa and Saudi Arabia's ACWA Power led the market in the ownership of projects that commenced operations or were under construction during 2016.[43] As a developer, owner and operator, ACWA continued to make strong inroads into the global CSP market, most notably through projects in South Africa and Morocco.[44] Other top companies that were engaged in construction, operation and/or manufacturing in 2016 included Rioglass Solar (Belgium); Supcon (China); Acciona, ACS Cobra, Sener and TSK (all Spain); and Brightsource, GE and Solar Reserve (all United States).[45]

Although commercial developers have continued to focus on trough and tower plants, with many facilities exceeding 100 MW in size, Fresnel facilities also are being planned and built, particularly for non-traditional or smaller facilities. This development is most notable in China, where four Fresnel plants totalling 90 MW were under construction at end-2016, and in France, where a 9 MW facility also under construction will be the first Fresnel plant to include several hours of TES capacity.[46]

The track record of larger TES systems continued to advance during the year, with various facilities proving their ability to generate power in the absence of sunlight and even throughout the night. In South Africa, for example, the newly commissioned Khi Solar One facility reached a technological milestone for the region when it completed a 24-hour cycle of uninterrupted solar power generation.[47] The bulk of new facilities coming online in 2017 is expected to include TES; the exceptions are plants that are hybridised with, or located alongside, natural gas plants – such as Israel's Ashalim facilities and the ISCC plants under construction in Saudi Arabia.[48]

CSP costs vary widely depending on the specific economic characteristics and DNI levels of a given location. Nonetheless, research specific to the US market found that CSP prices have declined in line with the trajectory proposed in 2012 by the US DOE's SunShot Initiative.[49] The initiative targeted a 75% decline in the cost of CSP systems between 2012 and 2020, to USD 0.06 per kWh; since 2012, costs have declined from a non-incentivised USD 0.206 per kWh (for an oil-based parabolic trough facility with no TES) to an estimated USD 0.12 per kWh in 2015 based on a new power tower facility with 10 hours of TES.[50] Cost declines also are evident elsewhere, with a 30% reduction over two bid cycles in Chile in 2015 and a 43% reduction over five bid cycles between 2011 and 2015 in South Africa.[51]

Although CSP costs have seen a significant decline, CSP deployment has been hampered by rapid and substantial decreases in the price of solar PV, driving the CSP industry's continued focus on maximising value through the use of TES systems, which enable CSP facilities to provide dispatchable power.[52]

R&D in the CSP sector in 2016 continued to focus strongly on improvements, alternatives and cost reductions in TES; on cost reductions in key CSP components (such as collectors); on alternate applications of CSP; and on efficiency of the heat transfer process.[53] R&D efforts were under way in numerous countries around the world, with universities, public scientific organisations and private companies in Australia, Europe and the United States announcing potentially significant advances.[54]

In Australia, for example, researchers achieved 97% efficiency in converting sunlight into steam.[55] Previously (in 2014), Australian researchers generated "supercritical" steam at the highest temperatures achieved from a non-fossil-based thermal fuel.[56] Research supported by the EU yielded advances in thermochemical energy storage and hybridised CSP systems.[57] In the United States, wide-ranging research programmes under way during 2016 included the analysis of sand-like particles as an alternative to molten salt in TES systems; efforts to advance thermochemical storage systems for CSP, which offer the possibility of increased energy storage density at lower costs; and the application of the supercritical CO_2 Brayton Cycle[i], which offers the potential to increase CSP efficiency and further reduce costs.[58]

Significant progress is being made in understanding the real value of CSP with TES in providing dispatchable power to grids with increasing shares of variable renewable power.[59] *(→ See Feature chapter.)* While CSP remains more expensive than wind power and solar PV on a pure generating cost basis, the overall value of CSP with TES can be higher as a result of its ability to dispatch power during periods of peak demand. During 2016, SolarPACES, an international network of CSP researchers and industry experts, made significant progress in quantifying the real value of CSP incorporating TES and standardising yield assessment methodologies required to evaluate new projects.[60]

i The Brayton Cycle uses air as the working fluid in a gas turbine. This is distinct from the Rankine Cycle (used in existing CSP plants) which makes use of water as the working fluid, in conjunction with a steam turbine. The Brayton Cycle can achieve higher operating temperatures, which results in higher efficiency.

SOLAR THERMAL HEATING AND COOLING

SOLAR THERMAL HEATING AND COOLING MARKETS

Solar thermal technology is used extensively in all regions of the world to provide hot water, to heat and cool space, to dry products and to provide heat, steam or refrigeration for industrial processes or commercial cooking. By the end of 2016, solar heating and cooling technologies had been sold in at least 127 countries.[1] The cumulative capacity of glazed (flat plate and vacuum tube technology) and unglazed collectors in operation increased to a year-end total of 456 GW_{th}, up from 435 GW_{th} a year earlier.[2] *(→ See Figure 22.)*

As in 2015, the top five countries for cumulative capacity were China, the United States, Turkey, Germany and Brazil.[3] *(→ See Figure 23.)* Solar thermal collectors of all types provided approximately 375 TWh (1,350 PJ) of heat annually by the end of 2016, equivalent to the energy content of 221 million barrels of oil.[4]

Due to low fossil fuel prices throughout the year, new global installations of solar thermal systems declined again in 2016. The year's gross additions of 36.7 GW_{th} were down by 8.5%, from 40.1 GW_{th} in 2015.[5] Significant slowdowns were reported in Poland (-58%), France (-35%), Austria (-19%) and Israel (-16%).[6] *(→ See Figure 24.)* Among the 20 largest markets, significant market growth was reported in Denmark (84%), Mexico and India (both 6%).[7] As in 2015, the five leading countries for new installations in 2016 were China, Turkey, Brazil, India and the United States. The top 20 countries for solar thermal installations accounted for an estimated 94% of the global market in 2016.

In most of these top 20 countries, markets were dominated by flat plate collectors. In China and India more than half of 2016 additions were vacuum tube collectors.[8] In the United States, Australia and South Africa more than half of new installations were unglazed collectors (used mostly for heating swimming pools). Among the top 20 markets, vacuum tube collectors accounted for 75% of new installations, flat plate collectors made up 21%, and unglazed water collectors accounted for the remaining 4%.[9]

Despite the downwards trend in China since its record year in 2013, the country remains the world's largest solar thermal market by far. New gross installations totalled 27.7 GW_{th} (39.5 million m^2) in 2016, almost 19 times more than the second largest market, Turkey.[10] At year's end, China's operating capacity was 325 GW_{th} (464 million m^2), just over half of the 560 GW_{th} by 2020 target that was announced in the 13th Five-Year Plan for Solar Applications.[11]

The transition in China from small residential solar thermal units to larger projects for multi-family houses, tourism and the public sector accelerated in 2016, with large projects accounting for 68% of the country's annual additions, up from 61% in 2015.[12] This trend was supported by an increasing demand for centralised solar space heating systems in southern China, where heating systems have been uncommon thus far and where fossil fuels are expensive.[13] The transition also was driven by building codes in urban areas, which mandate the use of solar thermal (and heat pumps) in new construction and major renovations as a means to reduce local air pollution.

Turkey's market remained strong but is difficult to measure because it again consisted of a formal sector with brand-name companies and an informal sector, in which systems are provided by unregistered small producers. The formal market remained fairly stable, with an estimated 1.1 GW_{th} (1.53 million m^2) installed in 2016.[14] Residential demand (primarily for vacuum tube collectors) accounted for 47% of new installations, up from 40% in 2015.[15] Demand for flat plate collectors remained strong for commercial projects at schools, dormitories, military stations and prisons.[16] Unregistered small producers accounted for another one-third of the year's installations, bringing total new additions to around 1.47 GW_{th} (2.1 million m^2).[17] The 13.6 GW_{th} (19.4 million m^2) of solar thermal capacity in operation at the end of 2015 saved Turkey around 10% of its annual natural gas consumption.[18]

Brazil continued to rank third for new installations and remained the largest solar thermal market in South America. With 0.91 GW_{th} (1.3 million m^2) added in 2016, Brazil was only slightly ahead of India.[19] The decrease in Brazil's solar thermal market was relatively small (-7%) considering the country's ongoing economic and political crises and the slowdown of the social housing programme Minha Casa Minha Visa ("My House, My Life"), which mandated solar water heaters in new buildings for very poor families.[20] Reduced purchasing power resulted in a 10% decline in sales of unglazed collectors for swimming pools.[21]

India added 0.9 GW_{th} (1.28 million m^2) in 2016, an increase of 6% relative to 2015.[22] The market appears to be bouncing back, following a temporary reduction in demand that resulted from the suspension of India's national grant scheme in 2014.[23] The share of imported vacuum tubes grew to 88% (up from 82% in 2015).[24] This segment included an increasing number of vacuum tubes backed with aluminium mirrors (so-called compound parabolic concentrators), which are used primarily for industrial process heat applications. This trend was supported by a national 30% capital subsidy scheme for concentrating solar thermal technologies, which has reduced the payback times to three to four years for manufacturing businesses.[25] Only 0.11 GW_{th} of flat plate collectors (down from 0.15 GW_{th} in 2015) was sold by the handful of manufacturers that remains in India.[26]

The United States was the fifth biggest market worldwide. The country's market volume was down only 3% relative to 2015,

with 0.68 GW_{th} (974,977 m^2) added in 2016, despite low oil and natural gas prices and the country's increasing focus on solar PV.[27] The United States continued to be the largest market for unglazed swimming pool systems (0.56 GW_{th}), followed by Brazil (0.38 GW_{th}) and Australia (0.27 GW_{th}).[28] The significantly smaller US segment of glazed collectors saw additions of 0.12 GW_{th} in 2016, representing a slight increase (1%) following two consecutive years of decline; the increase was driven by state-level rebate schemes such as the California Solar Initiative – Solar Thermal, and rebates in Massachusetts and New York State, as well as the solar obligation in Hawaii.[29]

The European Union (EU-28) was again the second largest regional market after Asia, with estimated gross additions of 1.8 GW_{th} (approximately 2.5 million m^2), 6.4% lower than in 2015.[30] The largest European market was again Germany, followed by Denmark, which almost doubled its new installations in 2016.[31] Beyond Denmark, 2016 was a challenging year in key markets because of factors such as low oil and gas prices, declining demand from homeowners and reduced interest in solar thermal technology among installers. In Germany and Italy, these impeding factors had a stronger impact on investment decisions than did a high level of subsidies.[32]

In addition, energy-efficient building regulations supported the installation of heat pumps in new buildings in Germany and France, suppressing markets for solar thermal systems.[33] In Poland, a lack of political support for solar thermal and increased competition with hot water heat pumps, which are considered cheaper and easier to install, resulted in a 58% decline in the annual solar thermal market, to 81 MW_{th}.[34] The EU´s cumulative installed capacity in operation at the end of 2016 was approximately 34.4 GW_{th}, representing around 8% of the world's total.[35]

Over the last five decades, the primary application of solar thermal technology globally has been for water heating in single-family houses; the residential segment accounted for 63% of the total installed collector capacity at the end of 2015 (the most recent data available).[36] In recent years, however, markets have been transitioning to large-scale systems for water heating in multi-family buildings and in the tourism and public sectors. In 2015, this commercial sector accounted for only 29% of the total collector capacity in operation worldwide, but it represented 54% of newly installed collector capacity.[37] *(→ See Figure 25.)*

Globalisation of solar heating and cooling technologies continued in 2016, with sales picking up in several new emerging markets, including Argentina, the Middle East and parts of eastern and central Africa.[38] In Argentina, solar water heater installations doubled year-on-year between 2012 and 2015.[39] They have seen increased popularity since July 2016, when the country's president ordered a 260-litre thermosiphon system for his residence.[40] Rising electricity prices (e.g., Argentina) and solar building obligations (e.g., Kenya and Dubai) also helped to drive demand in these new markets.[41]

Solar district heating enjoyed increased attention across Europe and China, led by Denmark, which had a record year for new installations and experienced the fastest growth of new solar thermal capacity among the top 20 markets. Denmark brought into operation 31 new solar district heating plants and expanded 5 existing plants, for a total of 347 MW_{th} added in 2016; this compares to 15 new and 3 expanded plants (totalling 175 MW_{th}) in 2015.[42] The large majority of all plants use flat plate collectors; the exception is the installation in Brønderslev (18.9 MW_{th}), which uses parabolic trough collectors.[43]

The strong market in Denmark was supported by good framework conditions – including national taxes on fossil fuels, sufficient land for cost-effective ground-mounted collector fields, and the existence of non-profit, user-owned co-operatives that operate local district heating systems. It also was motivated by pending expiration (in December 2016) of a 2012 energy savings agreement between Danish district heating companies and Denmark's energy ministry, which prompted several utilities to complete their solar district heating systems by year's end.[44] In December, the Danish Energy Ministry signed a new agreement with district heating companies, allowing them to fulfill energy savings mandates for the period 2016-2020 by extending existing solar district heating plants or by initiating the construction of new facilities by mid-2018.[45]

Among Denmark's new installations is the world´s largest solar thermal plant, with 110 MW_{th} (156,694 m^2) of installed capacity, in the town of Silkeborg.[46] The solar district heating plant was commissioned (by Danish turnkey supplier Arcon-Sunmark) in December, after only seven months of construction.[47] The world's second largest solar thermal plant – the 49 MW_{th} (70,000 m^2) district heating field in Vojens – also is located in Denmark.[48] At the end of 2016, Denmark's solar district heating capacity totalled 911 MW_{th} (1.3 million m^2), with 104 systems in operation.[49]

The successes in Denmark have inspired intensive discussions and project development activities in other central European countries, especially in Germany and Poland.[50] Consequently, Germany's first record-size solar district heating plant in 11 years came online in August 2016, when 5.8 MW_{th} (8,300 m^2) of vacuum tube collectors began feeding into the municipal district heating network in Senftenberg.[51] In total, Germany installed a combined 9 MW_{th} (12,921 m^2) in four new systems, increasing the country's district heating capacity to 39 MW_{th} by year's end.[52]

In addition, two other solar district heating plants larger than 350 kW_{th} (500 m^2) began operation in Europe in 2016: Sweden added a 0.7 MW_{th} (1,050 m^2) installation in Tornberget, and a 0.58 MW_{th} (830 m^2) solar thermal plant began supplying heat to multi-family houses in a new neighbourhood near Paris, France.[53] Spain's plans for new large-scale solar thermal installations in Barcelona did not materialise due to a lack of affordable space for the collectors in the dense urban area.[54] At the end of 2016, Europe was home to 290 large-scale systems with a total of 1.1 GW_{th} (1.58 million m^2), making up around 3% of the region´s total operating solar thermal capacity.[55]

Interest in solar district heat increased beyond Europe as well. In the Chinese province of Shandong, a subsidy scheme was announced in 2016 to support central space heating systems in public buildings, such as schools, hospitals, nursing homes and daycare facilities.[56] One of the first larger solar district heating plants, completed in 2013, is a 8.1 MW_{th} (11,592 m^2) vacuum tube collector system that provides heat for student flats at the Hebei University of Economics and Business; in recent years, this facility has helped to draw attention to the huge potential of solar thermal technology in the world's largest district heating market.[57]

The share of solar energy that can be achieved in a district heating network depends heavily on the type and scale of integrated storage solutions. The plant in Silkeborg, Denmark was built with short-term storage of 32,000 m^3 and was designed to meet around 20% of the annual heating demand of the network's 21,000 users.[58] In contrast, the solar share at Denmark's Vojens plant has reached 45% because the facility includes a water-filled basin with 203,000 m^3 of storage.[59] Canada's Drake Landing Solar community, with borehole seasonal storage, demonstrated in 2016 that solar district heating has the potential to cover even a 100% share of a system's heating demand in winter. System improvements such as lowering the district loop temperature and enhancing the thermal stratification in the tank made it possible for the system to meet the entire space heating demand of 52 energy-efficient residential buildings during the winter of 2015-16.[60]

Solar thermal technologies – including concentrating collector types such as linear Fresnel, parabolic trough and dish collectors – also are used to provide process heat for a growing number of manufacturing facilities.[61] Process heat accounts for around two-thirds of final energy consumption in the industry sector, and 52% of that heat demand is in the low- and medium-temperature range (below 400°C) and thus suitable for solar thermal technologies.[62] The potential for solar thermal in the industry sector is significant.

The year 2016 saw the first assessment for the world market of solar heat for industrial processes (SHIP).[63] At the end of 2016 at least 525 SHIP plants were in operation, totalling a minimum of 416,414 m^2 of collector and mirror area (291 MW_{th}) – enough capacity to provide approximately 18 GWh (1 PJ) of industrial process heat by the end of 2016.[64] Prior to the assessment, it was estimated that 195 SHIP systems were in operation worldwide, with a total collector/mirror area of 177,892 m^2 (125 MW_{th}).[65]

The industry segments with the highest numbers of realised SHIP plants in 2016 were food and beverage, machinery and textiles.[66] A number of projects were built around the world during the year, paving the way for other manufacturing businesses. One example was the Amul Fed Dairy in India, which installed a 561 m^2 parabolic trough collector field to supply steam for milk pasteurisation; this project has the potential to be replicated by several other dairies in the region.[67] In South Africa, the Cape Brewing Company installed a 120 m^2 flat plate collector field to supply heat for its brewing process; this system was only the fifth SHIP plant in the country.[68]

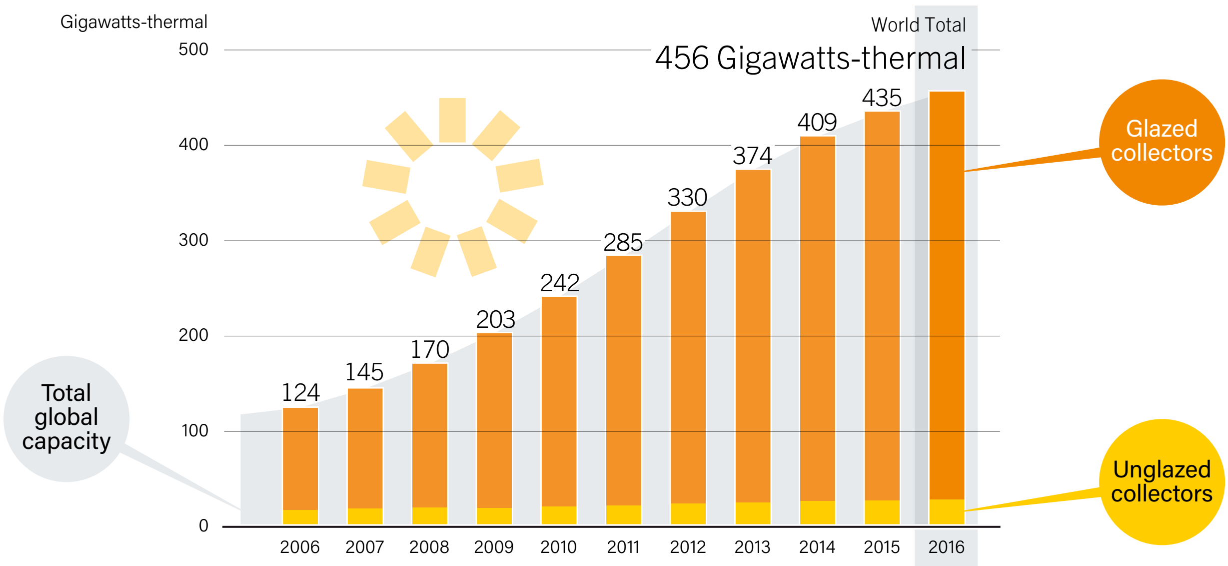
Good sun conditions for solar concentrating technologies in Australia's desert, coupled with relatively high gas and oil prices, facilitated the construction of a concentrating solar plant at a tomato farm in the state of South Australia.[69] A mirror field (52,000 m^2) reflects the sunlight towards a receiver that provides heat for three different applications: heating greenhouses in winter and during cold summer nights, desalinating seawater and periodically running a steam turbine to produce electricity.[70] Austria saw the installation of a record-size process heat installation at the automotive consulting company AVL List; the new 1,585 m^2 flat plate collector field supplies energy for the heat demand of the factory's test facilities.[71]

Copper mining and enhanced oil recovery have seen the largest SHIP installations to date. The largest solar process heat plant in operation worldwide in 2016 was a 27.5 MW_{th} (39,300 m^2) facility located at the Gabriela Mistral mine in Chile. Over the first 35 months of its operation, the plant recorded a specific yield of 1,112 kWh per m^2; the output was as simulated, notwithstanding the operational challenges of the large field's hydraulics and the dusty surroundings.[72] In September 2016, Mexico saw the completion of its first solar-heated copper mine project at La Parreña, in the centre of the country. The 4.4 MW_{th} (6,270 m^2) facility was designed to cover 58% of the mine's demand for heat.[73] Despite these positive developments, deployment of solar thermal technology in copper mining has been limited due to the industry's reluctance to make long-term investments while the global price of copper has been in decline.[74]

Also in 2016, construction continued on the 1 GW_{th} enhanced oil recovery plant in Oman.[75] As of early 2017, the USD 600 million facility, which is 36 times bigger than the largest SHIP plant in operation, was ahead of schedule and under budget, and the first of 36 greenhouse blocks was expected to start producing steam before the end of 2017.[76]

SOLAR THERMAL HEATING AND COOLING

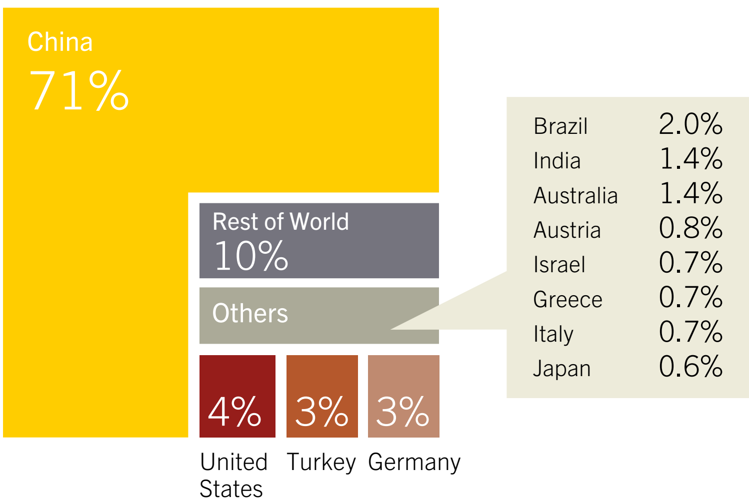
Figure 22. Solar Water Heating Collectors Global Capacity, 2006-2016

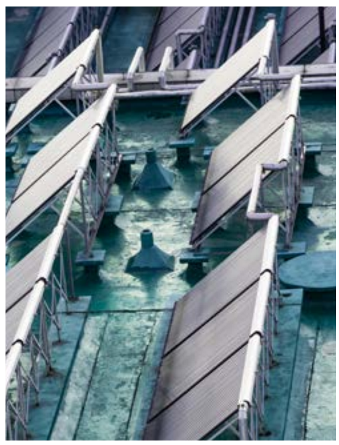


Source: IEA SHC. See endnote 2 for this section.

Solar district heating capacity **DOUBLED** in Denmark (in 2016).

Figure 23. Solar Water Heating Collectors Global Capacity in Operation, Shares of Top 12 Countries and Rest of World, 2015

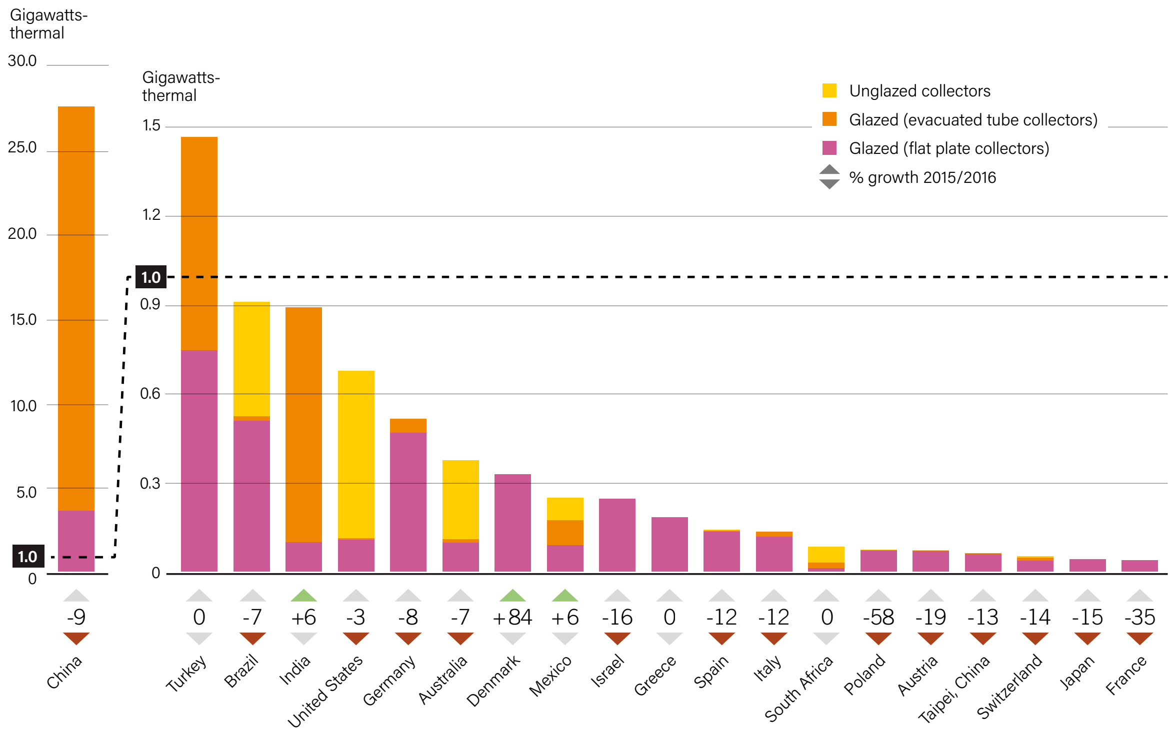




Note: Total does not add up to 100% due to rounding.

Source: IEA SHC. See endnote 3 for this section.

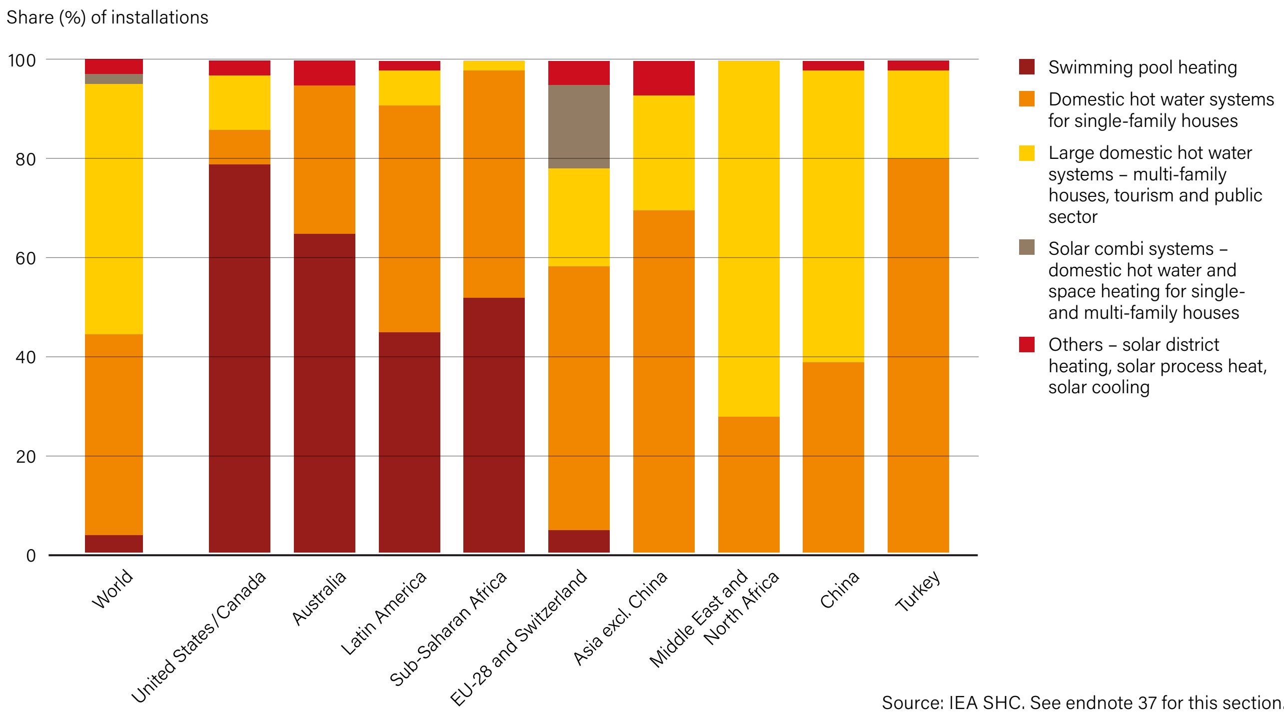
Figure 24. Solar Water Heating Collector Additions, Top 20 Countries for Capacity Added, 2016



Note: Additions represent gross capacity added.

Source: See endnote 6 for this section.

Figure 25. Solar Water Heater Applications for Newly Installed Capacity, by Economic Region, 2015



Source: IEA SHC. See endnote 37 for this section.

Solar process heat is far from meeting its economic and technical potential. Low fossil fuel prices and lack of concern among industry stakeholders about CO_2 emissions and other environmental challenges have limited interest in alternative energy sources, including solar thermal. According to suppliers of SHIP, the most important conditions for enabling robust market development are high fossil energy prices and political mandates for the use of solar process heat.[77] In a survey, 79% of participating SHIP suppliers identified energy heat supply contracts as an important means to increase deployment; however, only 34% offered such contracts as of 2016.[78] The industry has acknowledged a need to develop business models that reduce the risk and the upfront costs for small and medium-sized enterprises in order to expand the SHIP market.[79]

Solar PV-thermal (PV-T) technologies capture the waste heat from solar PV modules, which utilise only 12-15% of the incoming sunlight, to provide heat for space and water. Monitoring of a largescale demonstration PV-T plant in Switzerland found that the system could achieve an annual thermal yield of 330 kWh per m^2 in addition to the annual 163 kWh per m^2 of solar electricity that it produced.[80] In 2016, France and Switzerland both reported increased numbers of new PV-T projects, but with different applications. In France, about 55,000 m^2 of systems — mostly air-based PV-T elements for single-family houses — was installed during the year; this total was close to the newly installed water-driven flat plate collector area (65,900 m^2).[81] In Switzerland, unglazed water collectors dominate the market, increasingly in combination with heat pumps to regenerate boreholes over the summer; by the end of 2016, the country had an estimated 300 PV-T installations.[82]

Solar thermal cooling continued to face challenges during 2016 in the key markets of Europe and China due to falling solar PV prices, which allow for the cost-effective operation of compression chillers powered by solar electricity during daylight, and to low fossil fuel prices.[83] Even so, significantly hot summer periods in southern Europe, as well as the use of natural refrigerants like water or ammonia, have increased the awareness of solar cooling technologies in the region's construction industry. As a result, solar cooling systems are used increasingly for commercial and public buildings when also supplying year-round solar hot water.[84]

Preliminary findings in Europe are that multi-usage solar thermal systems that supply hot water throughout the year, space heating during transition periods, and space cooling during hot summer periods are highly efficient and have the potential to cover up to 50% of the total heat and cooling demand of high-efficient buildings in the region.[85] Server centres also are a promising market for solar cooling (as in Italy).[86] Thanks to the high subsidy of the national rebate programme Conto Termico 2.0, Italy was the key sales market for solar thermal-driven chillers in Europe in 2016.[87]

In China, increasing use of solar space heating installations during 2016 also offered new opportunities for solar cooling because surplus heat in summer can be used for air conditioning. This combined heating and cooling operation mode was first demonstrated in 2016 in an office building in Shanghai with a 200 m^2 flat plate collector field and a 23 kW absorption chiller.[88]

Increasing demand for air conditioning in sun-rich countries, combined with financial support from international development agencies, has helped to spread interest in solar heat-driven cooling systems in non-OECD countries. In 2016, three new solar cooling systems were completed in Jordan: Royal Culture Center (160 kW of cooling), Irbid Chamber of Commerce (50 kW of cooling) and Mutah University (20 kW of cooling).[89] During the non-cooling season, these systems can support the buildings' hot water demand and thereby increase the usable solar yield over the year. In neighbouring Egypt, a 35 kW chiller, supplied by a linear Fresnel collector, began cooling a medical centre north of Cairo in October 2016. The project was jointly implemented by experts from Egypt, Greece, Italy and Cyprus and received European funding.[90]

Also in 2016, a Brazilian university in the province of Minas Gerais, in co-operation with a local electricity supplier, installed two solar cooling demonstration systems, with a 10 kW and a 35 kW imported absorption chiller and locally produced collectors.[91] As of early 2017, a 3.1 MW_{th} (4,450 m^2) collector field was under construction to supply space cooling and hot water to a hospital in Managua, Nicaragua.[92] The USD 4.2 million (EUR 4 million) project was financed through a soft loan provided by Raiffeisen Bank International for developing countries.[93]

SOLAR THERMAL HEATING AND COOLING INDUSTRY

The year 2016 was a turning point in the solar thermal industry. Demand from homeowners, for many years the core sales segment for the solar thermal industry, again declined, and installers – the key supply chain partners of the industry in Europe – showed less interest in solar thermal technology. To counter the declining demand from established sales partners and end-consumers, an increasing number of manufacturers of solar collectors and tanks changed their product lines and sales strategies.

Many suppliers of solar thermal systems responded to the challenges by taking new directions and diversifying their portfolios. In Austria, for example, several collector manufacturers added heat pumps and solar PV solutions to their product offerings in order to provide complete heating system solutions.[94] In China, manufacturers concentrated on new applications such as space heating and cooling, as well as drying of agricultural products.[95]

In addition to focusing on new applications for solar thermal technologies, some suppliers are developing new business models. In Germany, manufacturers of solar thermal systems provided potential end-consumers with online sales platforms for heating systems with or without solar energy; clients could provide information online about their desired heating system and then receive an offer directly from the system supplier, bypassing the installer.[96] In Spain, the industry has sold a growing number of non-subsidised systems (20% of the total market volume) by offering loans in partnership with financial institutions.[97]

Despite the challenges in much of Europe and China, some industrial players benefited from strong tailwinds in 2016. In response to strong market growth in Argentina, at least 32 businesses started commercial activities during the year, for a total of at least 134 solar thermal businesses.[98] Greek manufacturers saw their exports rise 14% in 2016 (to 231 MW_{th}), following a 7% increase in 2015, due to the cost-competitiveness and good reputation of their products. Their exports even exceeded domestic sales, of 189 MW_{th}.[99]

Manufacturers of air collectors in Germany and Austria recorded increasing sales, despite the general downwards trend in these countries. This growth was supported by cost-effective system solutions (e.g., in contrast to water-driven solar systems, air units do not need tanks, pumps or expansion vessels), combined with high investment subsidies.[100]

The year 2016 was a bright period for suppliers of solar district heating systems in Denmark, where the capacity of solar thermal plants supplying district heat doubled in 2016.[101] The strong demand led market leader Arcon-Sunmark to greatly increase its production volume; this Danish collector manufacturer and turnkey system supplier was responsible for 87% of Denmark's new installations during the year.[102] In mid-2016, Arcon-Sunmark expanded its business model to China, the world's largest district heating market, with around 463 GW_{th} of installed capacity as of 2014 (the latest data available).[103] Arcon-Sunmark established a joint venture with China's market leader, Jiangsu Sunrain Solar Energy, to offer large-scale solar heating solutions to the Chinese market.[104]

Denmark's district heating networks are optimised for the feed-in of solar heat with low feed-line and return temperatures. Outside of Denmark, district heating networks usually operate at significantly higher temperatures, reducing the efficiency of conventional flat plate collectors.[105] To meet this challenge of transferring solar district heating to other countries, an increasing number of manufacturers in Europe developed mid-temperature flat plate collectors that employ either a second glass cover or a foil between the absorber and the glass cover.[106] In mid-2016, initial monitoring results confirmed the remarkable performance of this new generation of collectors even for use with higher-temperature district heating networks (feed-line 80-129°C and return line 58-70°C).[107]

Most leading solar thermal manufacturers worldwide consolidated their positions in 2016. The largest manufacturers of vacuum tube collectors were again Sunrise East Group (including the Sunrain and Micoe brands), Himin, Linuo Paradigma and Sangle – all based in China.[108] The largest manufacturers of flat plate collectors were again Greenonetec (Austria), Fivestar (China), Soletrol (Brazil) and Bosch Thermotechnik (Germany).[109] Two large players dropped from the ranking in 2016: Ezinç (Turkey) stopped production in June, and Prosunpro (China) has cut production sharply in recent years because of financial troubles.[110]

Poland's industry experienced significant consolidation in 2016. The Polish collector manufacturer Hewalex, which is among the leading flat plate collector manufacturers worldwide, saw its sales fall by 60% in 2016, due to a 58% drop in domestic sales.[111] Following the production closure of Watt in 2015, two additional Polish flat plate collector manufacturers – Solver and Geres Asco – stopped production in 2016. Several solar thermal system suppliers that focused on imported vacuum tubes closed up shop, following a near 90% drop in sales of vacuum tube collector systems in Poland during the year.[112]

An increasing number of companies considered solar thermal for industrial processes (SHIP) to be an attractive business area in 2016. A world map published in early 2017 included 71 SHIP-related companies from 22 countries; 42 of these companies reported that they had already completed turnkey SHIP reference plants.[113] An additional 29 companies were SHIP start-ups or market-ready SHIP plant suppliers that already had experience with commercial solar installations, such as solar for cooling or power generation.[114] Nearly two-thirds (58%) of the identified SHIP suppliers operated their own collector production facilities, with the most common collector type being parabolic trough (18 companies), followed by flat plate (10), linear Fresnel and vacuum tube (5 companies each) and concentrating dish (4).[115] The hubs of turnkey SHIP technology supply are China, Mexico, India and Germany.[116]

In the solar cooling industry, a key area of focus has been on reducing costs. Standardisation of systems is one way to reduce investment costs of technologies, such as solar cooling, that continue to see only small market volumes. Individually engineered solutions that consist of a chiller, a collector field, tanks and a re-cooler generally result in higher costs. Manufacturers from around the globe have responded to the challenge by developing pre-engineered solar cooling kits with cooling capacities between 2.5 kW and 40 kW that are suitable for single-family, multi-family and commercial properties.[117] As of early 2017, 10 such commercial or semi-commercial solar cooling kits were available, including 4 powered by solar thermal collectors, 5 powered by solar PV units, and 1 powered by both of these solar energy sources.[118]

PV-T technologies combine solar electricity with solar heat production in one element. After several years of a highly fluctuating industry landscape, with PV-T manufacturers coming and going, in 2016 the market was firmly in the hands of specialised suppliers with approved PV-T technologies.[119] As of early 2017, 53 manufacturers and suppliers of PV-T panels were identified, with 52% of them based in Germany (10), Italy (8), France (5) and Switzerland (5).[120] The majority of them (38 companies) offered water-driven unglazed PV-T elements, 9 firms sold air-driven PV-T collectors, and 6 companies offered glazed, water-driven PV-T models.[121]

WIND POWER

WIND POWER MARKETS

Almost 55 GW of wind power capacity was added during 2016, increasing the global total about 12% to nearly 487 GW.[1] Gross additions were 14% below the record high in 2015, but they represented the second largest annual market to date.[2] *(→ See Figure 26.)* By the end of 2016, over 90 countries had seen commercial wind power activity, and 29 countries – representing every region – had more than 1 GW in operation.[3]

A significant decline in the Chinese market (following a very strong 2015) was responsible for most of the market contraction.[4] Even so, China retained its lead for new installations, followed distantly by the United States and Germany, with India passing Brazil to rank fourth.[5] Others in the top 10 for additions were France, Turkey, the Netherlands, the United Kingdom and Canada.[6] *(→ See Figure 27 and **Reference Table R9**.)* New markets continued to open elsewhere in Asia and across Africa, Latin America and the Middle East; and Bolivia and Georgia installed their first wind plants of scale in 2016.[7] At year's end, the leading countries for total wind power capacity per inhabitant were Denmark, Sweden, Germany, Ireland and Portugal.[8]

For the eighth consecutive year, Asia was the largest regional market, representing about half of added capacity, with Europe and North America accounting for most of the rest.[9] Growth in some of the largest markets was affected by uncertainty about future policy changes, and cyclical or policy-related slowdowns affected some markets; however, wind deployment also was driven by cost-competitiveness and by environmental and other factors.[10] Wind has become the least-cost option for new power generating capacity in an increasing number of markets.[11]

China added 23.4 GW in 2016, for total installed capacity approaching 169 GW, and accounted for one-third of total global capacity by year's end.[12] New installations were down 24% relative to 2015, when a record annual market was driven by looming reductions in China's FIT.[13] The drop was due in part to weak electricity demand growth and to grid integration challenges.[14] About 19.3 GW was integrated into the national grid and started receiving the FIT premium in 2016, with approximately 149 GW considered officially grid-connected by year's end.[15]

The top provinces for capacity additions were Yunnan (3.3 GW), Hebei (1.7 GW) and Jiangsu (1.5 GW), with the latter two relatively close to demand centres.[16] Although the northern and western provinces were still home to a significant portion of China's wind power capacity at year's end, for the first time new installations increased substantially in the southern and eastern regions, in response to new regulations to steer investment away from high-curtailment areas.[17]

Despite the central government's introduction of new regulations to ensure guaranteed annual full load hours for wind (and solar) energy, curtailment remained a major challenge (even for nuclear power) in China in 2016 due to poor grid connections, lack of transmission infrastructure, slower-than-expected demand growth and grid managers' preference for coal-fired generation.[18] Overall, an estimated 49.7 TWh of potential wind energy was curtailed, or a national average of 17% for the year, with far higher rates in some provinces.[19] Even with curtailment, wind power's share of China's total generation has increased steadily in recent years, reaching 4% in 2016 (up from 3.3% in 2015), or 241 TWh.[20]

Elsewhere in Asia, India installed 3.6 GW to end 2016 with 28.7 GW, firming up its fourth-place position for total capacity.[21] India's record installations were due largely to a rush to take advantage of incentives that were set to decline or expire in early 2017.[22] Turkey had a record year, adding nearly 1.4 GW in 2016 to rank again among the top 10 for new capacity, for a total of 6.1 GW.[23] Pakistan (0.3 GW), the Republic of Korea and Japan (both around 0.2 GW) also added capacity, helping to push Asia's total above 203 GW.[24] By late 2016, significant additional capacity was under construction in the region, including Indonesia's first utility-scale wind farm, and Vietnam had just contracted another 940 MW.[25]

The United States ranked second for additions (8.2 GW), for cumulative capacity at year's end (82.1 GW) and for wind power generation (226.5 TWh; only 6% below China) during 2016.[26] Wind power accounted for one-fourth of newly installed US power generating capacity, ranking third after solar PV and natural gas for gross capacity additions, and second for net additions.[27] Texas led for capacity added (2.6 GW), and at year's end the state was home to one-quarter of US capacity; it was followed by Oklahoma (added 1.5 GW), Iowa (0.7 GW), Kansas and North Dakota.[28] Nebraska became the 18th US state to exceed 1 GW of cumulative wind power capacity.[29]

US utilities continued to invest strongly in wind power, with some going beyond state mandates based on favourable economics.[30] The cost-competitiveness of wind power also drove corporate and other purchasers, with a diverse range of new companies entering the market. Non-utilities accounted for 39% of more than 4 GW contracted in 2016, down from 2015 (52%) but up significantly over the previous two years (23% in 2014 and 5% in 2013).[31] By the end of 2016, an additional 10.4 GW of wind power capacity was under construction.[32]

To the north, Canada added 0.7 GW, about half the 2015 level, for a total of 11.9 GW.[33] Although growth slowed relative to 2014 and 2015, wind energy has represented Canada's largest source of new electricity generation for 11 years.[34] The province of Ontario continued to lead for cumulative capacity, adding 0.4 GW (for a total of 4.8 GW), followed by Québec (added 0.2 GW for a total of 3.5 GW), while Prince Edward Island had the country's highest penetration rate (25%).[35]

The EU installed nearly 12.5 GW of gross capacity (12 GW net, accounting for decommissioning), down 3% from the region's 2015 record high; additions were up 11% onshore and down almost 50% offshore.[36] Total capacity at year's end reached 153.7 GW (92% onshore and 8% offshore).[37] Wind represented the largest percentage of new power capacity in the region (51% of gross additions), followed by solar PV; new fossil fuel power capacity (less than 14% of additions) was far exceeded by retirements.[38] By the end of 2016, 16 EU member states had more than 1 GW each.[39]

However, ongoing economic crises and austerity measures, combined with the transition from regulated prices (under FITs) to tenders has affected growth.[40] In response to abrupt and, in some cases, retroactive policy changes, annual installations have contracted significantly in several well-established markets, including Italy and Spain.[41] As of early 2017, only seven EU member states had renewable energy targets in place for beyond 2020.[42] Consequently, installations were concentrated in a handful of countries: the top five markets in 2016 (Germany, France, the Netherlands, the United Kingdom and Poland) accounted for 75% of the region's newly added capacity.[43] Despite ranking among the top five, installations in Poland and the United Kingdom were down significantly relative to 2015.[44]

Germany again was the largest European market, increasing operating wind power capacity by almost 5 GW for a total of 49.5 GW (45.4 GW onshore and 4.2 GW offshore).[45] Germany's boom was driven largely by the looming shift from guaranteed FITs to competitive auctions for most renewables installations as of January 2017.[46] Five other EU countries had a record year for new installations, including France (adding 1.6 GW), the Netherlands (0.9 GW, mostly offshore), Finland (0.6 GW), Ireland (0.4 GW) and Lithuania (0.2 GW).[47] Finland and Lithuania both saw their total wind power capacity increase by over 56%, and the Netherlands joined the global top 10 for annual additions for the first time in decades.[48] Total EU generation from wind power in 2016 was around 300 TWh, up only slightly over 2015 due to a relatively poor wind year following an unusually strong one.[49] Elsewhere in Europe, the Russian Federation ended the year with little capacity but awarded about 700 MW of projects in its first wind power auction in 2016.[50]

Latin America and the Caribbean was the next largest installer by region. Eight countries added more than 3.5 GW and, by end-2016, the region had over 18.8 GW in at least 16 countries.[51] Additions were significantly below 2015, due largely to reductions in Brazil and Mexico.[52] Brazil continued to lead the region and to rank among the global top 10, despite the ongoing economic recession and weak electricity demand growth.[53] Approximately 2 GW was commissioned for a total exceeding 10.7 GW, although not all was grid-connected by year's end, due to a lack of transmission lines and to the slow pace of construction.[54] Brazil met 5.7% of its electricity demand with wind power in 2016.[55] The cancellation of December's auction made this the first year since 2009 that Brazil did not procure renewable power; as a result, wind equipment manufacturers were seeing idled capacity in early 2017.[56]

Other countries in the region to add capacity included Chile (0.5 GW), which had a record year; Mexico (0.5 GW), which held its first auction in 2016; Uruguay (0.4 GW); and Peru (0.1 GW).[57] Both Chile and Uruguay passed the 1 GW mark for total capacity.[58] Argentina brought no capacity online but built up a solid pipeline of more than 1.4 GW over the year in response to tenders.[59]

The African market was smaller than in 2014 and 2015, with South Africa adding only 0.4 GW for a total approaching 1.5 GW.[60] Morocco auctioned 850 MW of wind projects at record-low prices, and construction continued on Kenya's Lake Turkana project.[61] The Lake Turkana project (310 MW) is the single largest private investment in Kenya's history to date and, upon commissioning in 2017, will represent approximately 15% of the country's generating capacity and will be Africa's largest wind farm.[62]

There was little activity in the Oceania region during the year. Australia added only 140 MW for a total of 4.3 GW.[63] In the Middle East, Kuwait was constructing a 10 MW wind farm during 2016, and, in early 2017, Saudi Arabia commissioned its first utility-scale turbine and announced a 400 MW tender.[64]

Offshore, about 2.2 GW of capacity was connected to grids (and 9 MW decommissioned) in 2016, for a world total approaching 14.4 GW.[65] As in previous years, Europe was home to the majority of capacity brought online (1.6 GW; 70% of global additions) and total operating offshore (12.6 GW; almost 88%).[66] *(→ See Figure 28.)* Germany (0.9 GW), the Netherlands (0.7 GW) and the United Kingdom (56 MW) were the only European countries to add capacity offshore, although several gigawatts of projects were under construction in European waters at year's end, driven by rapidly falling costs.[67]

China accounted for most of the remainder (adding 0.6 GW), driven in part by limited potential for further onshore deployment in the country's northern and western regions.[68] Even so, development is proceeding relatively slowly, and China remains far short of its original target of 5 GW by 2015 (pushed to 2020 in 2016).[69] The Republic of Korea and the United States both completed their first commercial offshore wind farms (30 MW each), and Japan connected a single (7 MW) floating turbine.[70] The US offshore industry has advanced relatively slowly for several reasons, including a complex regulatory environment and higher relative costs; however, as of late 2016, several gigawatts of additional capacity were in various stages of development.[71]

In terms of total offshore capacity, the United Kingdom maintained its lead, with almost 5.2 GW at year's end, followed by Germany (4.15 GW), China (1.9 GW), which overtook Denmark (1.3 GW), and the Netherlands (1.1 GW), which passed Belgium (0.7 GW).[72]

Offshore and on land, independent power producers (IPPs) and energy utilities remained the most important clients in terms of capacity under construction and in operation, but interest increased in other sectors.[73] Corporations continued to purchase wind power from utilities, signing PPAs or buying their own turbines to power operations to obtain access to reliable low-cost power.[74] By end-2016, US cumulative corporate PPA capacity exceeded 5.6 GW, and Europe's had reached 1 GW.[75] Sweden and Norway, for example, have seen a surge in demand for wind generation from insurance companies and large corporations.[76]

Community and citizen ownership of wind generation also expanded during 2016, but only slowly.[77] Spain's first community-owned wind project was under development; a project was completed in Australia; and Ontario (Canada's) first community-owned project achieved commercial operation.[78] Japan had an estimated 37 MW of community[i] wind power capacity at end-2016.[79] However, there is concern that policy changes – particularly transitions from FITs to tenders – are slowing the pace of development.[80]

Policies also have affected the market for small-scale[ii] turbines, which are used for a variety of applications, including defence, rural electrification, water pumping, battery charging and telecommunications, and increasingly to displace diesel in remote locations.[81] The global market grew 5-7% in 2015 (the latest data available), and total capacity was up an estimated 12-15%.[82] By year's end, more than 995,000[iii] small-scale turbines, or over 935 MW, were operating worldwide (up from 830 MW at end-2014).[83]

While most countries have some small-scale turbines in use, the majority of units and capacity operating at the end of 2015 was in China (415 MW), the United States (230 MW) and the United Kingdom.[84] Other leaders included Italy (59 MW) and Germany (26 MW), with Italy seeing a significant increase in 2016.[85] In response to obstacles such as policy changes and competition with solar PV, the top markets have contracted in recent years.[86] China has seen a steady decline since its 2009-2011 high, the UK market was down significantly in 2015, and the US market increased slightly in 2015 but was down substantially relative to 2013.[87] However, other markets such as Japan are starting to emerge.[88]

Repowering has become a billion-dollar market, particularly in Europe.[89] While most repowering involves the replacement of old turbines with fewer, larger, taller, and more-efficient and reliable machines, some operators are switching even relatively new machines for upgraded turbines (including software improvements).[90] During 2016, at least 721 turbines (totalling around 533 MW) were decommissioned, representing a significant increase in numbers and capacity over 2015.[91] Germany dismantled 242 turbines (262 MW), followed by Denmark, the United States, Finland, Canada, the United Kingdom, the Netherlands, Sweden and Japan.[92] In the United States, the extension of federal tax credits has incentivised repowering (and retrofitting) of existing assets, which enables owners to quality for another decade of credits.[93]

Wind power is playing a greater role in power supply in a growing number of countries. In 2016, wind energy covered an estimated 10.4% of EU demand and equal or higher shares in at least 11 EU member states, as well as in Uruguay and Costa Rica.[94] *(→ See Figure 29.)* At least 24 countries around the world met 5% or more of their annual electricity demand with wind power.[95] In the United States, utility-scale wind power represented over 5.5% of total electricity generation and accounted for more than 15% of generation in nine states, including Iowa (36.6%).[96] Two German states had enough wind capacity at year's end to meet over 86% of their electricity needs, and four had enough capacity to meet over 60% of their needs.[97] Globally, wind power capacity in place by the end of 2016 was enough to meet an estimated 4% of total electricity consumption.[98]

i Defined as having at least two of the following three criteria: a project is mostly, if not fully, locally owned; a community-based organisation controls voting; and the majority of social and economic benefits are distributed locally.

ii Small-scale wind systems generally are considered to include turbines that produce enough power for a single home, farm or small business (keeping in mind that consumption levels vary considerably across countries). The International Electrotechnical Commission sets a limit at approximately 50 kW, and the World Wind Energy Association (WWEA) and the American Wind Energy Association define "small-scale" as up to 100 kW, which is the range also used in the GSR; however, size varies according to the needs and/or laws of a country or state/province, and there is no globally recognised definition or size limit. For more information, see, for example, WWEA, *Small Wind World Report 2017* (Bonn: 2017), Summary, http://small-wind.org/wp-content/uploads/2014/12/SWWR2017-SUMMARY.pdf.

iii Total number of units does not include some major markets, including India, for which data were not available. Taking this into account, more than 1 million units are estimated to be operating worldwide, from WWEA, *Small Wind World Report 2017*.

WIND POWER INDUSTRY

The year saw several developments that could have significant implications (positive and negative) for the wind power industry in future years, including ratification of the Paris Agreement, the United Kingdom's vote to exit the EU, elections in key wind power markets and additional large energy companies entering the sector.[99] It was a good year for top turbine manufacturers, with several seeing their orders and revenue up over 2015.[100] Driven largely by competition with low-cost natural gas capacity and increasingly with solar PV, companies continued innovating in order to reduce prices and improve yields.[101]

Energy costs vary widely according to wind resource, regulatory and fiscal framework, the cost of capital and other local influences.[102] In 2016, the LCOE of wind energy continued to fall as know-how about siting and maintenance advanced, turbine production became more standardised, and turbine size, efficiency and capacity factors increased further.[103] There were record low bids in tenders in Chile, India, Mexico and Morocco, and prices fell rapidly in some offshore tenders in Europe (see below).[104] Onshore wind was the most cost-effective option for new grid-based power during 2016 in many markets, including Brazil, Canada, Chile, Mexico, Morocco, South Africa, Turkey, and parts of Australia, China, Europe and the United States.[105]

Even so, challenges remain, with wind power still vulnerable to policy changes or measures to protect fossil fuels in some countries.[106] In addition, as the amount of wind output and its share of total generation have increased, so have grid-related challenges in several countries. Challenges for wind power – both onshore and offshore – include lack of transmission infrastructure, delays in grid connection, lack of public acceptance, and curtailment where regulations and current management systems make it difficult to integrate large amounts of variable renewables.[107] *(→ See Feature chapter.)* Curtailment in China cost the country's industry significant revenue in 2016.[108]

Most wind turbine manufacturing takes place in China, the EU, India and the United States, and the majority is concentrated among relatively few players.[109] In 2016, Vestas (Denmark) retook its lead from Goldwind (China), due largely to its strong year in the US market.[110] GE (United States) rose one step to take second place, followed closely by Goldwind (down two), with Gamesa (Spain; up one) and Enercon (Germany; up one) rounding out the top five.[111] Others in the top 10 were Siemens and Nordex Acciona (both Germany), followed by United Power, Envision and Mingyang (all China).[112] *(→ See Figure 30.)* Goldwind and other top Chinese companies lost ground due mainly to their heavy reliance on the domestic market.[113] Vestas was the most globalised supplier in 2016, with installations in 34 countries.[114]

The world's top 10 turbine manufacturers captured 75% of the 2016 market.[115] However, components are supplied from many countries: blade manufacturing, for example, has shifted from Europe to North America, South and East Asia and, most recently, Latin America and North Africa, to be closer to new markets.[116]

In response to increasing demand for wind power technologies and projects, turbine suppliers and project developers expanded or opened new factories and offices around the world. In the United States, at least seven companies enlarged existing manufacturing plants.[117] To support the European offshore industry, Siemens opened a new blade plant in England and broke ground on a nacelle factory in Germany.[118] The company also finalised an agreement to build a rotor blade manufacturing factory in Morocco.[119] Senvion (Germany) opened regional subsidiaries in Japan and India; Innogy (RWE; Germany) moved into Ireland to build an onshore portfolio, and DONG (Denmark) opened an office in Chinese Taipei to develop offshore projects.[120]

Companies expanded their scale and reach through some important mergers and acquisitions, and consolidation continued across the value chain.[121] Nordex completed its acquisition of Acciona Windpower, which was well-positioned in emerging markets, to form a new major player.[122] In June, the merger between Siemens and Gamesa was confirmed (and cleared by

the EU in early 2017), creating the world's largest wind power company in terms of capacity in operation.[123] Later in the year, Siemens-Gamesa announced plans to purchase French nuclear firm Areva's share of Adwen (Germany), a player in the offshore industry.[124] To gain assets upstream, GE acquired LM Wind Power (Denmark), a blade manufacturer that has supplied blades to most of the world's top turbine manufacturers; Senvion acquired blade manufacturer Euros Group (Germany); Nordex purchased SSP Technology (Germany), a developer and manufacturer of rotor blade moulds; and Vestas acquired Availon (Germany) to expand its service business.[125] Several state-owned Chinese companies acquired assets around the world, and Electricité de France (EDF) became the first European wind operator to enter the Chinese market when it acquired UPC Asia Wind Management.[126]

The wind industry also showed growing interest in hybrid installations, particularly with solar PV. By the end of 2016, four of the world's top turbine companies – GE, Gamesa, Goldwind and Mingyang – had entered the solar industry.[127] Some companies were developing locally integrated solar PV-wind hybrid projects during the year, and Suzlon (India) and Gamesa both announced plans to increase their focus on wind-solar hybrids, which can strengthen a plant's generation profile and enable sharing of resources for construction and maintenance.[128] Hybrid projects that include storage technologies also are being developed.[129] Early in 2016, Gamesa unveiled a hybrid solar-wind-diesel system with energy storage for the off-grid sector.[130]

At the same time, non-wind companies are moving (back) further into the wind power sector. During 2016, Shell (Netherlands), Statoil (Norway) and Keystone (United States) leveraged their expertise in offshore oil into offshore wind energy development; Swedish utility Vattenfall, which started with coal, had more offshore wind power capacity than coal-fired power capacity by year's end; and DONG Energy announced that it was selling its core oil and gas business to focus on offshore wind power.[131] In addition, China General Nuclear Power acquired 14 Irish wind farms from Gaelectric, and Russian state-owned nuclear company Rosatom entered the wind energy market with plans to develop a 610 MW project pipeline.[132]

Wind energy technology continued to evolve, driven by mounting global competition; by the need to improve the ease and cost of turbine manufacturing and transportation; by the need to optimise power generation at lower wind speeds; and increasingly by demanding grid codes to deal with rising penetration of variable renewable sources.[133]

The industry refined materials and design, as well as O&M regimes – particularly for blade tips, which undergo much wear and tear. To reduce logistical challenges and costs of transport, and to increase use of local labour, innovations have included two-part blades, nesting towers and portable concrete manufacturing facilities for tower construction.[134] Siemens unveiled a low-noise blade add-on, inspired by the silent flight of owls, and Vestas began testing its four-rotor concept turbine, which aims to reduce transportation requirements and to minimise structural costs.[135]

Digitalisation continued in an effort to provide better quality of and access to data for siting and design, performance management, and trading and balancing of output.[136] GE introduced new software applications for its digital ecosystem, released in 2015; other major manufacturers, including Vestas and Envision, launched advanced data analytics packages; and Goldwind introduced a 3 MW platform with smart turbine controls.[137]

To boost output, the general trend continued towards larger machines – including longer blades, higher hub heights and, in particular, larger rotor sizes.[138] Such changes have driven capacity factors significantly higher within given wind resource regimes, creating further opportunities in established markets as well as new ones.[139] For example, average capacity factors for all operational wind farms in Brazil increased from 38.8% in 2015 to over 40.9% in 2016, as new projects with better technology came online.[140]

Manufacturers raced to launch larger turbines during 2016, with new machines released or announced by several companies, including Enercon, GE, Nordex and Senvion for onshore, and Siemens and MHI Vestas for offshore.[141] Increasingly, large manufacturers are developing new turbine options based on tested and well-proven existing platforms, which enables them to more easily develop turbines for specific markets while also minimising costs.[142]

Not surprisingly, capacity ratings also climbed in 2016: the average size turbine delivered to market was up 6.4% over 2015, to 2.16 MW.[143] By region, average turbine sizes were highest in the Middle East and the Commonwealth of Independent States (2.8 MW), due to the installation of several 3.3 MW machines, followed by Europe (2.7 MW), Latin America (2.3 MW), North America (2.2 MW), and Africa and Oceania (both below 2 MW).[144] Turbines in the 2-2.5 MW size range accounted for nearly two-thirds of global supply in 2016.[145]

Offshore, the need to reduce costs through scale and standardisation has driven up sizes of turbines as well as of projects.[146] In Europe, the average capacity of new turbines

under construction offshore was 4.8 MW, up 15% relative to 2015 and 62% larger than a decade ago; the average size of turbines ordered in the second half of 2016 was 7.7 MW.[147] Vestas, Siemens, GE and Adwen all had 8 MW turbines on the market or nearly commercialised by year's end, and the first 8 MW turbines to be installed offshore were grid-connected in 2016.[148] In early 2017, MHI Vestas Offshore Wind unveiled an up-rated version of its 8 MW turbine that can achieve a rated power of 9 MW; the turbine's swept area is larger than the London Eye ferris wheel.[149]

The offshore wind industry differs technologically and logistically from onshore wind.[150] Siemens was the leading offshore turbine supplier in 2016, accounting for nearly 67% of added capacity, followed by Shanghai Electric Wind Power Equipment, or Sewind (China; 24.6%); considering all capacity operating globally by year-end, Siemens and MHI Vestas combined had supplied nearly three-fourths of the total.[151] DONG Energy (Denmark) was the largest owner, accounting for more than 16% of cumulative offshore installations in Europe, followed by Vattenfall, E.ON and Innogy.[152] During the year, GE moved into the offshore marketplace, and European developers, including DONG, were positioning to play a role offshore in the United States.[153]

The offshore industry continued to move farther out and into deeper waters, and the average size of projects under construction continued to rise.[154] Substructures are evolving to help reduce project costs and logistical challenges. Although the majority of turbines installed off Europe in 2016 continued to stand on monopiles (88%), followed by jackets (12%), a wide array of foundations is in demonstration and development.[155] Siemens, for example, is developing a hybrid gravity-jacket concept.[156] The industry also continued to develop floating turbines (anchored by mooring systems), adapted from deep water oil and gas drilling rigs.[157] In 2016, Japan added a turbine to its demonstration project off the coast of Fukushima, making it the largest floating project to date, and France awarded tenders for pilot plants.[158] A commercial project using Statoil's Hywind design off the Scottish coast was under development during the year, and, in early 2017, projects using floating turbines were announced or granted consent in Ireland, Japan and Scotland.[159]

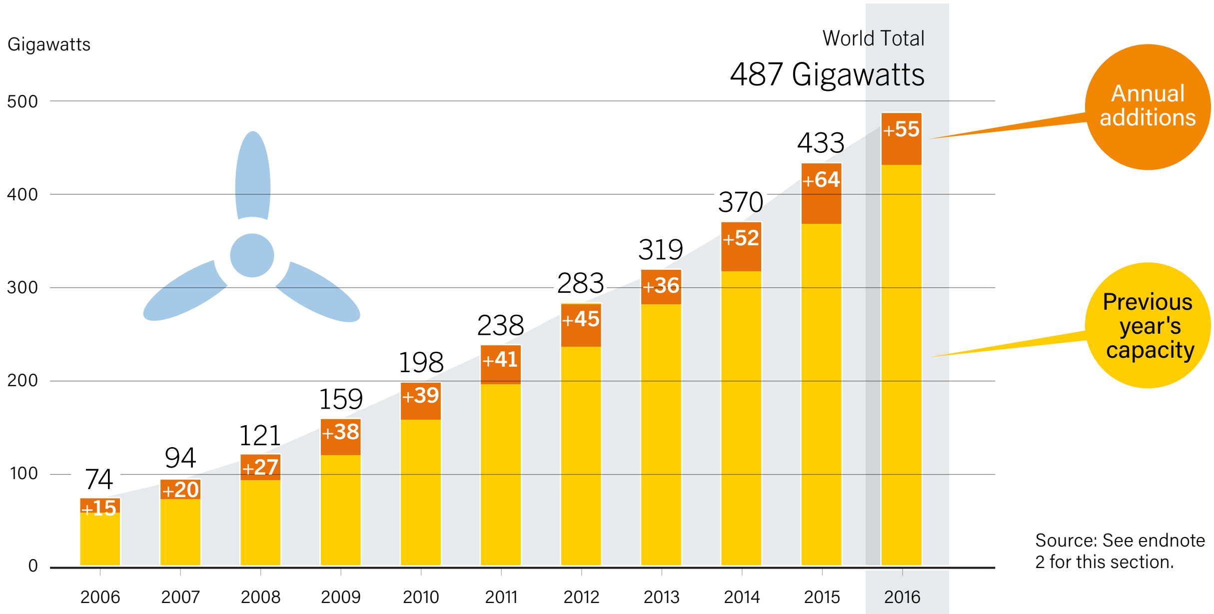
Other significant advances in 2016 included the installation of DONG Energy's advanced BEACon radar system, developed by SmartWind Technologies (United States), which provides minute-by-minute three-dimensional data of wind as it flows through a wind farm or stretch of sea. The radar can provide valuable insights to inform the siting, design and operation of future offshore projects.[160] In addition, Siemens launched a customised transport vessel that allows for rolling nacelles on and off deck, avoiding the need for crane operations.[161]

The economics of offshore wind power have improved far faster than experts expected, driven down rapidly by a combination of economies of scale achieved by larger turbines and large projects; increased competition among developers; increased experience, which reduces operating costs; technical improvements with turbines, installation processes, grid connection, and maintenance strategies and logistics; and lower cost of capital due to reduced perception of risk in financial markets.[162]

In June 2016, nine European countries agreed to co-operate on offshore wind power through joint tenders. The same day, 11 companies signed an open letter calling for a stable legal framework and aiming to produce offshore wind power more cheaply than coal within the decade: for less than EUR 80 per MWh (USD 84 per MWh as of end-2016) per project by 2025.[163] The industry moved closer to these targets during the year, and tenders in late 2016 brought record low bids for projects off the Danish and Dutch coasts: between EUR 50 per MWh and EUR 72 per MWh GBP 100 per MWh (USD 123 per MWh), excluding grid-connection costs.[164] By one estimate, the industry achieved a 2012 UK government goal – to reduce the offshore LCOE by one-third, to GBP 100 per MWh (USD 123 per MWh) by 2020 – four years ahead of schedule.[165]

WIND POWER

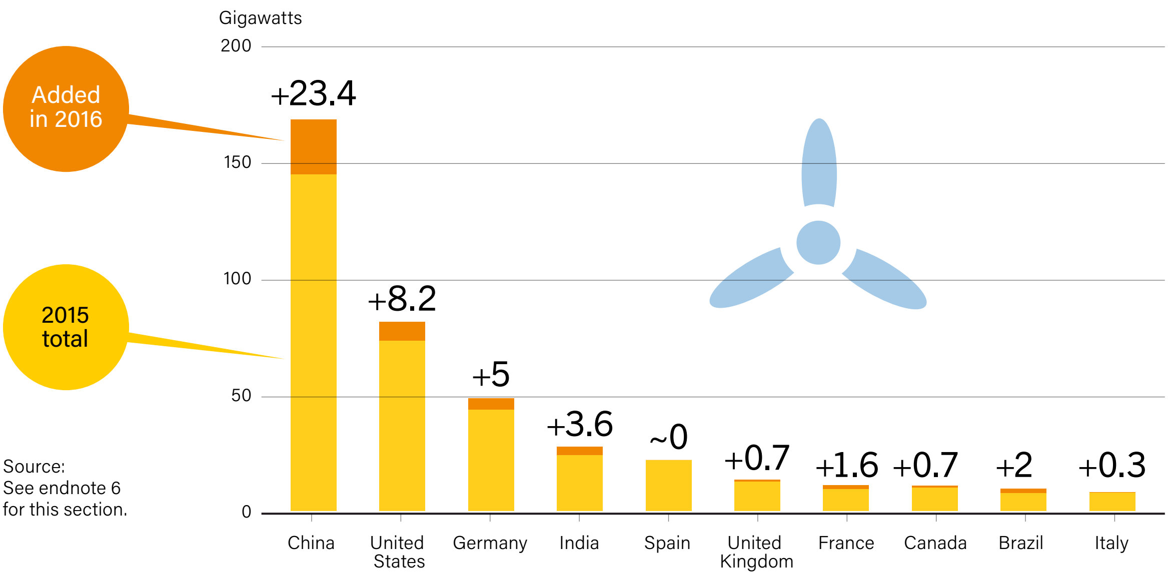
Figure 26. Wind Power Global Capacity and Annual Additions, 2006-2016



Source: See endnote 2 for this section.

By the end of 2016, **OVER 90 COUNTRIES** had seen commercial wind activity, and **29 COUNTRIES** had more than 1 GW in operation.

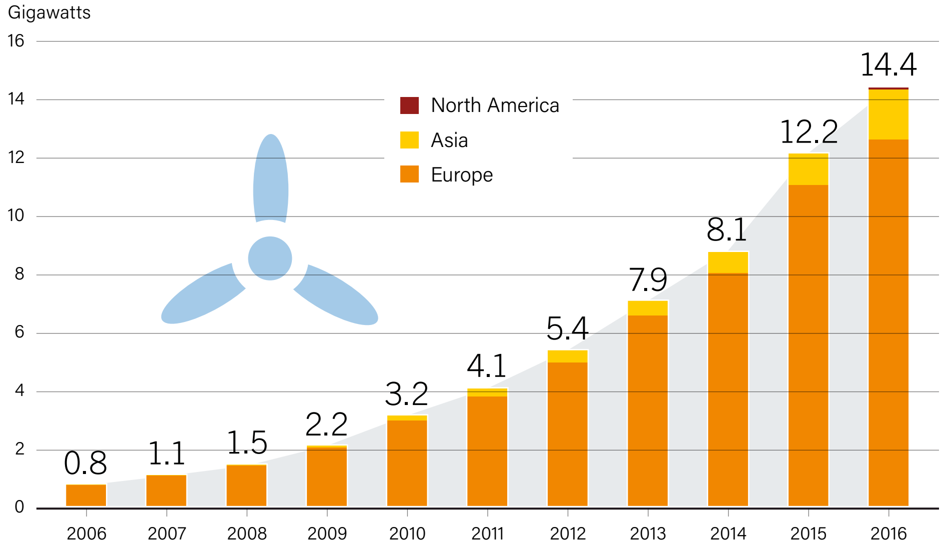
Figure 27. Wind Power Capacity and Additions, Top 10 Countries, 2016



Source: See endnote 6 for this section.

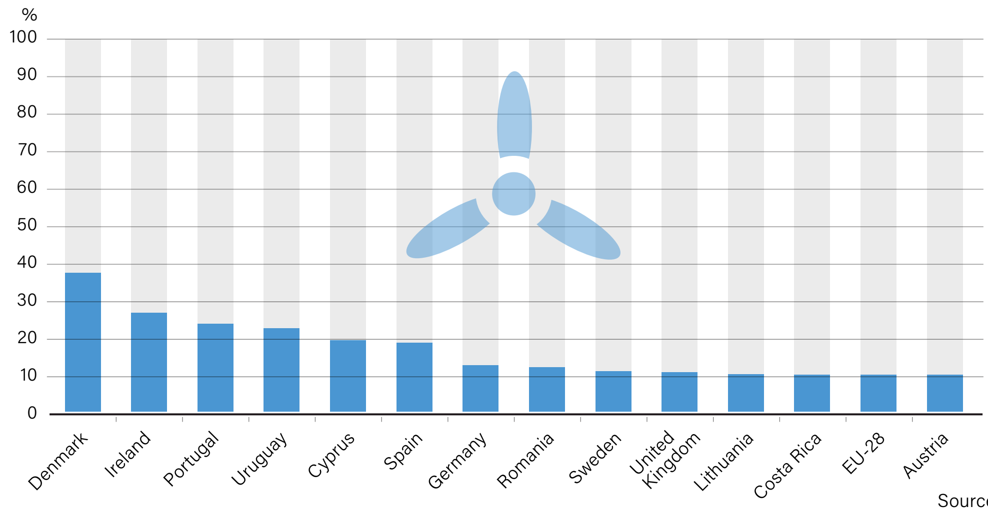
Note: Germany's additions are net of decommissioning and repowering. "~0" denotes capacity additions of less than 50 MW.

Figure 28. Wind Power Offshore Global Capacity, by Region, 2006-2016



Source: See endnote 66 for this section.

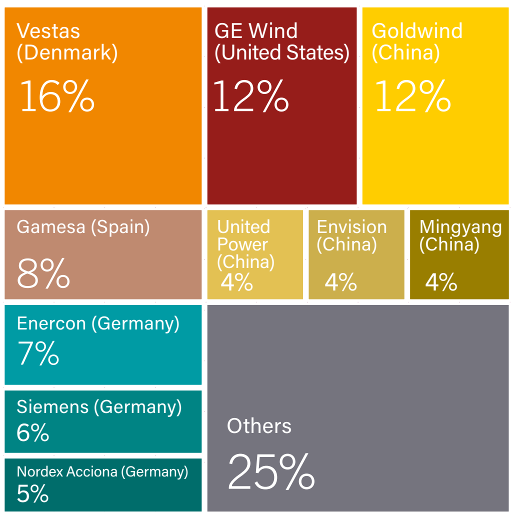
Figure 29. Share of Electricity Demand Met by Wind Power, Selected Countries with over 10% and EU-28, 2016



WIND has become the **LEAST-COST** option for new power generating capacity in an increasing number of markets.

Source: See endnote 94 for this section.

Figure 30. Market Shares of Top 10 Wind Turbine Manufacturers, 2016



Source: FTI Consulting. See endnote 112 for this section.

Note: Total exceeds 100% due to rounding.

Small-scale wind turbine costs also are trending downwards, while capacity factors are rising.[166] To increase the competitiveness of small-scale wind, several leading US companies have begun offering long-term leases to build on the success of third-party financing for solar PV.[167] In 2016, Statoil and United Wind (United States) announced a joint venture, securing Statoil's entry into the US small-scale and distributed wind market; and Northern Power Systems announced that it was partnering with LFC Capital (both United States) to offer a lease programme.[168] Other companies are building, owning and operating on-site turbines and selling power through PPAs.[169]

China, Germany, the United Kingdom and the United States account for a large portion of small-scale turbine manufacturers; aside from China, developing countries still play a minor role.[170] Even so, the number of producers in China and the United States has declined significantly in recent years.[171] Endurance Wind Power (Canada) filed for bankruptcy in 2016, after UK FIT cuts reduced demand in the company's primary market.[172] US manufacturers continued to rely heavily on export markets; US exports doubled (to 21.5 MW) from 2014 to 2015 (latest available data) and accounted for 83% of sales (up from 29% in 2010).[173] Chinese manufacturers also rely on international markets, mainly developed countries, for larger machines (e.g., 20-30 kW).[174]

→ *See Sidebar 2 and Table 2* on the following pages for a summary of the main renewable energy technologies and their characteristics and costs.[175]

SIDEBAR 2. Renewable Power Technology Cost Trends, 2010-2016

Among the most transformative events of the current decade has been the dramatic, and sustained, improvement in the competitiveness of renewable power generation technologies. Around the world, renewables have benefited from a cycle of falling costs spurred on by accelerated deployment, and the competiveness of renewable power generation technologies continues to improve. Bio-power, hydropower, geothermal and onshore wind power all can be competitive with fossil fuel-fired power generation where good resources exist.

Of all renewable energy technologies, utility-scale (larger than 1 MW capacity) solar PV has experienced the most rapid decline in the levelised cost of electricity (LCOE), driven by reductions in module prices and balance of systems costs[i]. Between 2010 and 2016, the global weighted average total installed cost of commissioned utility-scale solar PV projects fell by 65%, with the LCOE falling by 67% over the period. Projects commissioned in 2016 had an average LCOE of around USD 0.12 per kWh, and a range of USD 0.05 per kWh to USD 0.35 per kWh[ii]. Costs vary by region, with the 2016 weighted average LCOE of utility-scale solar PV at USD 0.09 per kWh in China and India (down 68% from 2010), USD 0.14 per kWh in OECD countries (down 61% from 2010) and USD 0.17 per kWh elsewhere (down 57% from 2011). *(→ See Table 2.)* LCOE ranges have narrowed significantly across all regional groupings, and there is evidence of acceleration in the convergence of solar PV installed costs towards the most competitive levels.

Onshore wind power has undergone a quiet revolution over the years. During the period 1983 to 2016, and considering the 12 countries that accounted for 87% of deployment, the LCOE dropped by an average of 15% for each doubling of installed capacity. The weighted average investment cost of onshore wind declined by more than two-thirds, from USD 4,880 per kW in 1983 to USD 1,457 per kW in 2016, due to increasing economies of scale and to improvements in manufacturing and technology. Due in large part to technology advances, the global weighted average capacity factor for onshore wind power rose from 20% in 1983 to 29% in 2016.

The global weighted average LCOE of onshore wind power fell by 18% between 2010 and 2016 alone, to USD 0.07 per kWh for wind farms commissioned in 2016. Onshore wind power has seen a significant convergence in average LCOEs across regions, despite differences in regional cost structures, market sizes and technical skills, and varying dynamics in supply chains. China and India have some of the world's lowest total installed costs, resulting in a weighted average LCOE of USD 0.065 per kWh in 2016 (down 7% from 2010); average LCOEs were higher in OECD countries (USD 0.074 per kWh; down 26% from 2010) and in the rest of the world (USD 0.083 per kWh; down 29% from 2010).

Offshore wind power costs, in general, are higher than for other renewable power generation technologies. However, they are falling due to several factors – including technology advances and economies of scale – and good cost reduction opportunities remain. In OECD countries, where most offshore wind capacity is deployed, the average LCOE of projects commissioned in 2016 was estimated at USD 0.15 per kWh. In China the LCOE of projects under construction or commissioned is estimated to average USD 0.16 per kWh (down 4% from 2010) – a bit higher than in Europe, even though projects are in shallower water and closer to shore. In 2016, where appropriate de-risking of projects had occurred, some PPAs and tenders for future projects were signed at much lower prices. This development highlights the likely impact of lower-than-average financing costs and technology improvements (notably the very large wind turbines being planned for new offshore projects).

CSP costs also remain higher than those for other renewable power generation options on average, but they have good cost-reduction opportunities, and costs are falling. It is estimated that the weighted average LCOE of CSP plants fell by 18% between 2010 and 2016, with an LCOE of USD 0.27 per kWh for plants commissioned in 2016.

LCOEs of the more mature renewable power generation technologies – bio-power, geothermal and hydropower – have been broadly stable, with some short-term exceptions. For example, the global weighted average LCOE of geothermal and hydropower rose between 2010 and 2016. The weighted average total installed cost of hydropower projects reached USD 1,755 per kW (weighted average LCOE of USD 0.05 per kWh) for plants commissioned in 2016, more than offsetting an increase since 2010 in the weighted average capacity factor of new plants.

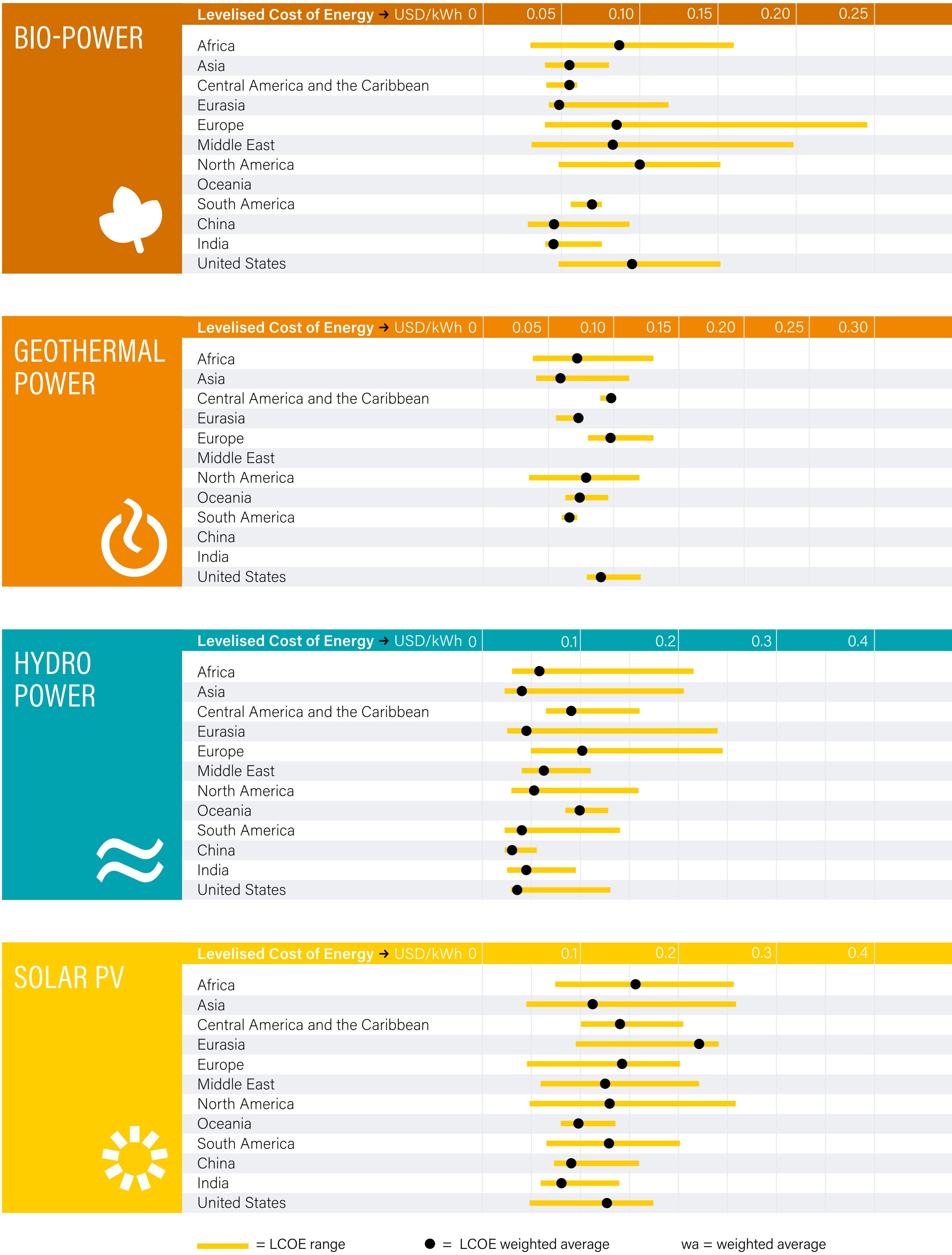
Further research is needed to identify the reasons for these increases, although the small sample size in the case of geothermal power means that the increase is not statistically significant. Even taking into account these average price increases, however, these mature technologies can provide some of the lowest-cost electricity of any source where untapped and economical resources remain.

i Between 2010 and 2016, module price reductions (of 80% or more) accounted for almost 60% of the decline in the global weighted average LCOE of utility-scale solar PV, and balance of systems cost reductions accounted for the remainder.

ii Assumes a real weighted average cost of capital of 7.5% in the OECD and China, and 10% in all other countries. This differentiation reflects the very wide range of costs between established markets with good civil engineering capabilities and excellent solar resources, and other locations with much more challenging logistics and poorer solar resources.

Source: IRENA. See endnote 175 of Wind Power section in this chapter.

Table 2. Status of Renewable Energy Technologies: Costs and Capacity Factors



Investment Cost → USD	min	max	wa	Capacity Factor →	min	max	wa
Africa	625	5579	● 1654		0.45	0.91	● 0.62
Asia	865	3334	● 1318		0.63	0.9	● 0.67
Central America and the Caribbean	534	7805	● 1666		0.27	0.63	● 0.6
Eurasia	1344	7106	● 1756		0.71	0.96	● 0.83
Europe	956	7599	● 3423		0.45	0.93	● 0.86
Middle East	885	4272	● 2895		0.29	0.93	● 0.57
North America	868	7375	● 3666		0.16	0.93	● 0.78
Oceania							
South America	1200	1666	● 1433		0.21	0.94	● 0.53
China	542	6082	● 1215		0.21	0.95	● 0.62
India	865	2113	● 1043		0.63	0.9	● 0.77
United States	1668	7375	● 4135		0.89	0.96	● 0.93

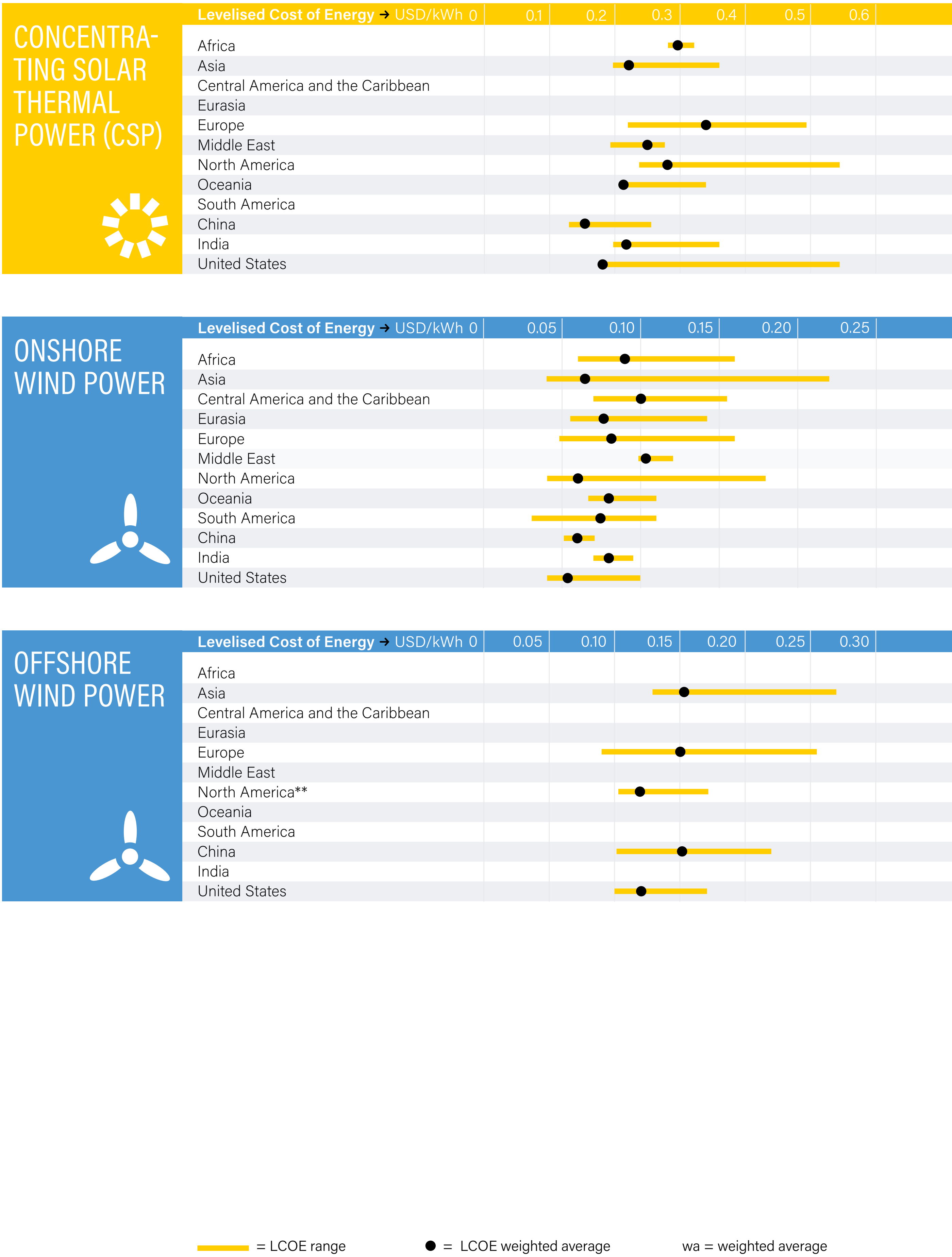
Investment Cost → USD	min	max	wa	Capacity Factor →	min	max	wa
Africa	1719	7689	● 3818		0.8	0.92	● 0.84
Asia	2047	5045	● 3116		0.58	0.9	● 0.85
Central America and the Caribbean	3260	3537	● 3413		0.57	0.6	● 0.58
Eurasia*	2613	3278	● 3113		0.8	0.8	● 0.8
Europe	3613	8919	● 5209		0.6	0.8	● 0.66
Middle East							
North America	2029	8353	● 5017		0.74	0.92	● 0.83
Oceania*	3303	4676	● 3796		0.8	0.8	● 0.8
South America	3027	4348	● 3587		0.8	0.95	● 0.82
China	1501	9722	● 1943				
India	1501	7475	● 2169				
United States	2941	8353	● 5961		0.74	0.9	● 0.79

Investment Cost → USD	min	max	wa	Capacity Factor →	min	max	wa
Africa	920	6730	● 1593		0.3	0.65	● 0.43
Asia	483	7553	● 1446		0.16	0.81	● 0.47
Central America and the Caribbean	1650	4474	● 3230		0.32	0.57	● 0.53
Eurasia	1111	5934	● 1530		0.3	0.72	● 0.54
Europe	570	5388	● 1847		0.16	0.7	● 0.38
Middle East	1238	1656	● 1526		0.2	0.76	● 0.36
North America	1051	5195	● 2309		0.38	0.78	● 0.49
Oceania	3470	4119	● 3689		0.39	0.48	● 0.45
South America	799	5743	● 1755		0.49	0.91	● 0.61
China	971	2581	● 1273		0.32	0.6	● 0.5
India	1014	2556	● 1519		0.25	0.81	● 0.44
United States	723	6757	● 1384		0.38	0.78	● 0.39

Investment Cost → USD	min	max	wa	Capacity Factor →	min	max	wa
Africa	818	6848	● 2344		0.14	0.28	● 0.2
Asia	832	6124	● 1414		0.1	0.25	● 0.16
Central America and the Caribbean	1337	4000	● 2001		0.16	0.23	● 0.19
Eurasia	1484	3697	● 2537		0.1	0.18	● 0.14
Europe	944	2827	● 1370		0.1	0.3	● 0.12
Middle East	1311	4000	● 2554		0.17	0.35	● 0.26
North America	965	5900	● 2203		0.12	0.34	● 0.2
Oceania	1600	2785	● 2477		0.2	0.25	● 0.23
South America	1407	4951	● 2477		0.12	0.34	● 0.24
China	1022	1953	● 1083		0.17	0.19	● 0.17
India	916	1832	● 1064		0.16	0.22	● 0.19
United States	1241	2971	● 1998		0.16	0.32	● 0.19

Source: IRENA. See endnote 175 of Wind Power section in this chapter.

Table 2. Status of Renewable Energy Technologies: Costs and Capacity Factors (continued)



Investment Cost → USD	min	max	wa	Capacity Factor →	min	max	wa
Africa	7164	11300	● 8392		0.36	0.53	● 0.4
Asia	3501	13693	● 4423		0.17	0.54	● 0.28
Central America and the Caribbean							
Eurasia							
Europe	4811	17341	● 8839		0.15	0.63	● 0.31
Middle East	3491	4097	● 3705		0.19	0.26	● 0.22
North America	4714	9009	● 6794		0.18	0.41	● 0.3
Oceania	9735	10767	● 9829		0.11	0.23	● 0.12
South America							
China*	2550	7800	● 3004		0.17	0.28	● 0.26
India	3539	7475	● 4328		0.21	0.54	● 0.28
United States	4714	9009	● 6794		0.18	0.41	● 0.3

Investment Cost → USD	min	max	wa	Capacity Factor →	min	max	wa
Africa	1345	2506	● 1924		0.19	0.48	● 0.37
Asia	909	2784	● 1263		0.13	0.46	● 0.25
Central America and the Caribbean	1680	3265	● 2144		0.24	0.54	● 0.35
Eurasia	1315	2651	● 1891		0.24	0.49	● 0.35
Europe	1054	3702	● 1866		0.14	0.51	● 0.28
Middle East	1857	3148	● 2531		0.29	0.4	● 0.34
North America	1270	3148	● 1805		0.17	0.52	● 0.39
Oceania	1600	3581	● 2150		0.3	0.44	● 0.35
South America	1108	2903	● 1912		0.27	0.54	● 0.43
China	1166	1414	● 1244		0.23	0.29	● 0.25
India	1044	1420	● 1120		0.19	0.33	● 0.24
United States	1481	2445	● 1715		0.23	0.5	● 0.4

Investment Cost → USD	min	max	wa	Capacity Factor →	min	max	wa
Africa							
Asia	2787	4258	● 3286		0.20	0.31	● 0.26
Central America and the Caribbean							
Eurasia							
Europe	2053	6480	● 4207		0.27	0.55	● 0.36
Middle East							
North America**	2251	5063	● 2972		0.32	0.41	● 0.33
Oceania							
South America							
China	1890	4258	● 3083		0.23	0.29	● 0.26
India							
United States	2250	5063	● 2972		0.32	0.36	● 0.33

Source: IRENA. See endnote 175 of Wind Power section in this chapter.

* All projects indicate the same capacity factor.

** Includes estimates for projects with completion dates to 2018.

Note: All monetary values are expressed in USD_{2016}. LCOE is computed using a weighted average cost of capital of 7.5% for OECD countries and China and 10% for the rest of the world. For recent cost and characteristics data for heating and cooling, biofuels and distributed renewable energy technologies, see Table 2 in GSR 2015. The costs and analysis exclude subsidies and/or taxes. Regional groupings for this table only are defined in IRENA, *Renewable Power Generation Costs in 2014* (Abu Dhabi: 2015), www.irena.org/costs.

03

Capabilities in communication and control evolve continuously and offer new opportunities for flexibility. **INFORMATION AND COMMUNICATION TECHNOLOGIES (ICTs)** are at the heart of advanced energy supply, demand and grid management. ICT enable remote systems control and automation, utilising timely flow of information on system resources for the optimal moment-to-moment operation of the grid.

Telecommunication tower – Maasai Mara National Park, Kenya

03 DISTRIBUTED RENEWABLE ENERGY FOR ENERGY ACCESS

Distributed renewable energy (DRE)[i] systems are power, cooking, heating and cooling systems that generate and distribute services independently of any centralised system, in both urban and rural areas of the developing world. They already provide energy services to millions of people, and their numbers continue to increase annually.

DRE systems can serve as a complement to centralised energy generation systems, or as a substitute. They can provide affordable lighting, enhance communications, and facilitate greater quality and availability of education due to longer studying periods and the enhanced use of informational technologies in the classroom. They also can provide greater quality and availability of health services. In addition, the use of DRE systems and integration of renewables into existing mini-grids can reduce dependence on fossil fuel imports.

DRE systems offer an unprecedented opportunity to accelerate the transition to modern energy services in remote and rural areas, while also offering co-benefits[ii]. Although these co-benefits are diverse and difficult to value and monetise, they cut across the following dimensions:

- Cost savings when compared to the grid in many markets
- Fuel availability and/or stability and predictability of prices
- Modularity, flexibility and rapid construction times
- Faster technological learning curves and rates of improvement compared to fossil fuels
- Enhanced reliability and resilience
- Improved health through reductions in indoor air pollution
- Contribution to climate change mitigation
- Reductions in deforestation and in environmental degradation
- Positive effects on women's empowerment
- Reductions of poverty among vulnerable groups.[1]

This chapter provides a picture of the current status of DRE markets in developing countries and presents an overview of the major networks and programmes that were operational in 2016.

i See Sidebar 9 of GSR 2014 for more on the definition and conceptualisation of DRE.

ii "Co-benefits" refers to the positive side effects, secondary benefits, collateral benefits or associated benefits from a particular policy or renewable energy system. Akiko Miyatsuka and Eric Zusman, "What Are Co-benefits?" (Kanagawa, Japan: Asian Co-benefits Partnership, October 2010), http://pub.iges.or.jp/modules/envirolib/upload/3378/attach/acp_factsheet_1_what_co-benefits.pdf.

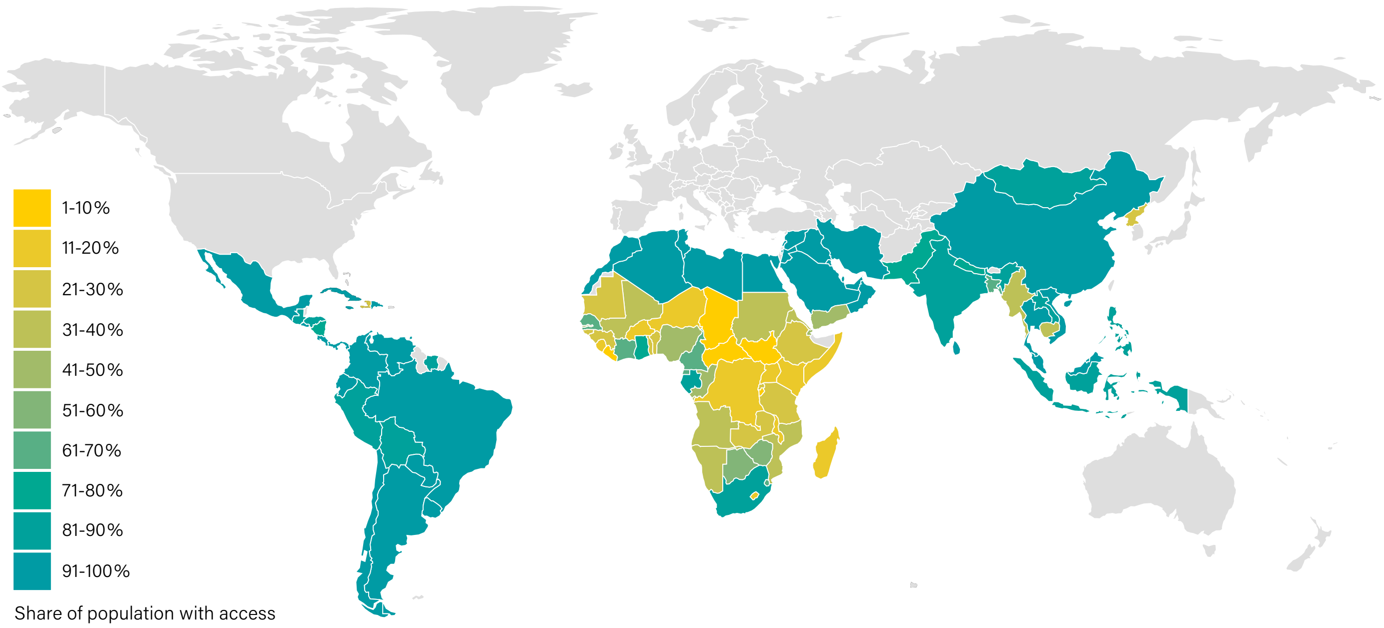
STATUS OF ENERGY ACCESS: AN OVERVIEW

Approximately 1.19 billion people (about 16% of the global population) lived without electricity in 2014, about 15 million people fewer than in 2013.[2] About 2.7 billion people (38% of the global population) are without clean cooking facilities.[3]

Numbers and trends differ greatly by region. The vast majority of people without access to electricity and clean cooking are in sub-Saharan Africa and the Oceania region, and most of them live in rural areas.[4] *(→ See Figures 31 and 32.)*

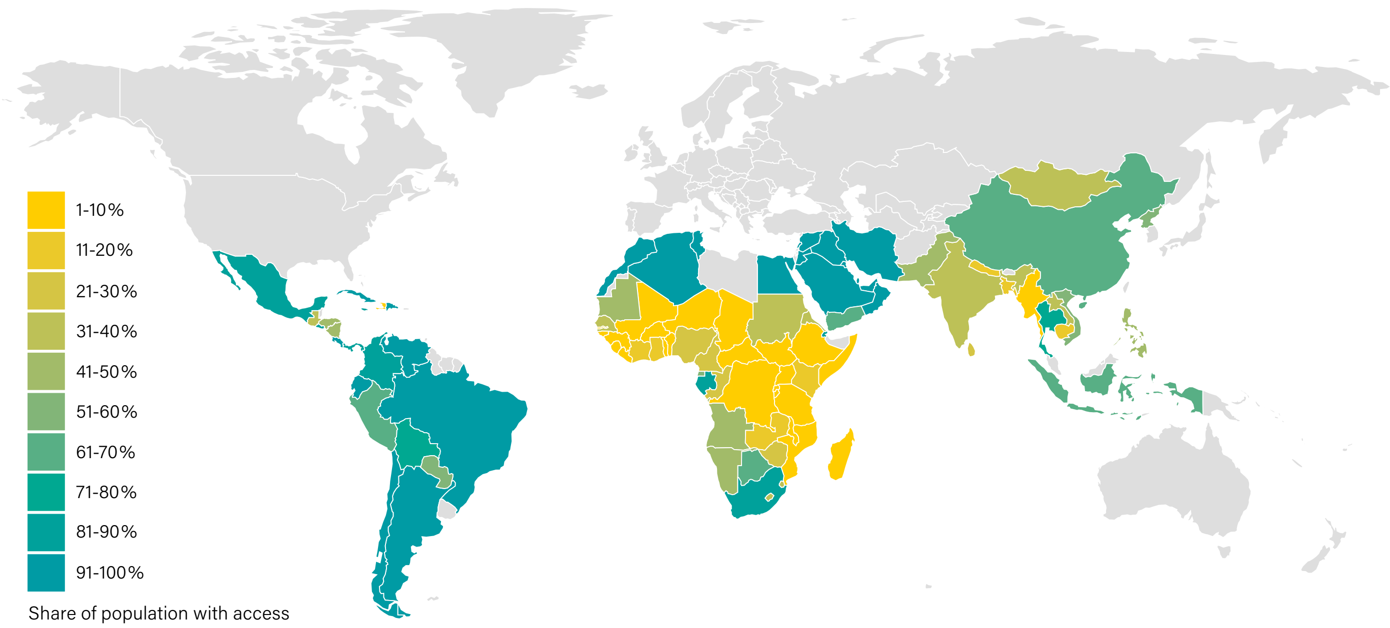
In Africa, nearly 60% of people have no access to reliable electricity.[5] To put these numbers in perspective, the entire continent of Africa has about 150 GW of installed power generating capacity, uses about 3% of the world's electricity (mostly within

Figure 31. Electricity Access in Developing Countries, 2014



Source: See endnote 4 for this chapter.

Figure 32. Access to Clean Cooking Facilities in Developing Countries, 2014



Source: See endnote 4 for this chapter.



South Africa) and accounts for only about 1% of the world's CO_2 emissions.[6] The official electrification rate for sub-Saharan Africa is 35%, and only 13 of the region's 38 countries have power systems larger than 1 GW.[7] With only 50 GW of installed capacity, the entire electricity supply of sub-Saharan Africa (excluding South Africa) is less than that of the Republic of Korea.[8]

In addition, about 793 million people (69%) in Africa lack access to clean cooking facilities, the vast majority of which (792 million) are concentrated in sub-Saharan Africa.[9] Roughly 134 million people in Nigeria, 92 million people in Ethiopia and 71 million people in the Democratic Republic of the Congo still rely on firewood, charcoal or dung for cooking purposes.[10]

In Asia, countries such as China, Malaysia and Singapore have made great strides towards electrification. Elsewhere in the region, however, comparatively high percentages of national populations remain without access to modern energy. India is home to more people without reliable access to electricity networks (244 million, or 19% of the population) than any other country worldwide.[11] Bangladesh has approximately 60 million people without electricity access (38% of the population), Pakistan has 51 million people (27%), and Indonesia has 41 million people (16%).[12] In Cambodia, 97% of the urban population has access to electricity, while only 18% of the rural population has access.[13] In addition, the number of people relying on firewood, dung cakes, charcoal or crop residue to meet their household cooking needs is more than 819 million (63%) in India, 453 million (33%) in China, 142 million (89%) in Bangladesh, 105 million (56%) in Pakistan and 97 million (38%) in Indonesia.[14]

Although the Middle East and Northern Africa regions have electrification rates of almost 92% and 99%, respectively, in some individual countries high shares of the population still lack access to modern energy.[15] In Yemen, 54% of the population (14 million people) does not have access to electricity, and 31% (8 million people) lacks access to modern cooking fuels and technologies.[16]

Similarly, in Latin America and the Caribbean, 95% of inhabitants have access to grid electricity; the 22 million people without access are concentrated largely in six countries: Bolivia, Colombia, Guatemala, Haiti, Nicaragua and Peru.[17] About 65 million people in the region (14% of the population) do not have access to clean forms of cooking.[18] In Haiti, 92% of the population is dependent on traditional cooking fuels and devices, while in Honduras, Guatemala and Nicaragua 50% or less of the population has access to clean cooking solutions.[19]

DISTRIBUTED RENEWABLE ENERGY TECHNOLOGIES AND MARKETS

People in rural and remote regions generally acquire improved access to energy in three ways: 1) through household-level use of isolated devices and systems to generate power and heat for space and water heating, cooking and productive uses; 2) through community-level or renewable energy-based mini- or micro-grid systems; and 3) through grid-based electrification, where the grid is extended beyond urban and peri-urban areas.

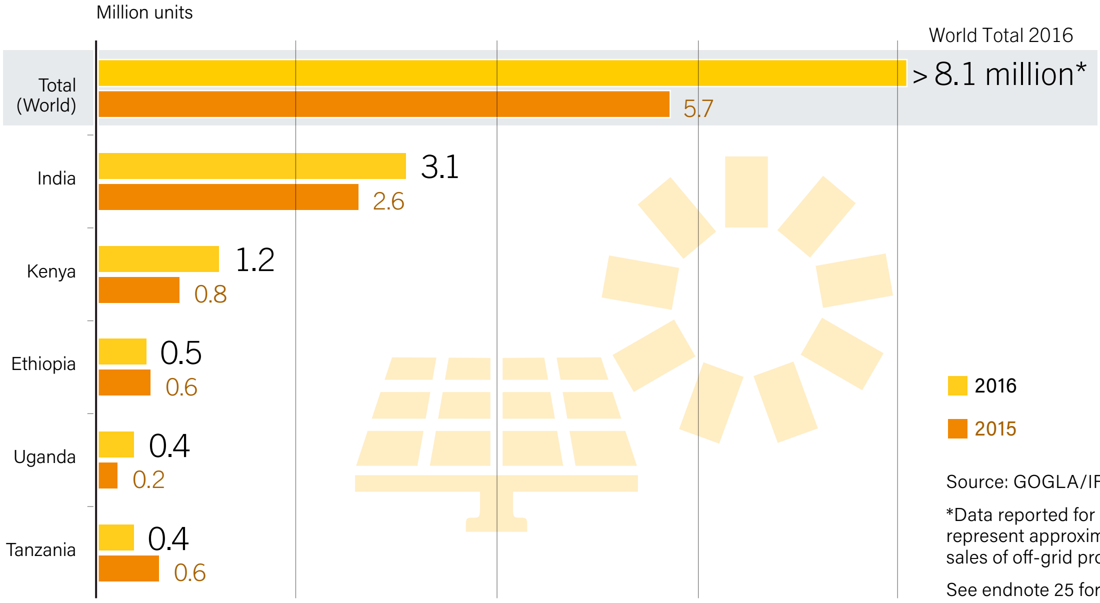
This section focuses on the first two (distributed) means of improving energy access and includes small-scale solar PV and stand-alone lighting systems; wind turbines; biodiesel generators and micro-and pico-hydro stations for electricity generation; mini-grids; and solar and biomass heating and cooling units and cooking devices. Distributed energy use varies by price, resource base and type of household, among other factors.[20]

In recent years, off-grid solar energy has been one of the fastest growing industries in providing energy access.[21] Between 2010 and 2016, about 23.5 million off-grid solar systems (pico-solar and solar home systems of less than 100 W) were sold worldwide, providing an array of services.[22] In 2016, nearly 8.2 million off-grid solar systems were sold, representing a global increase of 41% compared to 2015.[23] By 2016, more than 100 companies worldwide actively focused on stand-alone solar lanterns and solar home system (SHS) kits.[24]

Across the top five countries of the distributed solar industry, sales in India, Kenya and Uganda increased in 2016 compared to 2015, whereas sales in Ethiopia and Tanzania decreased.[25] *(→ See Figure 33.)* Sales were highest in sub-Saharan Africa, although sales in that region decreased by about 1 million in 2016 (35%) compared to 2015..[26]

Roughly 10% of the 600 million people living off-grid on the African continent are supplied with energy through DRE systems.[27] Eastern Africa accounted for an estimated 70% of sales of pico-PV and SHS in sub-Saharan Africa in 2016 .[28] In Kenya, more than 30% of people living off the grid have a solar product at home.[29] Several countries, including Benin, Nigeria and Rwanda, recorded sales exceeding 100,000 units in 2016.[30] Benin recorded more than five-fold growth, which may be attributed mainly to active government engagement and to the introduction of Pay-As-You-Go (PAYG) models.[31] In South-Central Asia, the second largest market for

Figure 33. Sales of Off-Grid Solar Systems in Top 5 Countries, 2015-2016



Source: GOGLA/IFC.

*Data reported for global sales represent approximately 50% of all sales of off-grid products.

See endnote 25 for this chapter.

distributed solar systems, sales increased 19% from 2015 to 2016, including record sales of 3.1 million off-grid solar products in India.[32]

The smallest distributed solar PV systems are pico-PV systems (1-10 W), which can power small lights, low-power appliances and mobile phone charging stations.[33] These systems typically decrease in size as the efficiency of appliances that use the generated power improves. Pico-PV systems replace kerosene lamps, candles and battery-powered flashlights and are the most widely used DRE technologies by far.[34]

Cumulative sales of branded pico-solar products (mainly portable lights) since 2010 surpassed 23 million units in 2016.[35] In 2016, more than 7.5 million pico-PV products were sold, representing 94% of all off-grid solar products sales; sub-Saharan Africa and South Asia together accounted for 81% of global sales (6.57 million units).[36] Products with a single light and mobile phone charging capability were the most-sold pico-PV products in the first half of 2016 and represented 38% and 41% of reported off-grid sales, respectively.[37]

Sales of small 3-10 W pico-solar systems are gaining momentum. In the first half of 2016, sales of these systems increased nearly five-fold to 750,000 units, from about 150,000 units in the second half of 2015.[38] In South Asia, sales grew 547%, from 35,000 units to 227,000 units.[39]

Solar home systems (10-500 W) generally consist of a solar module and a battery, along with a charge control device, so that direct current (DC) power is available during dark and cloudy periods. SHS provide electricity to off-grid households for lighting, radios, television, refrigeration and access to the Internet. Systems in this size range also can be used for non-domestic applications such as powering telecommunications, water pumping, navigational aids, health clinics, educational facilities and community centres. For higher power demands (e.g., 500-1,000 W), larger solar panels, additional battery capacity and inverters may be needed; the advantages of such systems lie in their ability to power more-sophisticated electric appliances.[40]

As of 2016, more than 6 million SHS and kits were in operation worldwide, with 25 million people benefiting from them.[41] Some 377,000 SHS (ranging from 10 W to 100-plus W) were sold worldwide in 2016; sales increased by more than 55% in the first half of 2016, to 204,000 units (compared to the 132,000 units sold from July to December 2015), and reached 172,000 units in the second half of 2016.[42] Market leaders such as M-KOPA, Off Grid Electric, d.Light, BBOXX, Nova Lumos and Mobisol served about 700,000 customers as of 2016.[43] Bangladesh – the largest SHS market worldwide – now has more than 4 million units installed. Off-grid SHS units are cost-competitive with the grid in many African countries and often offer energy services at equal or lower cost that are of better quality than lighting from kerosene lanterns.[44]

Small-scale wind turbines[i] (100 kW or less) often are used to produce electricity for farms, homes and small businesses; off-grid applications include rural electrification, water pumping, telecommunication and hybrid systems with diesel and solar PV. Total installed capacity reached 415 MW in China by the end of 2015, and limited amounts of small-scale wind power capacity operate in other developing countries, including Argentina, India and Morocco.[45]

i For definition of small-scale wind turbines, see Wind Power section in Market and Industry Trends chapter.

Biogas systems continued to be adopted for electricity provision in 2016. Natural oils from crops such as jatropha, and recycled agricultural or animal waste can produce a substitute fuel for diesel for power generation in small-scale applications, and agricultural residues (such as rice husks, straw, coconut husks, shell and maize stover) can be used for commercial-scale power generation. *(→ See Biomass Energy section in Market and Industry Trends chapter.)* At the end of 2015, at least 700,000 biogas digesters were in use across the developing world.[46]

During 2016, micro-hydropower systems (generally less than 100 kW; some micro-turbine systems produce 50-1,500 W) continued to be installed for off-grid applications, including irrigation, pumping and other forms of mechanical power as well as supplemental power sources for grid-connected users.[47] In Nepal, more than 2,500 micro-hydro-based mini-grid systems, with a total capacity of about 25 MW, had been installed as of early 2016.[48] In late 2016, the ADB announced plans to fund 1,000 micro-hydro plants in Pakistan's Khyber Pakhtunkhwa province.[49]

In tandem with exponential increases in access to electricity supply, the use of electric household appliances is growing. Televisions and space cooling and refrigeration units are seen as key preferences for households after satisfying basic lighting and communication needs.[50] Increasing the energy efficiency of these devices may have a positive impact on energy access.[51] *(→ See Sidebar 3.)*

The deployment of renewable mini-grids accelerated in 2016 as well, and this market now exceeds USD 200 billion annually.[52] Renewable mini/micro-grids are either emerging or mature in markets on almost every continent.[53] *(→ See Figure 34.)* Mini-grid projects are being implemented with an increasing interest in interconnection, both to centralised grids and/or to other mini-grids.[54]

More than 23 MW of mini/micro-grid projects based on solar PV and wind power were announced in 2016, most of them in Africa.[55] Madagascar partnered with Fluidic Energy to connect 100 remote villages (400,000 people) to electricity through a 7.5 MW solar PV-based mini-grid.[56] Kenya successfully secured financing to build 9.6 MW of solar-powered mini-grids and 0.6 MW of wind-powered mini-grids.[57] In 2016, a Tanzanian company launched the first of 30 hybrid mini-grids planned for a two-year period; the solar-diesel-power system, installed on Ukara Island, was expected to provide power to some 2,000 customers.[58] In Asia, more than 156 Indian households were connected to a solar mini-grid project in the Ghatpendhri region during 2016.[59]

The use of DRE systems for cooking and heating continued to

Figure 34. Status of Renewable Energy Mini/Micro-grid Markets, by Region

■ Limited
□ Pilots
■ Emerging
■ Mature

Region	Autonomous Basic	Autonomous Full	Interconnected Community
Central America and the Caribbean	Mature	Emerging	Emerging
South America	Mature	Emerging	Limited
Northern Africa	Mature	Emerging	Limited
Sub-Saharan Africa	Emerging, Mature	Emerging	Limited
Central and North Asia	Pilots, Emerging	Limited	Limited
East and South Asia	Mature	Pilots, Emerging, Mature	Emerging
Middle East	Limited	Pilots	Limited
Oceania	Mature	Emerging, Mature	Pilots

Source: See endnote 53 for this chapter.

Note: The figure provides an assessment of the maturity of the market, ranging from very few (limited), to isolated exploration (pilots), to developing market (emerging) to active deployment today (mature). Autonomous basic mini-grids refer to systems for which power is supplied for less than 24 hours and may be turned off when there is insufficient renewable energy to meet load. Autonomous full mini-grids refer to systems that can provide power on a 24-hour basis. Interconnected community mini-grids refer to systems that may be used as a back-up to the main grid, designed to sustain only the most critical loads, or that could be used to provide primary power, with the main grid as a back-up.

SIDEBAR 3. Energy Access and the Energy Efficiency Nexus

By reducing the amount of energy required to provide modern energy services, energy efficiency plays an important, and in some cases necessary, role in driving energy access. Although experience from the field is limited, evidence shows that energy efficiency can dramatically improve the economics of energy access by reducing the upfront investment and ongoing fuel costs and by improving system reliability and performance where existing supply resources fall short. By one estimate, the use of currently available energy efficiency measures could result in the delivery of universal access to modern energy services using 50-85% less energy than prevailing estimates say is required.

Energy efficiency enables distributed off-grid renewable energy systems – such as pico-PV, solar home systems and renewable mini-grids – to deliver energy services that otherwise might be economically or technically infeasible, especially for poor populations. Renewables already are the most economical option for off-grid electrification in many rural areas, thanks to dramatic cost reductions in recent years. Combining renewables with energy efficiency enables people to get the most out of every unit of energy, improving the affordability of a system to meet their given needs.

LED lighting and highly efficient televisions, fans, refrigerators and other appliances that are designed and optimised for use with off-grid renewable energy technologies deliver higher orders of energy service. Such super-efficient appliances may cost more than less-efficient alternatives, but their higher costs are offset by the lower upfront costs of the energy system (a smaller system is required, reducing costs by as much as 50%). Thus, these appliances reduce energy service costs over the lifetime of the entire appliance-energy system package.

In other words, by coupling high-efficiency products with smaller energy systems (such as solar PV and batteries), consumers can get the same or higher level of energy service at lower cost overall. In Bangladesh, meeting the same energy service needs with a 40 W solar home system rather than an 85 W system reduces costs from around USD 565 to USD 300.

In some cases, energy efficiency has led to significant advancements in energy access efforts. For example, the rapidly improving energy efficiency and falling costs of LED technology have helped to drive growth in the off-grid lighting market. Global sales of quality-assured LED systems exceeded 20.5 million units between mid-2010 and mid-2016.

Despite the vast potential for energy efficiency to improve energy access and sustainable development efforts, it is underutilised in both grid-connected and off-grid contexts. Key financial and political decision makers often think of energy access exclusively as a supply-side issue; as a result, energy efficiency policy and related market activities often are undertaken too late to be optimised. If large-scale projects consider possible joint energy efficiency measures, more energy services can be delivered, providing greater impact. Therefore, energy efficiency is part of the equation for providing energy services to the largest number of people and at least cost.

In the off-grid context, even though economic incentives are strongly aligned with energy efficiency, additional barriers remain. These include:

- **A lack of products** geared to the off-grid market and a lack of expertise among appliance distributors regarding the off-grid market. Few appliance manufacturers consider the off-grid market seriously, and fewer still have expertise in designing products for the base of the economic pyramid.
- **A lack of knowledge** among solar developers about energy efficiency appliances. Few off-grid solar developers and distributors are experts in sourcing appliances.
- **A lack of information** (and perhaps also a lack of financial and political pressure) needed for policy makers, investors and other essential actors to prioritise energy efficiency in access projects.

Nevertheless, the productive interplay of energy access and energy efficiency – whether on or off the grid – is beginning to attract more attention, with increased focus among experts on the important role of energy efficiency. For example, investors such as Acumen and Shell Foundation are considering adding off-grid (direct current) appliance enterprises to their investment portfolios. With support from development institutions such as the US Agency for International Development (USAID) and the UK Department for International Development (DFID), programmes such as the Global LEAP Awards are driving innovation and filling important information gaps by recognising and promoting the world's best and most efficient appliances designed and optimised for use with off-grid renewable energy technologies. The Rockefeller Foundation-supported Smart Power for Rural Development Initiative announced in 2016 a pilot project to deploy super-efficient appliances at its renewable mini-grid sites.

In addition, there is growing policy support aimed at advancing the linkages between energy access and energy efficiency. For example, in 2016 the Global Off-Grid Lighting Association (GOGLA) began work with the East African Community to provide a stable policy framework that supports the import of appliances optimised for use with solar PV.

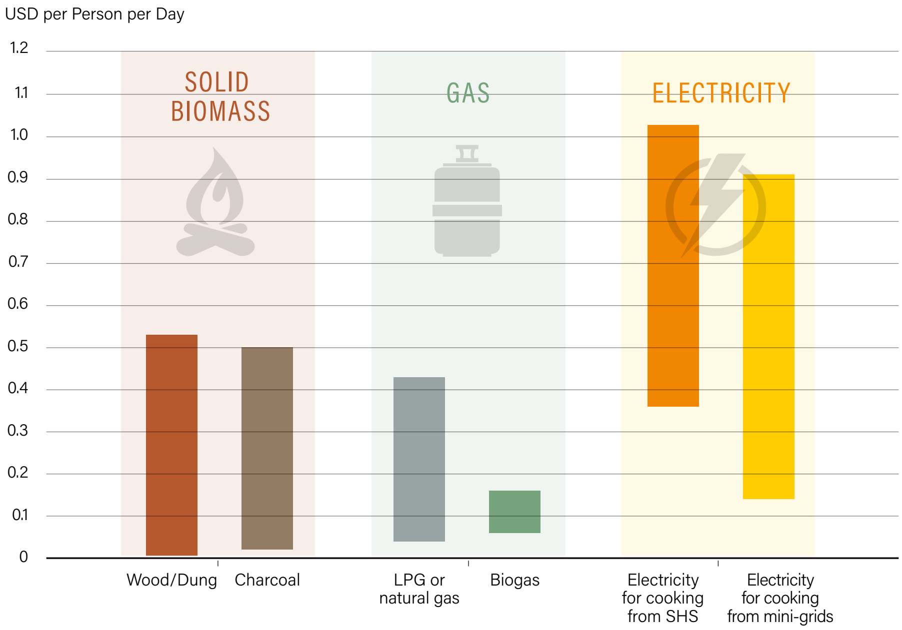
Source: See endnote 51 for this chapter.

increase in 2016. A variety of technologies can provide cooking services in different capacities, which correspond to differences in performance and cost.[60] *(→ See Figure 35.)* Wood, charcoal and dung are still widely used around the world for cooking purposes: dung is a major cooking fuel for about 185 million people.[61] Existing substitutes include improved and cost-efficient biomass cook stoves, biogas cook stoves and electric hot plates powered by SHS or mini-grids. Electric cooking has reduced the consumption of firewood and/or charcoal between 10% and 40%, whereas biogas stoves, which are more widely used, have reduced these consumption levels between 66% and 80%.[62]

In 2015, some 20 million clean cook stoves were distributed, an 18% increase from the 17 million distributed in 2014.[63] China continued to lead installations in 2015, followed distantly by India, Ethiopia, Nigeria and Bangladesh. Outside of China, sub-Saharan Africa and South Asia were the two main markets for clean cook stoves, accounting for 24% (4.8 million) and 20% (3.9 million) of the units distributed.[64] *(→ See Figure 36.)*

About 2.9 million solar cookers had been installed in the developing world by 2016.[65] China had installed the highest number of units overall (100,000 solar cookers), and Madagascar had installed the highest number per capita (about 27 solar cookers per 100,000 inhabitants).[66]

Figure 35. Cost of Various Cooking Technologies



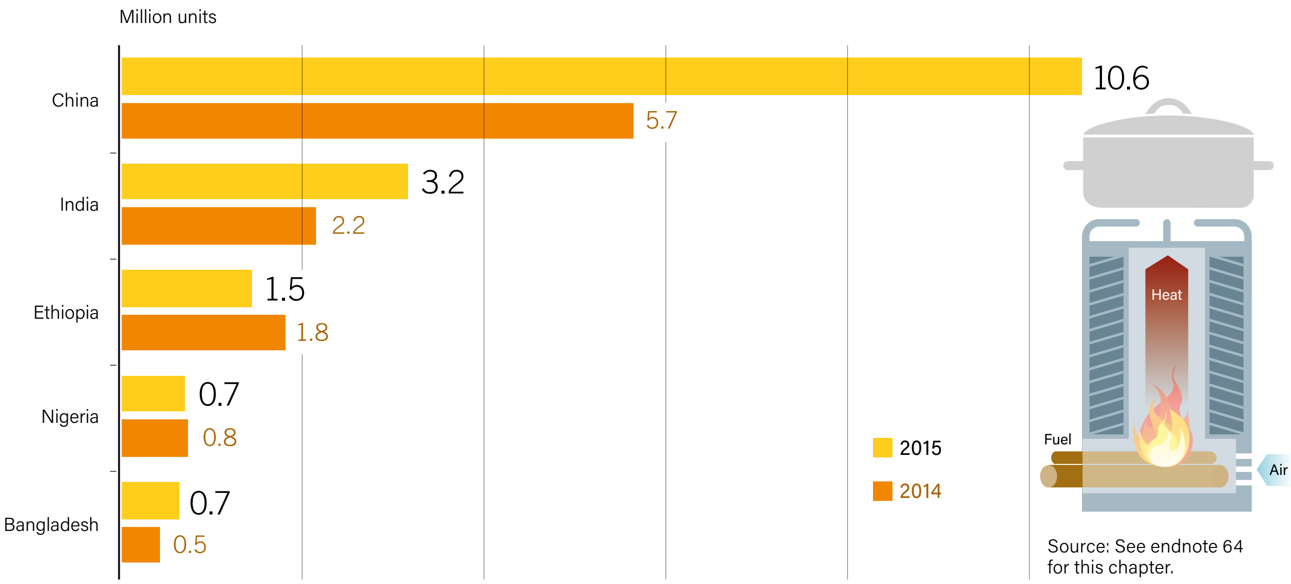
Cooking with wood/dung

Cooking with gas

Cooking with electricity

Source: See endnote 60 for this chapter.

Figure 36. Number of Clean Cook Stoves Added in Top 5 Countries, 2014 and 2015



Source: See endnote 64 for this chapter.

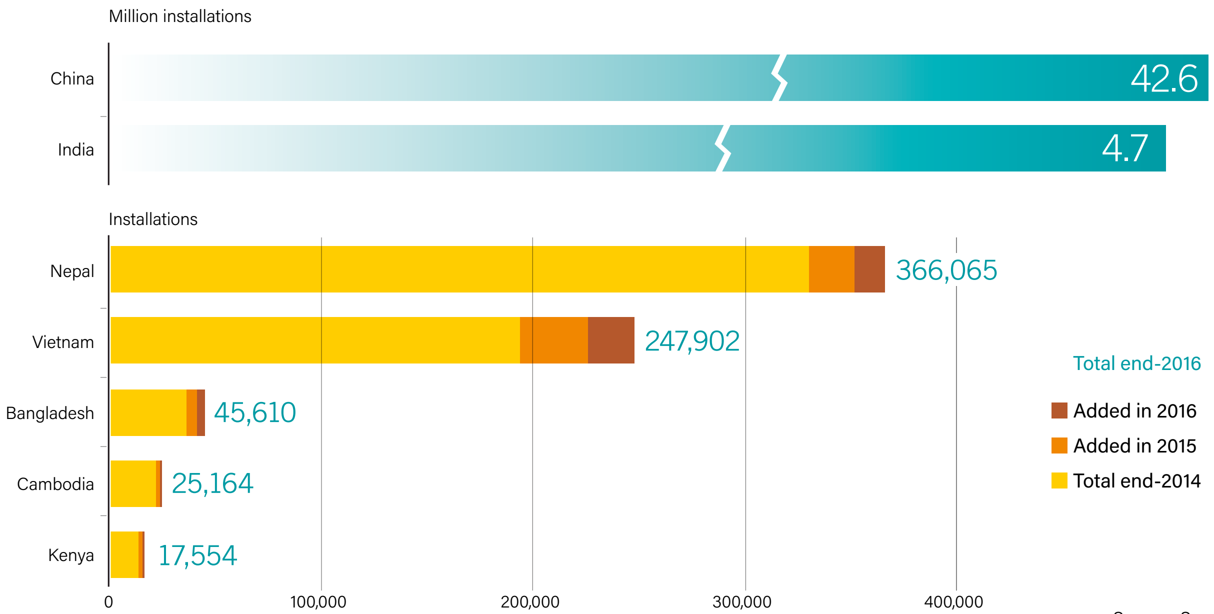
The use of biogas for cooking also continued to increase in 2016.[67] *(→ See Figure 37.)* Asia leads in total installations of domestic biogas plants, most of which are in China (42.6 million units at the end of 2016) and India (4.7 million units), with an estimated 620,000 units installed elsewhere in the region.[68] Asia also saw more new installations of domestic biogas plants in 2016 than any other region.[69] In Africa, 68,000 biogas plants had been installed as of late 2016, mainly through the African Biogas Partnership Programme; markets for biogas plants are growing on the continent, particularly in Kenya and Ethiopia.[70] In Latin America, 90% of the cumulative biogas plants installed in 2016 were in Nicaragua.[71]

Total energy systems, which integrate different technologies to provide a bundle of services – usually electricity plus heating, cooking, pumping or other end-uses – showed noteworthy development, with new efforts emerging in 2016. Gamesa (Spain) launched its first energy system targeting the supply of electricity in areas without grid access by integrating solar PV, wind power, diesel and energy storage technologies to provide more than 2 MW of capacity.[72] Mali expanded its electrification model of "Hybrid Systems Projects" consisting of diesel generators integrated with solar units and batteries.[73] The "Powerhive" approach to total energy, which combines solar PV arrays, battery storage and smart metering systems with mobile telecommunications and payment applications, continued in East Africa during the year, and an additional USD 20 million in funding was announced to expand operations.[74]

INVESTMENT AND FINANCING

To achieve the objective of universal access to energy by 2030, the Sustainable Energy for All (SEforALL) platform recommends an annual investment of USD 50 billion.[75] Current levels (around USD 13 billion in 2013, focused mostly on electricity) are far from this target.[76] Funding from multilateral organisations and bilateral donors continued to be the main source of financing for energy access investments (accounting for 55% of all such investments in 2013), though out of the total energy investment portfolios of major multilateral donors, the share of investment allocated to energy access and distributed renewable energy in particular, remains comparatively small.[77] *(→ See Figure 38.)* Although public international finance for climate change and clean energy systems – one of many channels through which DRE is financed

Figure 37. Number of Domestic Biogas Plants Installed in Top 5 Countries, Total and Annual Additions, 2014-2016



Source: See endnote 67 for this chapter.

– totalled about USD 14.1 billion over the period 2003-2015, only 3% of this total (USD 475 million) was allocated to DRE-specific activities.[78] Debt financing, equity and to some extent grants are the main financing vehicles in the DRE sector.

Investments from multilateral and bilateral funding sources continued to flow to DRE activities or projects in 2016. The World Bank pledged USD 625 million for a project that will install solar PV panels on rooftops around India.[79] The ADB granted USD 1.1 billion in loans towards off-grid energy initiatives in India, Pakistan and Sri Lanka.[80] The African Development Bank (AfDB), through the Sustainable Energy Fund for Africa (SEFA), awarded some USD 1 million to the Republic of Niger and USD 840,000 to Rwanda to promote mini-grids.[81]

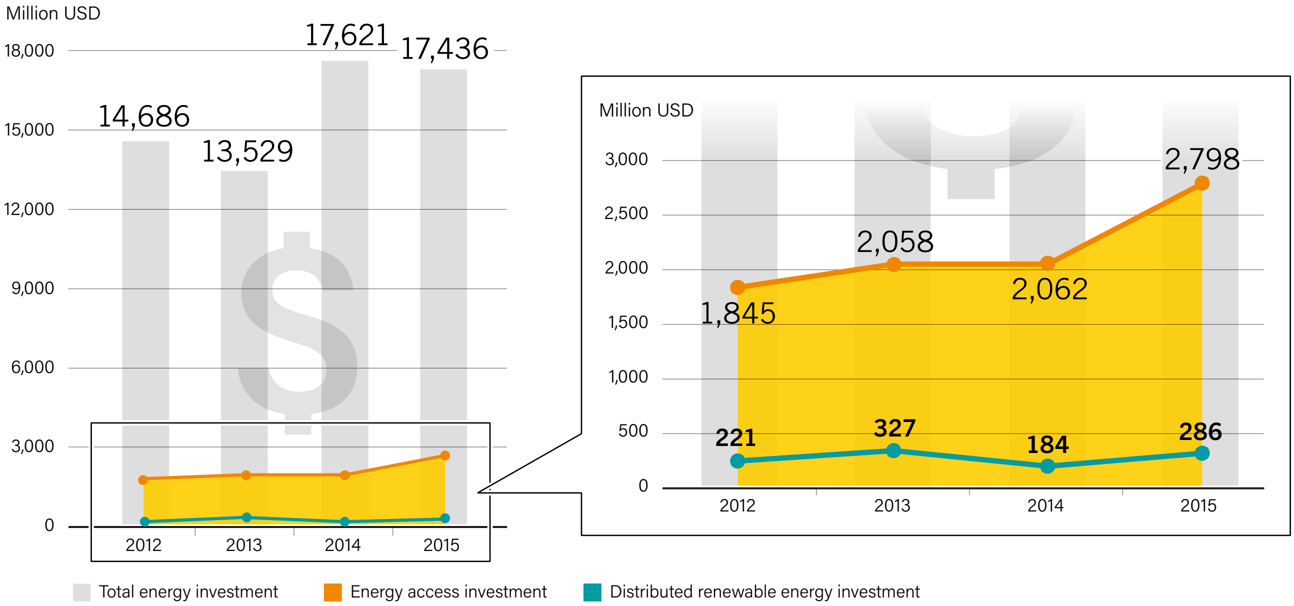
During 2016, the Green Climate Fund (GCF) approved investments of USD 78.4 million in the Deutsche Bank Universal Green Energy Access Program (UGEAP) fund for Africa, which aims to raise USD 300 million total for DRE projects in Benin, Namibia, Nigeria and Tanzania.[82] Deutsche Bank, through the UGEAP, will work with local financial institutions in an innovative structure that enables local banks to extend medium- and long-term loans to DRE companies and initiatives.[83]

The KawiSafi Ventures Fund for East Africa received USD 25 million in funding from the GCF in late 2015.[84] In 2016, these funds (by means of equity and debt financing) were used to support d.light and BBOXX in expanding their businesses.[85] Sweden donated USD 4.3 million to Uganda's CleanStart programme, which is expected to enable 150,000 households to shift to clean energy by 2020.[86]

Investment in off-grid solar PV continued to grow in 2016, dominated mainly by investments in PAYG companies. *(→ See Business Models section.)* In 2016, some USD 223 million was raised by PAYG solar PV companies, an increase of about 40% from 2015.[87] *(→ See Figure 39.)*

Lumos Global, an off-grid solar company operating in Nigeria, announced that it raised funding of USD 90 million (both debt financing and equity) during 2016 to further develop its operations – one of the largest amounts raised by a single company in a calendar year to date in the sector.[88] d.light, a manufacturer of off-grid solar lighting and power products traditionally focused on cash sales, raised USD 30 million in 2016 to expand its PAYG business.[89] BBOXX and Mobisol each raised USD 20 million to expand their operations in Kenya, Rwanda and Tanzania, and Off

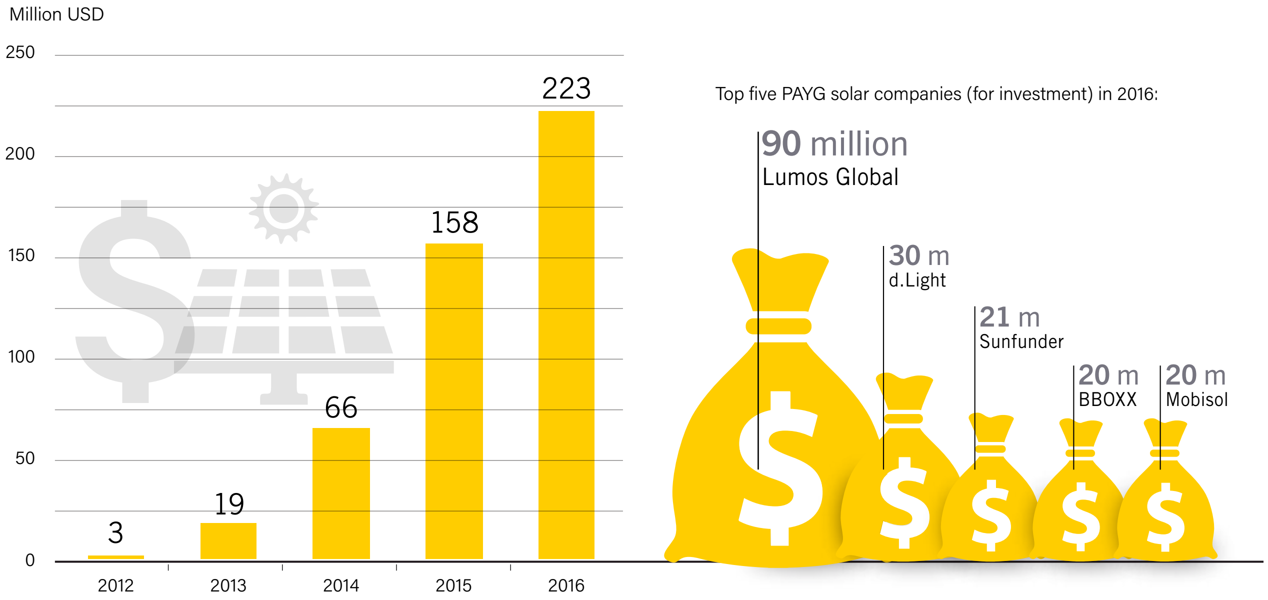
Figure 38. Overview of Multilateral Funding for Energy Access and Distributed Renewable Energy, 2012-2015



Source: See endnote 78 for this chapter.

Note: The figure provides an assessment of the maturity of the market, ranging from very few (limited), to isolated exploration (pilots), to developing market (emerging) to active deployment today (mature). Autonomous basic mini-grids refer to systems for which power is supplied for less than 24 hours and may be turned off when there is insufficient renewable energy to meet load. Autonomous full mini-grids refer to systems that can provide power on a 24-hour basis. Interconnected community mini-grids refer to systems that may be used as a back-up to the main grid, designed to sustain only the most critical loads, or that could be used to provide primary power, with the main grid as a back-up.

Figure 39. Investment in Pay-As-You-Go Solar Companies, 2012-2016



Source: See endnote 87 for this chapter.

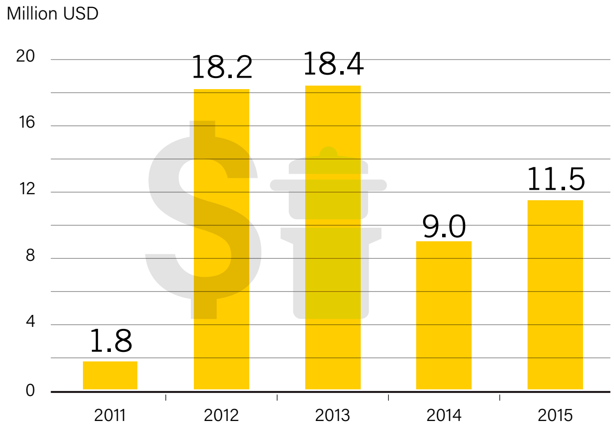
Grid Electric raised USD 18 million to expand its activities in the East Africa region.[90] Although the off-grid solar market in South America is comparatively small, PowerMundo secured a grant of USD 300,000 during the year to expand its PAYG activities in Peru.[91]

Significant investment in mini-grids occurred in 2016, from both private and public entities. More than USD 75 million was raised for mini- and micro-grids through debt financing and equity in East Africa and South-Eastern Asia.[92] The Kenyan government secured a loan of USD 37 million to install 23 solar mini-grids.[93] PowerGen secured USD 4.5 million to expand its mini-grid portfolios in Kenya and Tanzania.[94] In South-Eastern Asia, Fluidic Energy received USD 20 million from Asia Climate Partners to support the installation of its mini-grid systems.[95] Powerhive secured USD 20 million to expand its micro-grid business in Africa and Oceania.[96]

Investment in clean cook stoves increased 28% (to USD 11.5 million) between 2014 and 2015, although this was still well below the high of USD 18 million witnessed in 2012 and 2013.[97] *(→ See Figure 40.)* In 2016, the Uganda Clean Cooking Supply Expansion Project secured a grant of USD 2.2 million from the World Bank.[98] A new USD 4 million fund, the Clean Cooking Working Capital Fund, awarded its first loans to Envirofit International and BioLite during the year to support the production and distribution of clean cook stoves in sub-Saharan Africa, India and Latin America.[99]

Alternative funding mechanisms such as crowdfunding continued to support the development of small DRE companies and initiatives, with USD 3.4 million raised in 2015.[100] In 2016, Awango, the off-grid solar arm of Total (France), launched a social business and crowdfunding platform dedicated to providing access to energy.[101] Crowdfunding for clean cook stoves in the private sector also is slowly gaining popularity, with early projects in Guatemala, Kenya and South Africa.[102]

Figure 40. Investment in Clean Cook Stoves, 2011-2015



Source: See endnote 97 for this chapter.

BUSINESS MODELS FOR DISTRIBUTED RENEWABLE ENERGY

The most popular business models within the DRE sector in 2016 were distributed energy service companies (DESCOs) for mini/micro/pico-grids, the PAYG model for stand-alone systems, and microfinance and microcredit. Technological advances are helping to revolutionise business models for DRE systems. For example, in the developing world it is becoming increasingly common to use smart phones to pay for energy services.[103]

Under the DESCO, or "fee for service", model, a customer pays regular fees for the use of a renewable energy system that is owned, operated and maintained by a supplying company. Benefits include service delivery, professional maintenance and system replacement in case of default; however, lack of ownership by users can lead to careless handling and damage.[104] In 2016, the Rockefeller Foundation announced its Smart Power for Rural Development Initiative in India, which will support DESCOs such as OMC, DESI Power, TARAUrja and others to provide electricity to 1,000 villages through mini-grids.[105] Also in 2016, the International Finance Corporation and the Bank of the Philippine Islands agreed to a risk-sharing facility that will provide loans and technical advice to clients investing in renewable energy and energy efficiency projects in the Philippines, helping to promote distributed energy projects, DESCOs and green building construction.[106]

The PAYG payment model, based on the DESCO principle, is a rapidly growing energy access solution. As of 2016, more than 32 companies operating in over 30 countries in Africa and South Asia were selling pico-solar products and SHS to more than 700,000 households in exchange for an upfront fee and regular payments through mobile money services.[107] M-KOPA, the market leader, has connected some 400,000 East African households to solar power systems, installing 500 new SHS every day as of the end of 2016.[108]

The PAYG model, already well established in East Africa, is rapidly gaining prominence in Western Africa and Southern Asia as well. In Nigeria, by 2016, Arnergy's PAYG service had deployed solar mini-grids across three previously off-grid villages, powering 600 homes.[109] In Ghana, PEG secured financing during the year to expand its PAYG operations to Côte d'Ivoire.[110] In Myanmar, Bright Lite began installing SHS in 3,000 households using the PAYG model.[111]

The PAYG model also is being used on a smaller scale to support the productive use of energy and clean cooking solutions. For example, Gham Power is using the model for the application of off-grid renewable energy used for water pumping and agro-processing mills, and KopaGas uses it for clean cooking.[112]

Under the microfinance and microcredit model, purchasers (such as households and small businesses) take out a small loan from a bank to cover the cost of DRE equipment. In 2016, Arc Finance announced that its Renewable Energy Microfinance and Microenterprise Program had benefited more than 1 million people across Haiti, Kenya, India, Nepal and Uganda through the sale of 200,000 DRE products.[113] In Africa, a new microfinance project was launched in 2016 in Sierra Leone that provides microfinance-backed loans for SHS.[114]

In India, microfinance has become popular for the installation of solar PV. In 2016, Thrive Solar Energy partnered with WSDS Microfinance of Manipur to distribute its solar devices in the country's rural areas.[115] Frontier Markets finances and trains village-level entrepreneurs in rural areas of Rajasthan and Andhra Pradeshand on DRE applications.[116] The social enterprise Boond also has relied on microfinance to disseminate solar systems, benefiting 100,000 people across Delhi National Capital Region, Rajasthan, Uttar Pradesh and other northern Indian states by 2016.[117]

Microfinance also has been used to address the upfront costs of clean cooking devices. In-house asset finance – loans provided to customers by energy companies, allowing them to pay on an instalment basis – enables households to purchase improved cook stoves immediately and to pay for the stoves over time based on their ability to pay. By shifting to more efficient improved cook stoves, households often reduce their cooking-related expenses, thereby increasing their ability to pay back their loans.[118] Microfinance has become an important option for households in rural areas of developing countries that often lack access to finance for the upfront costs of clean cook stoves.[119]

BARRIERS AND POLICY DEVELOPMENTS

The deployment of DRE systems in developing countries is subject to an array of barriers and challenges, including technical, economic, financial, political, institutional and socio-cultural factors, many of which are interconnected.[120] Companies operating in the dynamic off-grid solar sector have identified the barriers that need to be overcome for the successful diffusion of DRE systems.[121] The main barriers hindering expansion of the off-grid market include:

- **Policy uncertainty** about off-grid electrification in national strategies, policies and regulations;
- **Lack of access to finance for both companies and consumers.** A lack of working capital for companies, particularly those that provide end-user financing, may limit market development. Consumers without access to finance may be unable to pay the sometimes significant upfront costs of DRE systems;
- **Subsidies on kerosene and diesel,** which affect the relative price of off-grid products compared to conventional products;
- **Fiscal and import barriers,** such as high import tariffs and value-added tax (VAT) on DRE products, which may significantly increase the price of the products;
- **Lack of consumer awareness** about the benefits of off-grid electrification solutions, especially during the early phase of market development;
- **Lack of product standards,** which allows for the sale of low-quality and counterfeit products; and
- **Lack of a qualified and skilled workforce** to support the development of the sector.[122]

In 2016, many countries implemented policy measures aimed at addressing these barriers and supporting DRE deployment, including dedicated electrification targets, fiscal incentives, regulations, auctions and exemptions on VAT and import duties.[123] Quality Assurance (QA) frameworks also were adopted, particularly for off-grid solar products, to reduce the sale of low-quality offerings on the market.

Dedicated electrification targets, as well as specific targets for DRE technologies and mini-grids, were established during 2016. In Africa, Nigeria approved its Rural Electrification Strategy, which aims to increase the country's electrification rate to 75% by 2020.[124] Rwanda announced targets to increase access to electricity to more than 70% by 2018, out of which 22% will be through off-grid connections.[125] In Asia, India announced plans for 10 GW of DRE capacity through the installation of 10,000 micro- and mini-grids by 2019, and China highlighted the importance of increasing future shares of renewable energy and distributed power generation as part of its ongoing electric power system reforms.[126]

Fiscal incentives to promote DRE products also were announced in 2016. In Asia, Indonesia put in place a rural electrification regulation that provides the framework and subsidies for electrifying the 12,000 villages currently without electricity in the country.[127] The Indian state of Maharashtra began offering subsidies to government institutions and to the private sector for the use of off-grid solar PV, and the state of Uttar Pradesh enacted a 30% subsidy for mini-grid projects with a maximum capacity of 500 kW.[128]

Regulations in support of DRE were enacted during the year as well. The Nigerian Electricity Regulatory Commission released plans to finalise its mini-grid regulation, which will streamline permit and tariff procedures.[129] Indonesia amended its FIT to apply new rates to distributed solar PV installations.[130]

In South America, Argentina launched tenders for 6,500 off-grid solar PV systems to supply electricity to an estimated 26,000 people in rural areas.[131] Brazil's 10th reserve auction also accepted 11 micro-hydro projects during the year.[132] In Africa, Sierra Leone exempted all SHS from VAT and import duties.[133] In Asia, Bangladesh reduced its import duty on improved cook stoves by 10%, making the stoves more cost-competitive.[134] The Indian state of Madhya Pradesh enacted a policy in 2016 targeting distributed solar PV that includes tax exemptions alongside regulations for net metering.[135]

By the end of 2016, the Lighting Global QA programme for off-grid solar products had been adopted by Bangladesh, Ethiopia, Kenya and Nepal.[136] In 2016, the Economic Community of West African States (ECOWAS) adopted a QA framework for off-grid rechargeable lighting appliances, which may be incorporated into the national legislation of member countries.[137]

PROGRAMME DEVELOPMENTS

Dozens of international actors were involved in deploying DRE in 2016. ***(→ See Reference Tables 12 and 13.)*** Perhaps the most far-reaching and influential programme was the continuation of efforts to support the UN Sustainable Development Goals, of which SDG 7 focuses on universal energy access.[138] The UN also continued to advance its SEforALL platform in 2016, focusing on building capacity in governments, organisations and private sector actors, and bringing various actors together to enable effective coalitions and partnerships.[139] Between 2011 and 2015, more than 106 countries engaged with SEforALL, providing financial or in-kind contributions or working on tailored national strategies and investment plans.[140] As of 2016, 68 rapid assessment and gap analyses had been developed to take stock of energy sector development at the national level.[141]

The UN Development Programme (UNDP) continued to provide grant financing for sustainable energy projects in 2016; since 1996, UNDP has provided more than USD 130 million for small, community-level projects.[142] During 2016, UNDP focused efforts on policy support for DRE, including support for SHS and mini-grids through its Derisking Renewable Energy Investment (DREI) programme.[143]

Another major effort, Energising Development (EnDev), is an energy access partnership financed by seven donor countries: Australia, Germany, the Netherlands, Norway, Sweden, Switzerland and the United Kingdom. In the first half of 2016, 370,000 people gained access to modern energy services through EnDev; in total, the partnership has provided efficient cooking technologies to more than 15 million people since 2005.[144]

In 2016, Power Africa announced USD 1 billion in new commitments to help double access to electricity in sub-Saharan Africa by adding 30 GW of capacity and 60 million household connections to the grid by 2030.[145] This included 20 new USD 100,000 grants from the US African Development Foundation for African energy entrepreneurs in the newest round of the Off-Grid Energy Challenge.[146] At the 22nd session of the UN climate conference (COP 22) in November 2016, Power Africa and USAID announced USD 4 million in new investments to eight companies that are revolutionising household solar power across Africa through the Scaling Off-Grid Energy Grand Challenge for Development.[147] In addition, two new joint initiatives between the United States and India were announced in 2016 that will mobilise up to USD 1.4 billion to finance India's commitment to universal energy access.[148]

The Global Alliance for Clean Cookstoves (GACC) continued to expand its operations, working with a strong network of public, private and non-profit partners to accelerate the production, deployment and use of clean and efficient cook stoves and fuels.[149] As of November 2016, GACC had invested in competitive research grants to support studies across 23 countries.[150] In collaboration with national alliances, GACC also invested energy in its awareness and Behaviour Change Communication (BCC) programme, which aims to increase demand for clean cook stoves in Bangladesh, Ghana, Guatemala and Uganda. Through innovative communication channels (such as radio ads, demonstrations and soap operas), the BCC reached millions of households and increased sales of clean cook stoves in 2016.[151]

The AfDB, through its New Deal on Energy for Africa project, aims to achieve universal access to modern energy services for the continent by 2025. Among the project's goals are to increase off-grid generation by adding 75 million grid connections by 2025, 20 times the current total, as well as to increase access to clean cooking for around 130 million households.[152] In 2016, the AfDB also launched a Green Mini-Grid Help Desk to provide online technical assistance on the myriad activities important to the business cycle of developing and operating a clean energy mini-grid.[153]

Also in 2016, the World Bank launched the Global Facility on Mini-Grids through its Energy Sector Management Assistance Program (ESMAP). ESMAP seeks to enhance the enabling environment for the development of mini-grids through adequate regulations, access to finance, and flexible and innovative payment models.[154]

THE FUTURE OF DRE

The technical, economic and social potential of DRE systems remains a matter of great significance for more than 2 billion households around the world, particularly for women and young children, who spend a large portion of their time cooking or doing chores.[155] The old paradigm of energy access through grid extension alone is becoming obsolete as bottom-up customer demand is motivating hundreds of millions of households to generate their own modern energy services through off-grid units or community-scale mini-grids.[156] Mobile technology, PAYG business models, availability of microloans, the viability of micro-grids and falling technology prices continue to support DRE deployment worldwide. Sufficient levels of financing and optimal policy support could transform the ways in which private and public entities deliver energy access via DRE systems.

04

Robust **TRANSMISSION AND DISTRIBUTION** networks are critical for balancing supply and demand in a power system. Flexibility can be augmented by increasing the capacity of network lines and by using advanced network technologies to optimise transmission usage. Strengthening regional interconnections of neighbouring power systems effectively expands balancing areas, facilitating further integration of variable renewable generation.

High-voltage direct current converter tower – Siemens factory, Nuremberg, Germany

04 INVESTMENT FLOWS

Global new investment in renewable power and fuels (not including hydropower projects larger than 50 MW) was USD 241.6 billion in 2016, as estimated by Bloomberg New Energy Finance (BNEF)[i]. Although this represents a decrease of 23% compared to the previous year, the decline accompanied a record installation of renewable power capacity worldwide in 2016[ii]. Investment in renewable power and fuels has exceeded USD 200 billion per year for the past seven years. (→ *See Figure 41.*) Including investments in hydropower projects larger than 50 MW, total new investment in renewable power and fuels was at least USD 264.8 billion in 2016[iii].[1] Note that these estimates do not include investment in renewable heating and cooling technologies. ***(→ See Reference Table R14.)***

For the fifth consecutive year, investment in new renewable power capacity (including all hydropower) was roughly double that in fossil fuel generating capacity.

Investment in renewables continued to focus on solar power, followed closely by wind power, although investment in both sectors was down relative to 2015. Asset finance of utility-scale[iv] projects, such as wind farms and solar parks, dominated investment during the year, at USD 187.1 billion. Small-scale solar PV installations (less than 1 MW) accounted for USD 39.8 billion worldwide, representing a decline of 28%.

i This chapter is derived from UN Environment's *Global Trends in Renewable Energy Investment 2017* (Frankfurt: 2017), the sister publication to the GSR, prepared by the Frankfurt School–UNEP Collaborating Centre for Climate & Sustainable Energy Finance (FS-UNEP) in co-operation with BNEF. Data are based on the output of the Desktop database of BNEF, unless otherwise noted, and reflect the timing of investment decisions. The following renewable energy projects are included: all biomass and waste-to-energy, geothermal and wind power projects of more than 1 MW; all hydropower projects of between 1 and 50 MW; all solar power projects, with those less than 1 MW estimated separately and referred to as small-scale projects or small-scale distributed capacity; all ocean energy projects; and all biofuel projects with an annual production capacity of 1 million litres or more. For more information, please refer to the FS-UNEP and BNEF Global Trends report. Where totals do not add up, the difference is due to rounding.

ii Note that declining costs of some renewable energy technologies (particularly solar PV and wind power) have a decremental impact on total investment (all else being equal). Thus, changes in investment (monetary) do not necessarily reflect changes in capacity additions.

iii Investment in large-scale hydropower (>50 MW) is not included in the overall total for investment in renewable energy. Similarly, investment in large-scale hydropower is not included in the chapter figures, unless otherwise mentioned.

iv "Utility-scale" in this chapter refers to wind farms, solar parks and other renewable power installations of 1 MW or more in size, and to biofuel production facilities with capacity exceeding 1 million litres.

Renewable energy investment in developed countries, as a group, fell 14% in 2016, to USD 125 billion. While investment in Japan and the United States declined, Europe witnessed a slight increase. Among developing and emerging countries, renewable energy investment fell 30%, to USD 116.6 billion. China played a dominant role in this turnaround, breaking an 11-year rising trend. Chile, Mexico, Morocco, Pakistan, the Philippines, South Africa, Turkey and Uruguay became billion-dollar markets in 2015, but in 2016 each of these countries saw a sharp drop in investment due in part to delayed auctions or to delays in securing equity for projects that won capacity in tenders. Argentina, Bolivia, Egypt, Indonesia, Jordan, Kenya, Mongolia, Peru, Thailand and Vietnam all saw investment rise in 2016.

There were two main reasons for the decline in global investment in renewable energy during 2016. One was the slowdown in investments in Japan, China and some other emerging countries. The other was the significant cost reductions in solar PV and onshore and offshore wind power, which also improved the cost-competitiveness of those technologies. The result was that in 2016 investors were able to acquire more renewable energy capacity for less money.

INVESTMENT BY ECONOMY

Developing and emerging economies overtook developed countries in renewable energy investment for the first time in 2015, but developed countries retook the lead in 2016. Trends in renewable energy investment varied by region[i], with investment up in Europe and Australia; down in China, the United States, the Middle East, Africa, Asia-Oceania (except Australia) and Latin America; and stable in India. (→ *See Figure 42.)* Considering all financing of renewable energy (but excluding hydropower larger than 50 MW), China accounted for 32%, followed by Europe (25%), the United States (19%) and Asia-Oceania (excluding China and India; 11%); the Americas (excluding Brazil and the United States), Brazil and the Middle East and Africa accounted for 3% each.

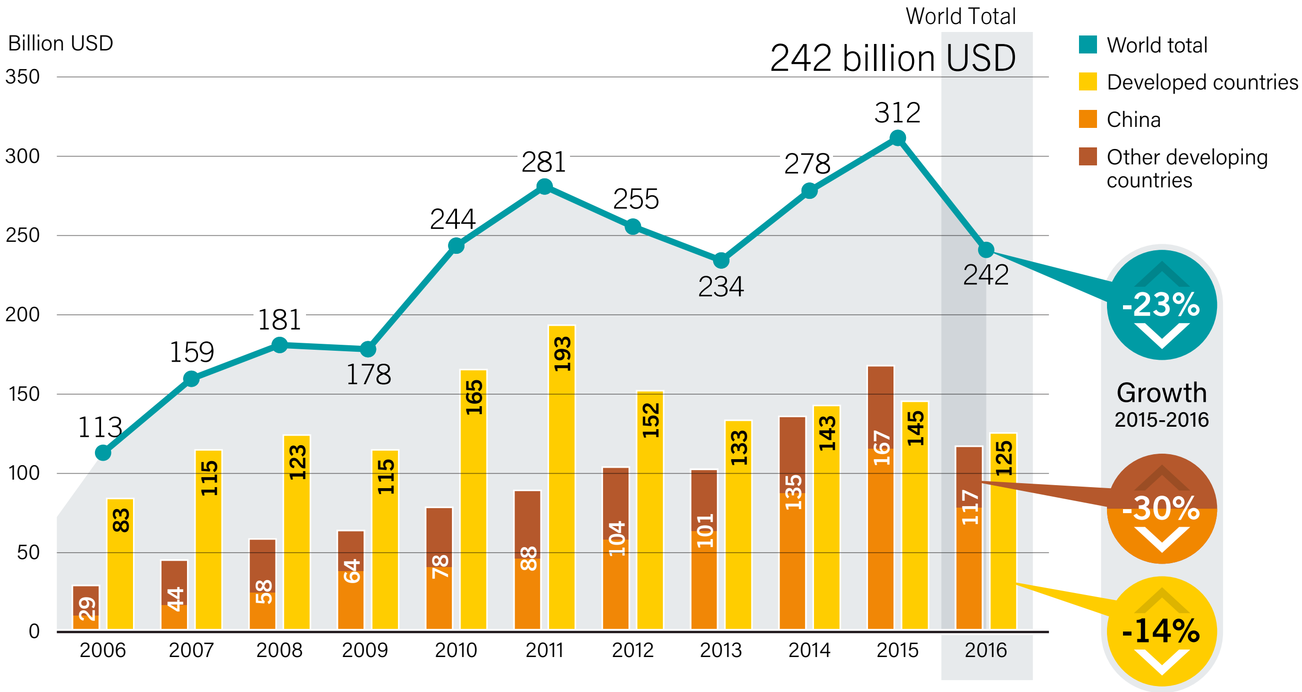
The top 10 national investors consisted of three emerging countries (all of which are BRICS[ii] countries) and seven developed countries. In addition to China and the United States, top countries included the United Kingdom, Japan and Germany. The next five countries were India, Brazil, Australia, Belgium and France.

Although China again accounted for the largest dollar commitments to new renewable energy investment, its total of USD 78.3 billion was down 32% from 2015, the lowest level since 2013. Most of this total (USD 72.9 billion) was in asset finance, which declined 34% relative to 2015. However, investment in small-scale solar PV project development increased 32%, to

i Regions presented in this chapter reflect those as presented in UNEP-FS and BNEF, *Global Trends in Renewable Energy Investment 2017* (Frankfurt: 2017), and differ from the regional definitions across the rest of the GSR, which can be found at www.ren21.net/GSR-Regions.

ii The five BRICS countries are Brazil, the Russian Federation, India, China and South Africa.

Figure 41. Global New Investment in Renewable Power and Fuels, Developed, Emerging and Developing Countries, 2006-2016



Note: Figure does not include investment in hydropower projects larger than 50 MW. Investment totals have been rounded to nearest billion.

Source: BNEF

USD 3.5 billion, and government R&D also was up (by 7%), to USD 1.9 billion. Overall, China invested roughly the same amount in both solar and wind power. The country also invested significant sums in large-scale hydropower[i], although down relative to 2015; China commissioned nearly 9 GW of capacity during the year, a large portion of which was projects larger than 50 MW.[2] *(→ See Hydropower section in Market and Industry Trends chapter.)*

Investment in Europe totalled USD 59.8 billion (up 3%) in 2016, due mainly to significant investments in offshore wind power. Asset finance accounted for 78% of the region's investment, at USD 46.9 billion, of which USD 40.6 billion was invested in wind power (up 10% from 2015) and USD 1.6 billion was invested in solar power (down 75%). Small-scale distributed capacity in Europe attracted USD 6.7 billion in 2016 (down 18%), with Germany, the United Kingdom and the Netherlands being the three biggest contributors.

Within Europe, the United Kingdom was the largest national investor in renewable energy for the second consecutive year, at USD 24 billion. Most of this total was in asset finance (USD 22.5 billion), with four offshore wind projects accounting for USD 14.2 billion. Germany was the second largest European investor at USD 13.2 billion, down 14% from 2015. Of this total, German asset finance was USD 8.4 billion (down 34%), and it was dominated by offshore and onshore wind power.

The United States remained the largest individual investor among developed economies. The country invested USD 46.4 billion in 2016, a decrease of 10% compared to 2015. Despite this reduction, there was strong growth (up 33%) in small-scale distributed capacity investment, with USD 13.1 billion of investment in rooftop and other small-scale solar PV projects. Utility-scale asset finance was down 2%, at USD 29.8 billion, with wind and solar power each accounting for equal shares. Investment in public markets in the United States fell 87%, to USD 1.3 billion, the lowest level in five years.

Japan's investment fell 56% to USD 14.4 billion. The reduction resulted largely from grid access difficulties and from a shift in policy from a generous FIT to tendering. Investment in small-scale capacity fell 69%, to its lowest level since 2011 (USD 8.5 billion).

Investment in India remained stable compared to 2015, with a total of USD 9.7 billion. Approximately USD 5.5 billion was invested in new solar power capacity, and USD 3.7 billion was invested in wind power during 2016.

Brazil was the third emerging economy among the top 10 investors in 2016, with total investment reaching USD 6.8 billion, a decrease compared to 2015. While asset finance of wind power projects fell 15% to USD 4.9 billion, solar asset finance rose 75% to USD 1 billion.

Elsewhere in the Americas (beyond Brazil and the United States) investment totalled USD 6.1 billion (down 54%), with large variations across countries. Some countries showed significant decreases: for example, investments in Chile (USD 800 million), Mexico (USD 600 million) and Uruguay (USD 400 million) all were down more than 70% relative to 2015. In Honduras, investment decreased 32% to USD 300 million. Other countries saw significant increases, however, including Argentina (up 356% to USD 400 million) and Peru (up 151% to USD 400 million). Bolivia, which recorded no renewable energy investment in 2015, reached USD 800 million in 2016.

Investment in the Middle East and Africa was down 32% to USD 7.7 billion – the lowest level of investment since 2011. The decline was due primarily to pauses in financing in South Africa (USD 900 million) and Morocco (USD 700 million); both countries saw investment fall 75% relative to 2015. At the same time, investment increased during the year in Jordan (up 148% to USD 1.2 billion), Kenya (up 31% to USD 600 million) and Egypt, which recorded no renewable energy investment in 2015 and reached USD 700 million in 2016.

In Asia-Oceania (excluding China and India) investment fell 42% to USD 26.8 billion – the lowest since 2011, due largely to the decline in Japan. Other countries in the region with decreases included the Philippines (down 47% to USD 1 billion), Pakistan (down 58% to USD 900 million) and Chinese Taipei (down 2% to USD 700 million). However, some countries saw significant increases in investment, including Singapore (up 14-fold to USD 700 million), Vietnam (up 143% to USD 700 million) and Indonesia (up 84% to USD 500 million). Mongolia, which recorded no renewable energy investment in 2015, reached USD 200 million. Thailand recorded an investment of USD 1.4 billion (up 4%), the highest level in the region (after China and India).

i The Chinese government estimates that hydropower facilities of all sizes completed in 2016 represent an investment of USD 8.8 billion (CNY 61.2 billion); as such, 2016 marked the fourth consecutive year of decline, per National Energy Administration of China, national electric industry statistics as sourced from China's National Energy Board, 16 January 2017, http://www.nea.gov.cn/2017-01/16/c_135986964.htm.

INVESTMENT BY TECHNOLOGY

New investment in renewable energy in 2016 continued to be dominated by solar (mostly solar PV) and wind power, which each accounted for roughly 47% of total investment. Both technologies experienced declines in dollars invested in 2016, with solar power down 34% to USD 113.7 billion and wind power down 9% to USD 112.5 billion. Significant cost reductions played a large role in these falling investment numbers, particularly for solar PV, which saw a market increase of nearly 50% relative to 2015. *(→ See Solar PV section in Market and Industry Trends chapter.)*

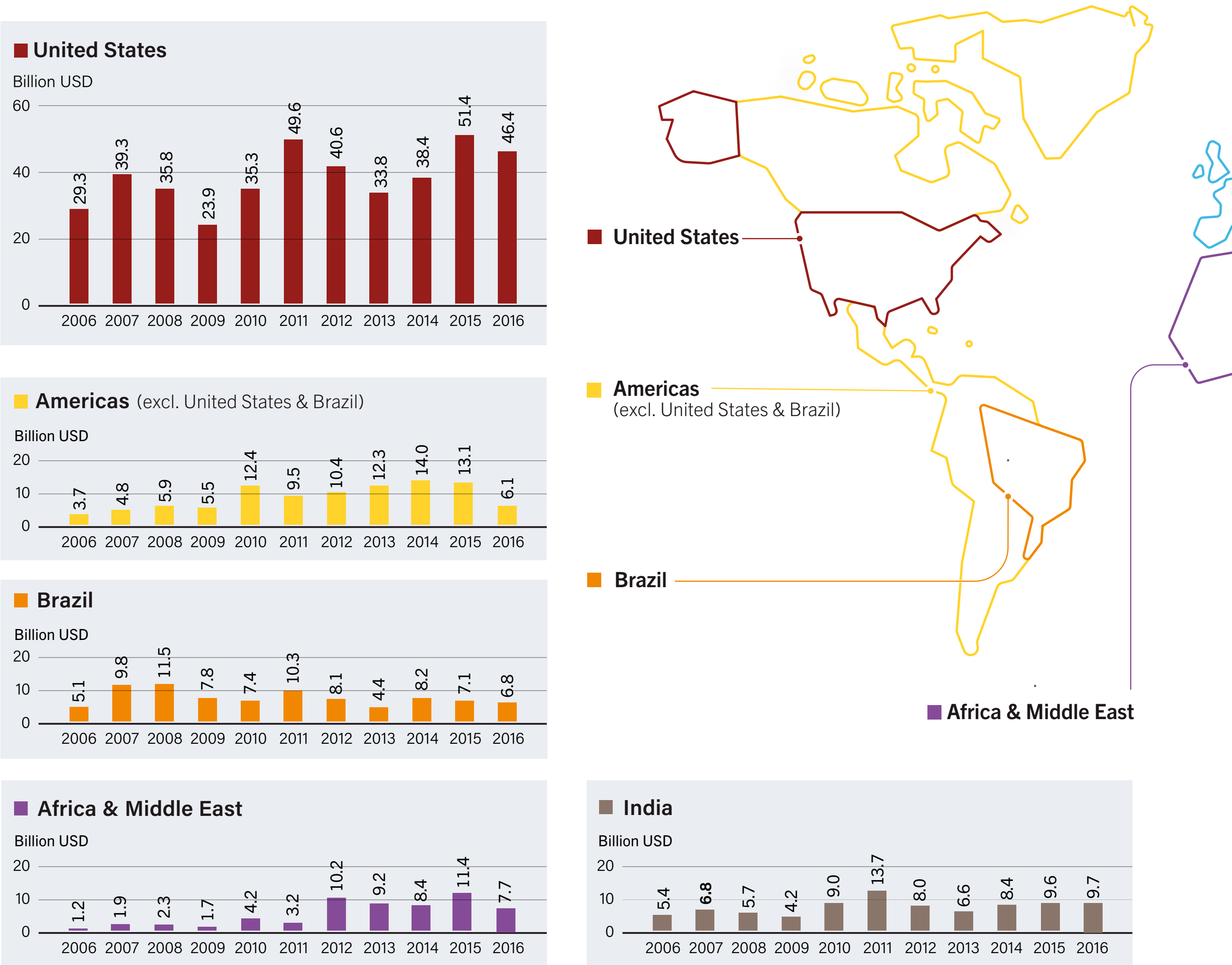
Investment in biomass/waste-to-energy[i] and small-scale hydropower remained stable at USD 6.8 billion and 3.5 billion respectively. Investment in biofuels (down 37%) and ocean energy (down 7%) declined to USD 2.2 billion and USD 200 million respectively. The only technology to witness increases in new investment in 2016 was geothermal power, which was up 17% to USD 2.8 billion. *(→ See Figure 43.)*

In 2015, emerging and developing economies accounted for more than half of global investment in both wind and solar power, but in 2016 they lost the lead in wind power and only narrowly maintained it in solar power. Investment in wind power was up 13% to USD 60.6 billion in developed countries, but down 27% to USD 51.9 billion in developing countries. Solar power investment declined in developed and in developing and emerging countries, down 33% (to USD 56.2 billion) and 35% (to USD 57.5 billion), respectively.

Large-scale hydropower projects over 50 MW in size represented the third most important sector (after solar and wind power) for

i Includes all waste-to-power technologies, but not waste-to-gas.

Figure 42. Global New Investment in Renewable Power and Fuels, by Country and Region, 2006-2016



Source: BNEF.

Note: Data include government and corporate R&D.

renewable energy investment in 2016. Translating hydropower capacity additions into asset finance dollars per year is not straightforward because the average project takes four years to build. Although BNEF does not track detailed statistics for large-scale hydropower projects, it estimates that asset financing for large-scale hydropower projects reaching financial go-ahead in 2016 totalled at least USD 23.2 billion, down 48% from 2015.

INVESTMENT BY TYPE

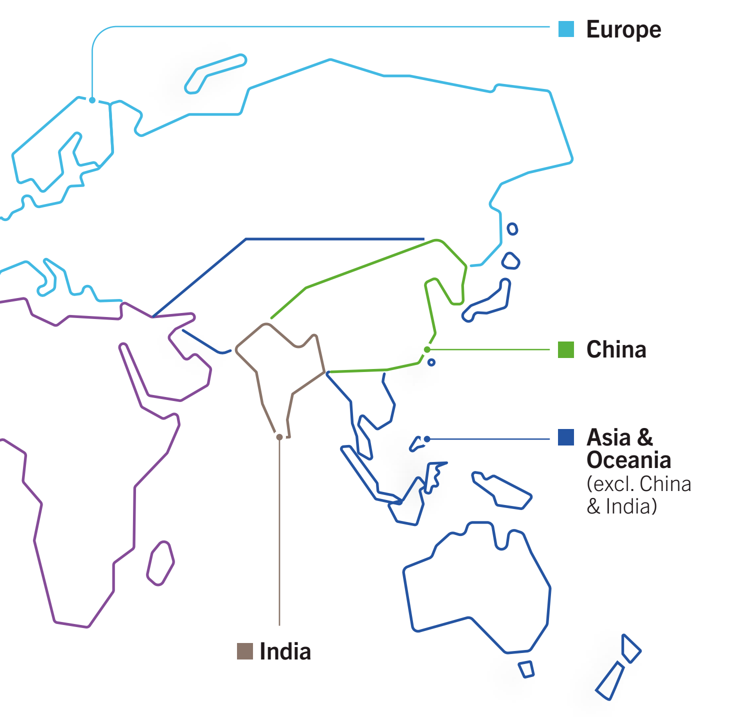
Global research and development[i] (R&D) spending fell 7% in 2016, to USD 8 billion, due to a decline in the corporate sector. While government R&D increased 25% relative to 2015, to a record USD 5.5 billion, corporate R&D decreased almost 40% as wind and solar power manufacturers reduced their spending.

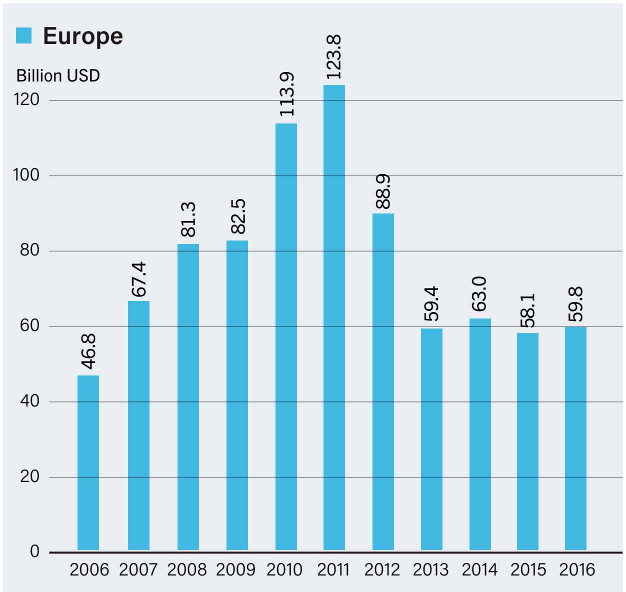
Europe was again the biggest regional investor in R&D, despite an 8% decrease to USD 2.2 billion. China's investment declined 2% to USD 2 billion but stayed well ahead of the United States, where spending rose 13% to USD 1.5 billion.

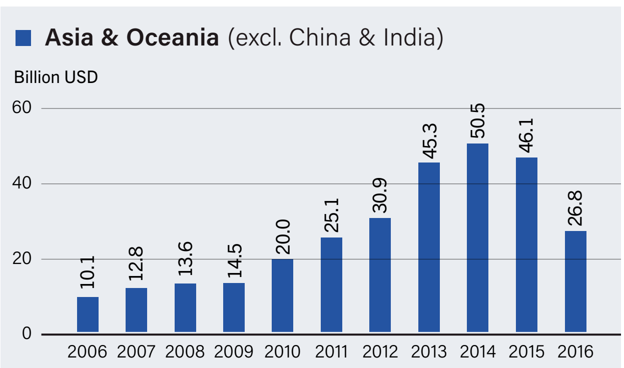
Total R&D spending was down for both solar (down 20% to USD 3.6 billion) and wind power (down 13% to USD 1.2 billion) in 2016. Despite low oil prices and a challenging regulatory environment, R&D spending on biofuels increased 11% to USD 1.7 billion.

Asset finance of utility-scale projects accounted for the vast majority of total investment in renewable energy. It totalled USD 187.1 billion during the year, a decrease of 21% relative to 2015, due to lower per MW installed costs of wind and solar power, as well as to a slowdown in China and Latin America.

i See Sidebar 5 in GSR 2013, "Investment Types and Terminology", for an explanation of investment terms used in this section.







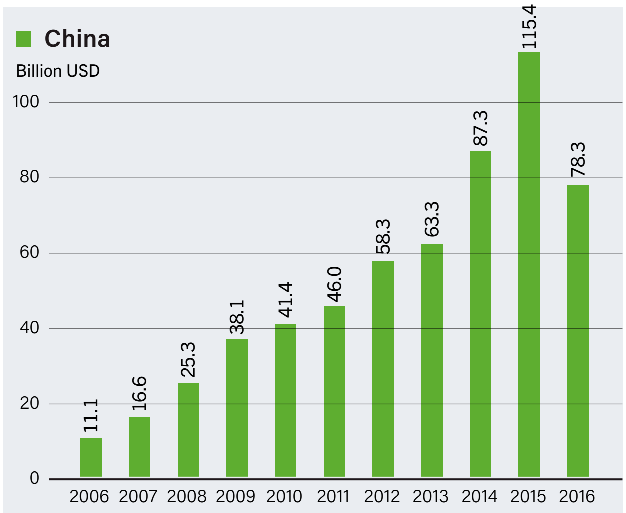
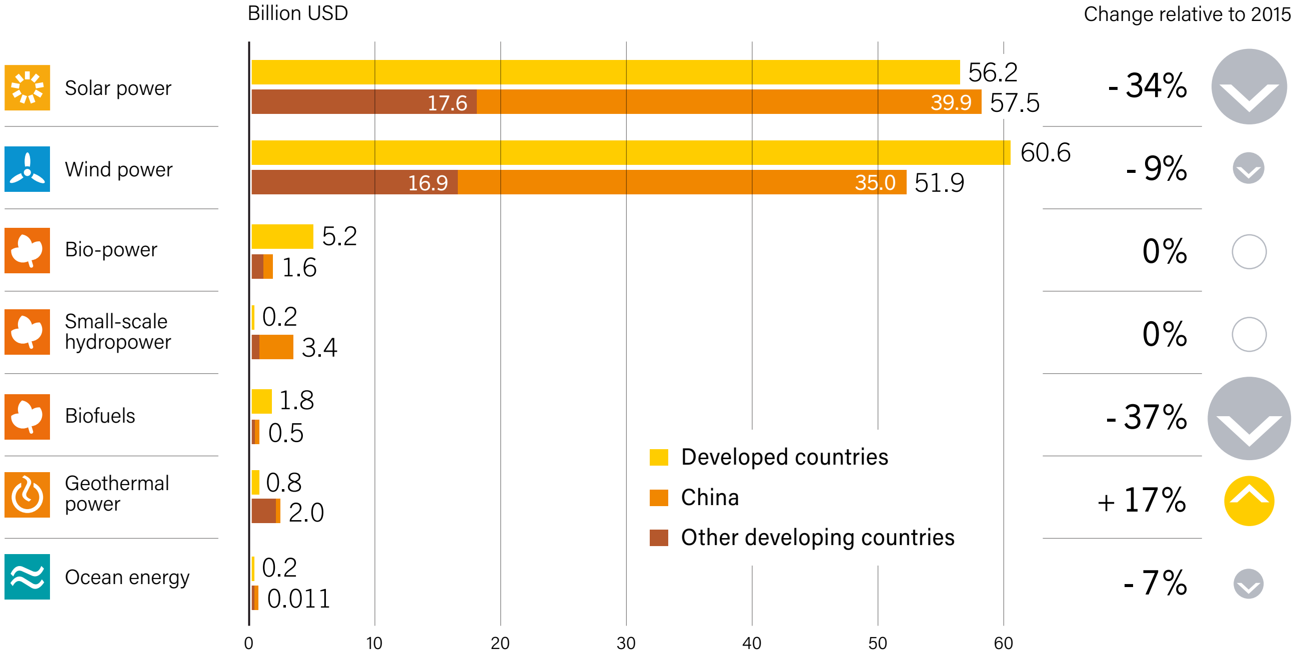


Figure 43. Global New Investment in Renewable Energy by Technology, Developed and Developing Countries, 2016



Source: BNEF

Small-scale distributed capacity investment, largely solar PV systems of less than 1 MW, declined 28% to USD 39.8 billion. The United States led investments in this category with USD 13.1 billion, followed by Japan with USD 8.5 billion (down from USD 27.9 billion) and China with USD 3.5 billion.

Public market investment in renewable energy companies and funds fell 53%, to USD 6.3 billion. Funds raised by initial public offerings (IPOs) increased 12% to USD 2.6 billion. In the United States, investments via public markets in "yield companies" (yieldcos) were much less active in 2016 than in 2015, and no new funds were launched. Overall, solar power companies and related funds raised USD 1.7 billion (less than one-fifth of the previous year's total), while wind power raised USD 4.2 billion (an increase of 66% compared to 2015).

Venture capital and private equity investment (VC/PE) in renewable energy decreased 4% to USD 3.3 billion in 2016. As in previous years, solar power companies attracted the most venture capital and private equity investment, with more than two-thirds of the total, although funding decreased 2% to USD 2.3 billion. Increases were seen in both wind (up 41% to USD 539 million) and small-scale hydropower, with investment in the latter almost quintupling, to USD 165 million, due mainly to a single deal. Biofuels decreased 60% to USD 254 million. The United States remained the centre of worldwide VC/PE investment in renewables, representing more than two-thirds of the total with USD 2.3 billion (down 2% from 2015).

Acquisition activity – which is not counted as part of the USD 241.6 billion in new investment – jumped 17% to a new record of USD 110 billion. Growth was driven mainly by corporate mergers and acquisitions (M&A; the buying and selling of companies), which increased 58% to USD 27.6 billion, and by public market investor exits, which almost quadrupled, to USD 6.7 billion. Asset acquisitions and refinancing remained the largest single category of acquisition activity, with deals worth USD 72.7 billion equating to 66% of the total. Within this category, activity increased in the United States (up 14% to USD 29.2 billion), Europe (up 8% to USD 28.6 billion) and China (up 7% to USD 4.4 billion). In all other regions, asset acquisitions and refinancing decreased. Private equity buy-outs were down 2% relative to 2015, to USD 3.4 billion.

RENEWABLE ENERGY INVESTMENT IN PERSPECTIVE

In 2016, renewable power technologies continued to attract far more investment dollars than did fossil fuel or nuclear power generating plants. An estimated USD 249.8 billion was committed to constructing new renewable power plants (including USD 226.6 billion[i] without large-scale hydropower, plus an estimated USD 23.2 billion for hydropower projects larger than 50 MW). This compares to approximately USD 113.8 billion committed to fossil fuel-fired generating capacity and USD 30 billion for nuclear power capacity. Overall, renewable energy accounted for about 63.5% of the total amount committed to new power generating capacity in 2016. (→ *See Figure 44.)*

i This number is for renewable power asset finance and small-scale projects. It differs from the overall total for renewable energy investment (USD 241.6 billion) provided elsewhere in this chapter because it excludes biofuels and some types of noncapacity investment, such as equity-raising on public markets and development R&D.

SOURCES OF INVESTMENT

Debt makes up the majority of the investment going into many utility-scale renewable energy projects, either at the project level in the form of non-recourse loans, bonds or leasing; or at the corporate level in the form of borrowings by the utility or project developer. In 2016, commercial banks provided most of the project-level debt for renewable energy projects.

Green bonds are a growing asset class for investors around the world. They include qualifying debt securities issued by development banks, central and local governments, commercial banks, public sector agencies and corporations, asset-backed securities and green mortgage-backed securities, and project bonds. In 2016, issuance of green bonds globally almost doubled to USD 95.1 billion. This included the first sovereign green bond, issued by Poland. China increased its issuance to USD 27.1 billion, overtaking the United States with USD 15.5 billion.

In addition to commercial banks and bond issues, the other major source of debt for renewable power assets is borrowing directly from the world's large array of national and multilateral development banks. Aggregate figures for development bank lending to renewables in 2016 were not yet available at the time of publication. Among those that had published data in early 2017, Germany's KfW provided the Euro-equivalent of USD 39 billion for "environmental and climate protection financing" (up 20% in Euro-value relative to 2015), including USD 8 billion for renewable energy and USD 23.5 billion for energy efficiency. The ADB approved USD 3.7 billion in climate finance investments, an increase of 42% relative to 2015, to support efforts in developing member countries.

Electric utilities continued to be an important source of on-balance-sheet finance and project-level equity in 2016. Nine of the largest European utilities invested a total of USD 11.5 billion in renewables in 2015 and were on track to invest USD 10.2 billion in 2016.

Institutional investors such as insurance companies and pension funds tend to be more risk-averse and therefore are interested in the predictable cash flows of a project already in operation. In Europe, direct investment by institutional investors in renewable energy totalled USD 2.8 billion in 2016, on par with the record set in 2014, more than double the 2015 level and nearly 10 times the total in 2010.

EARLY INVESTMENT TRENDS IN 2017

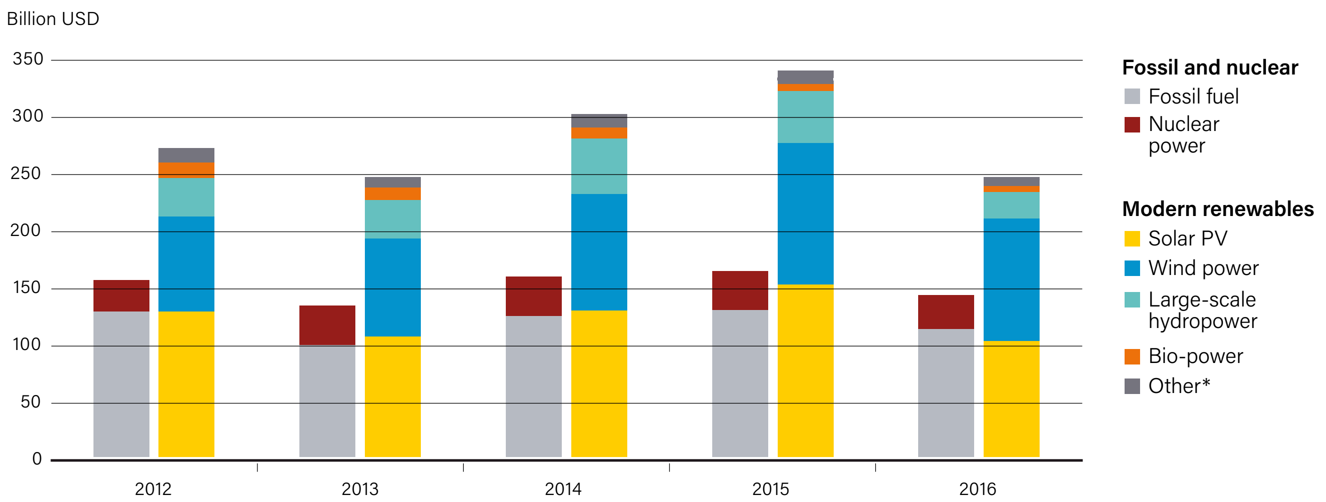
Global investment in renewable energy was USD 50.84 billion in the first quarter (Q1) of 2017, down 20.9% from Q1 in 2016 (USD 64.25 billion). This decline reflects drops in investment in the two biggest markets, the United States and China. US investment in Q1 2017 was down 42% relative to Q1 in 2016, to USD 6.9 billion, and China's investment declined 11% to USD 17.2 billion. Investment in Europe also dropped significantly (down 61.7%): in the United Kingdom, where there was no new finance in offshore wind power, investment fell 92% to USD 1.1 billion in Q1. Countering this drop, investments in Germany and France were up 94% and 138%, respectively.

Developing countries showed varying investment patterns in Q1 2017. Investment fell slightly in India (down 2% to USD 2.8 billion) and Brazil (down 3% to USD 1.8 billion), while Mexico's investment was up 47-fold, to USD 2.3 billion.

Investment in both solar and wind power, which accounted for the lion's share, declined in Q1 2017 compared to Q1 2016, by 6.7% and 40.6% respectively. Investment in offshore wind power was down 60% relative to Q1 2016, to USD 4.6 billion. Biomass and waste-to-energy, small-scale hydro and geothermal power all saw increased investment in Q1 2017.

Asset finance of utility-scale renewable energy projects amounted to USD 39 billion in Q1 2017, down 27.5% relative to Q1 2016. Small-scale solar projects (less than 1 MW) represented the second largest category of spending, worth an estimated USD 10.7 billion in Q1, up 8% compared to Q1 in 2016.

Figure 44. Global Investment in Power Capacity, by Type (Renewable, Fossil Fuel and Nuclear Power), 2012-2016



* CSP, geothermal, small-scale hydropower and ocean energy

Source: BNEF.

05

Various technical and operational solutions exist for improving system flexibility, including energy storage and demand-side management solutions. **MARKETS CAN BE DESIGNED** to establish the economic value of such solutions to the power system, and to allow commensurate compensation for flexibility services.

BP Helios Plaza Trading Floor – Houston, Texas, United States

05 POLICY LANDSCAPE

As of 2016, nearly all countries directly supported renewable energy technology development and deployment through some mix of policies.[1] *(→ See Table 3.)* Decision makers continued to implement policies during the year to attract investment, drive deployment, foster innovation and encourage greater flexibility in energy infrastructure that supports enabling technologies such as energy storage.[2] *(→ See Enabling Technologies chapter.)* A broad range of policies provided direct and indirect support, aimed at economy-wide economic development, environmental protection and national security. Technology advances, falling costs and rising penetration of renewables in many countries also have continued to require that policies evolve to stimulate renewables deployment and integration as effectively as possible.

Many countries built on the momentum spurred by the landmark Paris Agreement of the United Nations Framework Convention on Climate Change (UNFCCC) by communicating their first Nationally Determined Contributions (NDCs)[i]. A total of 117 NDCs were submitted by year-end 2016, largely from countries that formalised the commitments made in their Intended Nationally Determined Contributions (INDCs) submitted prior to the Paris climate conference. Of the 117 NDCs, 55 included targets for increasing renewable energy, while 89 made reference to renewable energy more broadly.[3]

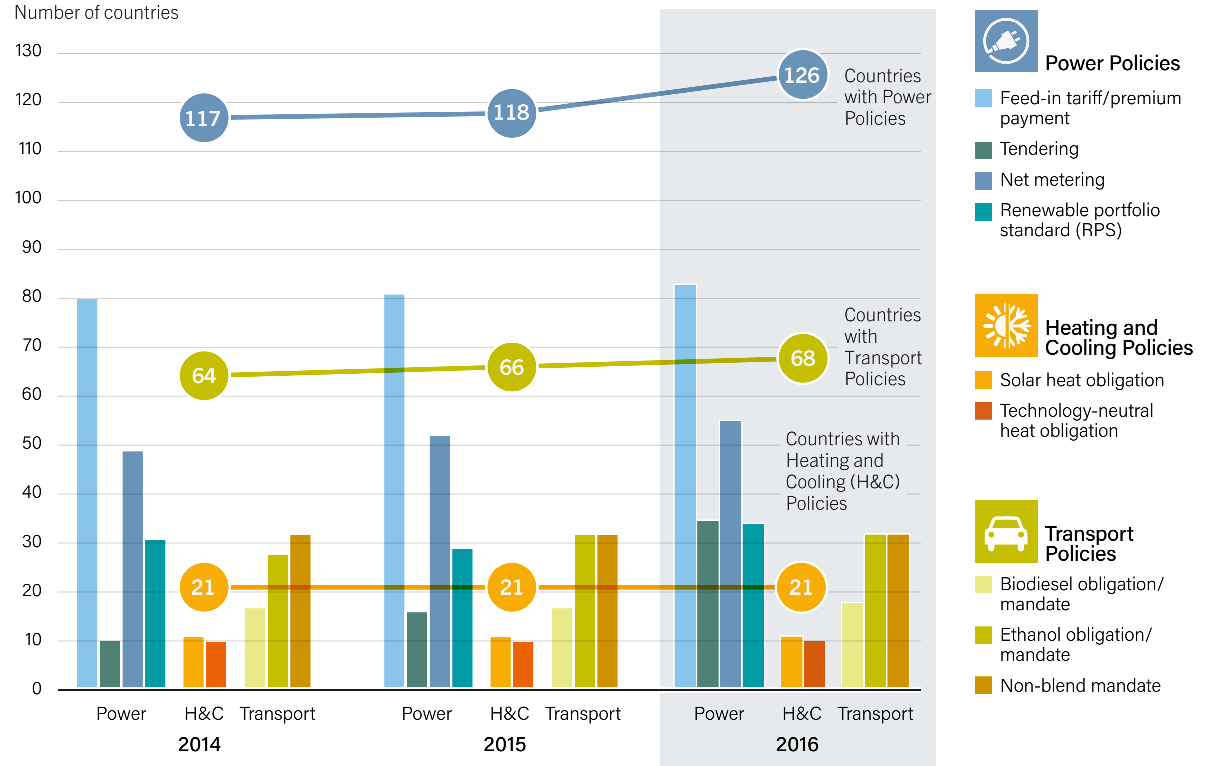
By late 2016 at the 22nd Conference of the Parties (COP22) in Marrakesh, Morocco, more than 100 countries had officially joined the Paris Agreement, formalising their commitments to sustainable development, often through decarbonisation of the energy sector.[4] At COP22, leaders of the 48 developing countries that constitute the Climate Vulnerable Forum (CVF), including COP22's host nation of Morocco, committed jointly to work towards achieving 100% renewable energy in their respective nations.[5] In addition, a new 20-country coalition launched the Biofuture Platform, dedicated to promoting the use of biofuels in transport and industry.[6]

Policies targeting broader environmental concerns or other resources and technologies in the energy sector also may impact renewable energy markets. For example, carbon pricing policies (either carbon taxes or emissions trading systems), if designed effectively, may incentivise renewable energy development and deployment across sectors by increasing the comparative costs of higher-emission technologies. On the counter side, fossil fuel subsidies continued to temper renewable energy growth globally in 2016.[7] *(→ See Global Overview chapter.)*

Policy support specifically for renewable energy in 2016, as in past years, was focused mostly on power generation, whereas support for renewable technologies in the heating and cooling and transport sectors developed at a slower pace. *(→ See Figure 45.)* Policy makers in many countries also continued to advance policies to integrate renewable generation into national energy systems.[8]

i NDCs are country-specific pathways for realising emissions reduction pledges; see Sidebar 4 in GSR 2016.

Figure 45. Number of Renewable Energy Regulatory Incentives and Mandates, by Type, 2014-2016



Note: Figure does not show all policy types in use. In many cases countries have enacted additional fiscal incentives or public finance mechanisms to support renewable energy. Heating and cooling policies do not include renewable heat FITs (i.e., in the United Kingdom). Countries are considered to have policies when at least one national or state/provincial-level policy is in place. A country is counted a single time if it has one or more national and/or state/provincial-level policies. Some transport policies include both biodiesel and ethanol; in this case, the policy is counted once in each category (biodiesel and ethanol). Tendering policies are presented in a given year if a jurisdiction has held at least one tender during that year. For more information see Table 3.

Source: REN21 Policy Database

This chapter provides a snapshot of 2016 developments and emerging trends in renewable energy policy across all sectors (power, heating and cooling, and transport) at the regional, national and sub-national levels. The final section focuses on local policy developments. The chapter does not attempt to assess or analyse the effectiveness of specific policy mechanisms. Developments related to each type of policy mechanism are described independently, although often a targeted mix of complementary policies is applied jointly. Renewable energy policies may be implemented in conjunction with policies specifically designed to expand energy access through the deployment of distributed renewable energy technologies *(→ see Distributed Renewable Energy chapter)* or with policies that promote energy efficiency *(→ see Energy Efficiency chapter and Figure 58)*. Specific details on new policy adoptions and policy revisions are included in the policy reference tables and policy endnotes.

TARGETS

Targets for renewable energy continued to be a primary means by which governments expressed their commitment to renewable energy deployment during the year. Renewable energy targets range from official announcements made by governments or heads of state to fully codified plans accompanied by quantifiable metrics and compliance mechanisms, and can focus on individual technologies or sectors, or on economy-wide energy use[i, 9] ***(→ See Reference Tables R15-R19.)***

As of year-end 2016, renewable energy targets were in place in 176 countries. The majority of targets continue to focus on renewable energy use in the power sector, with targets for a specific share of renewable power instituted in 150 countries, and economy-wide targets for primary energy and/or final energy shares in place in 89 countries. Targets for renewable heating and cooling and transport energy use have been introduced to a much lesser degree, in place in 47 and 41 countries, respectively, by year-end 2016.

i The lines between target and regulatory policy mechanisms are often blurred, as in the case of Renewable Portfolio Standards (RPS), which establish mandatory shares, or mandated "targets", of renewable generation that utilities must achieve by a specified date. RPS policies are covered here under regulatory policy mechanisms.

Several joint commitments were made at the regional and international levels. In addition to the 100% renewable electricity commitments made by the 48 CVF member states (see above), the EU proposed a new 2030 Framework under which it aims for renewables to account for at least 27% of total energy consumption and at least a 27% improvement in energy efficiency (relative to a business-as-usual scenario) to help reduce greenhouse gas emissions by 40% in 2030 (compared to 1990 levels).[10] Leaders of Canada, Mexico and the United States reached a deal to source 50% of the region's electricity from non-carbon sources by 2025[i].[11]

At the national level, countries in Asia were particularly active in launching new targets or revising existing ones. China's newest Five-Year Plan sets an overall goal of increasing renewable energy capacity to 680 GW by 2020, accounting for 27% of total power generation.[12] China's Five-Year Plan on Ocean Energy also established a target for achieving a total cumulative capacity of 50 MW of ocean energy from tidal, wave and temperature-gradient technologies by 2020.[13] Additional renewable energy shares or installed capacity targets were enacted in India, Malaysia, the Republic of Korea, Singapore, Taiwan, Thailand and Vietnam.[14]

Elsewhere, targets were adopted or revised in Africa (Cabo Verde, Morocco , Nigeria and South Africa), Europe (France, Finland and Norway), Latin America and the Caribbean (Argentina, Aruba, Cuba, Jamaica and Mexico) and the Middle East (Azerbaijan and Saudi Arabia).[15] Notably, Aruba joined a growing list of countries committed to achieving a 100% share of renewable energy in the electricity sector.[16]

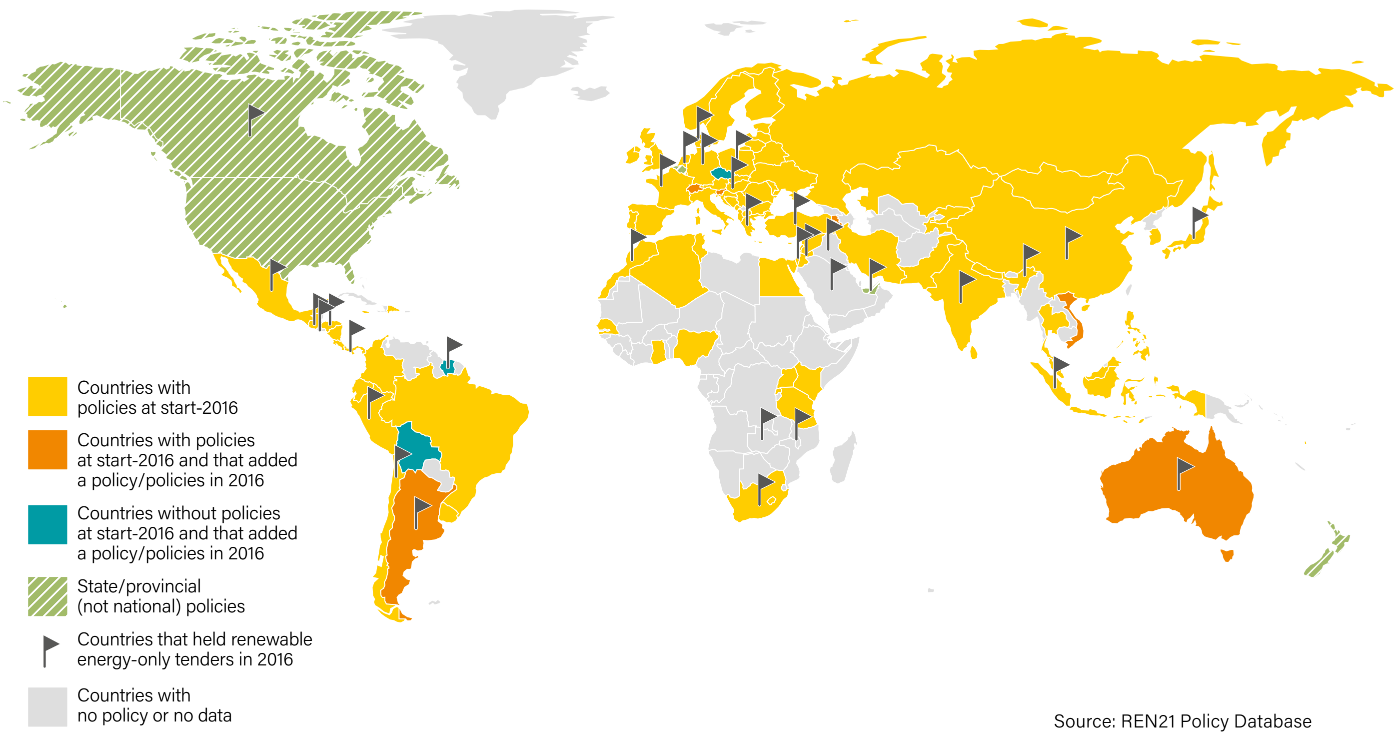
A small number of new renewable transport targets also were established in 2016. In Finland, a target was set for 30% biofuel blending and 40% renewable transport fuels use by 2030, and in Norway a goal was set for 20% biofuels use in transport fuels by 2020.[17] ***(→ See Reference Table R24.)***

New or revised targets also were established at the sub-national level in Australia (Victoria) and in Canada, where all 10 provinces have set renewable energy targets; Alberta announced a 30% renewable electricity target by 2030.[18] The US state of Massachusetts also established targets for installed power capacity.[19] ***(→ See Reference Table R17.)***

Although targets are an important tool, they do not guarantee success. For example, a number of countries in the EU (France, Luxembourg, the Netherlands and the United Kingdom) were identified as likely to miss their 2020 targets.[20] Similarly, targets can become outdated quickly if deployment exceeds the original goals, such as in Europe where solar PV already has exceeded both its 2014 and 2020 targets.[21]

i The 50% by 2025 goal includes renewable energy, nuclear energy, and carbon capture and storage technologies.

Figure 46. Countries with Renewable Energy Power Policies, by Type, 2016



Source: REN21 Policy Database

Note: Figure shows countries with Renewable Portfolio Standards, feed-in tariffs/premium payments and net metering policies. Countries are considered to have policies when at least one national-level policy is in place; these countries may have state/provincial-level policies in place as well. Diagonal lines indicate that countries have no policies in place at the national level but have at least one policy at the state/provincial level.

POWER GENERATION

As in past years, policy makers introduced new support mechanisms and revised existing policies in an effort to respond to changing political, societal and market conditions, with the power sector continuing to receive the majority of attention. *(→ See Figure 46.)* Feed-in policies – feed-in tariffs (FITs) and feed-in premiums (FIPs) – remained the most prominent form of regulatory policy support for renewable power promotion in 2016. ***(→ See Reference Table R20.)*** However, throughout the year countries around the world (most notably in Europe and Asia) continued to shift away from these policies; this was particularly the case when supporting large-scale project deployment, where these mechanisms often have been replaced with auction-based procurement.

The year 2016 marked the second in a row in which no new countries adopted feed-in policies at the national level. Although support for large-scale projects is shifting to tendering in an increasing number of countries, feed-in policies remain in force in many of these countries for the deployment of small-scale installations. Policy makers continue to adjust FIT rates as the technologies become more cost-competitive in ever more areas.

In 2016, the European Commission (EC) approved revisions to several feed-in mechanisms proposed by its member countries. These changes often included the adoption of market premiums for large-scale projects.[22] In a separate move, the EC also announced plans (not yet adopted in 2016) to remove priority dispatch rights for new renewable energy projects, a notable feature of feed-in policies, with the objective of further restricting priority dispatch so that only installations smaller than 250 kW will qualify by 2026.[23]

At the national level, in the Czech Republic, the FIT that previously had been halted was reapproved for new projects and for projects built between 2006 and 2012.[24] The EC approved France's revised renewable energy support scheme, with only installations of less than 500 kW remaining eligible for the FIT; larger projects are to receive premium payments.[25] Germany's Renewable Energy Law (EEG) was reformed to transition from government-set FIT rates (a central component of the EEG originally adopted in 1990) to an auction-based scheme for projects larger than 100 kW.[26] Greece's FIT was amended to allow for small-scale projects and installations on non-interconnected islands to receive support; in separate legislation, Greece transitioned large-scale project support to a FIP that is to be provided over 20 years (25 years for CSP).[27] Slovenia also amended its FIT, making it applicable only to projects below 500 kW.[28]

Elsewhere in Europe, Denmark reintroduced a FIT for small-scale wind power projects, after a previous programme reached its cap and was closed, and the United Kingdom reduced its FIT for all technologies by 65%.[29] Ukraine reduced rates for commercial solar installations greater than 10 MW.[30]

In Asia, several countries reduced rates, including China (which reduced rates by 13-19% for its solar FIT but kept the distributed generation FIT unchanged), Japan (which reduced its solar FIT by 11% for 2016 and aims for cuts of 20% or more in three years), Pakistan (which cut tariffs for solar power by 36%) and the Philippines (which proposed new, lower rates for the third round of its FIT).[31] Moving away from the general trend, Indonesia increased its solar FIT by more than 70% and set a fixed FIT rate for geothermal power.[32]

Modifications were made to feed-in policies in Africa as well. Ghana announced plans to update its solar PV FIT to last for 20 years (up from 10 years); Kenya announced its intention to transition away from FITs to tendering; and Egypt announced a new phase of its FIT programme, including requirements for 30% of financing for solar PV projects and 40% of financing for wind power projects to come from Egyptian sources.[33]

Sub-national jurisdictions in India (Tamil Nadu), Canada (Ontario) and Australia (Victoria and Queensland) also made changes to existing feed-in policies in 2016.[34] Ontario offered 241 MW of contracts to solar PV, hydropower, wind and bio-power projects under the fourth round of its FIT and opened its fifth round of applications, and Queensland increased the size of solar power systems eligible for its FIT from 5 kW to 30 kW.[35] In contrast, Tamil Nadu cut its solar PV FIT rates by 27%.[36] ***(→ See Reference Table R20.)***

Tenders (competitive bidding or auctions) for renewable energy are the most rapidly expanding form of support for renewable

energy project deployment and are becoming the preferred policy tool for supporting deployment of large-scale projects. ***(→ See Reference Table R22.)*** At least 33 countries issued new tenders in 2016; most renewable energy tenders were for solar PV, and to a lesser extent for wind and geothermal power. Renewable technologies also were competitive in some technology-neutral tenders.

Asia was home to some of the largest tenders by capacity in 2016. For example, China tendered 5.5 GW of renewable energy capacity in 2016, up from 1 GW offered in 2015.[37] India held a tender for the deployment of 1 GW of new solar PV capacity alone.[38] Japan announced a schedule for its solar PV tender system, which will be introduced in 2017; Indonesia held a tender for 680 MW of new geothermal capacity spread across six regions; and Turkey held a tender for a single 1 GW solar PV plant.[39] Sub-national tenders were launched during the year in Australia (New South Wales) and India (Tamil Nadu).[40]

Tenders and FITs increasingly are implemented alongside one another. In Europe, this is being driven by EC State Aid guidelines, which have led to policy changes in member countries attempting to meet the requirement to shift towards tendering for certain projects. In 2016, for example, Poland's Renewable Energy Law replaced the existing green certificate scheme with a mix of tenders for large projects and feed-in payments for small-scale projects (up to 10 kW); Slovenia revised its feed-in support scheme to include a two-round tender process for projects over 500 kW; and Greece introduced a package of incentives that includes FIPs, tenders and virtual net metering[i].[41] These reforms led to both Greece and Poland holding their first solar PV tenders in 2016, aiming to contract 40 MW and 100 MW of small-scale projects, respectively.[42]

National solar PV tenders also were held in France and Germany, while the Netherlands held solar power tenders and two rounds of offshore wind power tenders.[43] In December 2016, Spain announced its intention to hold 3 GW of technology-neutral tenders in 2017.[44] A new development in 2016 saw Denmark and Germany enter a unique partnership to launch mutual cross-border solar PV tenders. The pilot programme, the first of its kind, opened auctions to installations in either country, with the objective of expanding cross-border co-operation to include additional countries as well as onshore wind power.[45]

In Africa, Nigeria, in a similar fashion to the multi-pronged approach established in Europe, adopted a tender system for projects larger than 30 MW while formally approving its FIT rates first announced in 2015.[46] Both Malawi and Zambia held their first renewable energy tenders in 2016: Malawi held tenders for four solar PV plants with a cumulative capacity of 70 MW, and Zambia held solar tenders for a total of 100 MW and set a record-low bid price for Africa at USD 0.06 per kWh under a 25-year PPA.[47]

In the Middle East and North Africa (MENA) region, Morocco called for tenders totalling 1 GW of large-scale renewable energy projects.[48] Elsewhere in the MENA region, the Palestinian Energy Authority launched its first tenders in 2016, aiming to boost installed solar PV capacity by as much as 100 MW; Saudi Arabia launched a 100 MW solar PV tender; and Iraq announced a tender for a 50 MW solar PV project.[49] Israel ended its two-year hiatus on new solar power deployment by launching plans to issue more than 1 GW of new solar tenders, as well as tenders for a 500 MW solar PV project in the Negev desert and a 40 MW PV project in Ashalim.[50] Jordan announced its third round of tendering for solar power and its second round for wind power, including a new 200 MW solar PV tender.[51] Sub-national tenders were held in the UAE (Abu Dhabi and Dubai).[52]

In the western hemisphere, Argentina held the first tenders under its RENOVAR programme, which aims to develop 1 GW of renewable energy and includes a green trust fund to help secure investment.[53] Chile held its largest power auction to date to supply 12,430 GWh of electricity annually for 20 years, or about one-third of the country's energy needs; wind power received 40% of the available capacity in this auction, and the world's lowest price for solar PV generation (USD 29.10 per MWh) also was bid.[54] In Central America, El Salvador launched tenders calling for 100 MW of solar power and 50 MW of wind power capacity.[55] Additional auctions were held in Guatemala, Honduras, Panama and Peru. Mexico selected 23 bidders to develop USD 4 billion worth of clean power projects, primarily from solar PV and wind power.[56] Tenders also were held at the sub-national level in the Canadian province of Alberta.[57]

By contrast, South Africa's successful tender programme, a model for many others around the world, was threatened by the country's switch in focus from renewables to nuclear power and by the national utility's refusal to sign PPAs with solar and wind power energy projects.[58] A similarly negative trend was witnessed in Brazil, where reduced demand for electricity and economic challenges caused by the country's contracting national economy led officials to abandon plans to add new solar and wind power capacity through auctions in 2016. After multiple delays, the country's only scheduled solar and wind power auction for the year was cancelled in December, making 2016 the first year since 2009 in which Brazil did not hold a tender for wind power.[59] Due to the country's economic slump, Brazil also took steps to ease the financial burden for now-struggling developers who had won contracts under previous tendering rounds, reducing penalty fees and considering extending project durations to 30 years.[60]

Net metering / net billing has been used to support the deployment of small-scale, distributed renewable energy systems by enabling generators to receive credits or payments for electricity generated but not consumed on site. In many cases, net metering policies have been adopted alongside other policy mechanisms – such as FITs or auctions – that support larger-scale projects. The pace of adoption of new net metering policies slowed in 2016, with Suriname and Slovenia adding new policies.[61] As in past years, net metering continued to see opposition through challenges to the rates paid to power producers and through the adoption of connection fees for self-generators. However, a new trend towards increased accessibility of net metering through virtual net metering continued to emerge throughout the year.

At the national level, a number of amendments were made to net metering policies. Brazil's net metering revision, adopted in 2015 and providing financial incentives to small-scale distributed solar

i Virtual net metering allows for shared electricity output from a single power project that is not installed on-site. Credits are provided, typically in proportion to an individual's ownership share in the system.

PV systems, came into force in 2016.[62] Costa Rica enacted a new net metering price structure designed to encourage businesses and homeowners to generate solar electricity, and Greece approved virtual net metering for specific investors, a change that allows for these investors to receive net metering credits from their ownership stake in off-site generation.[63]

At the sub-national level, in the United States, 41 states, the District of Columbia and 4 territories had adopted net metering policies as of 2016. Battles continued over net metering policies in state legislatures, public utility commissions and the courts between those promoting net metering programmes and electric utilities and their supporters[i].[64] Despite ongoing debate, California, Colorado, Michigan and Nevada all upheld or expanded support to self-generators under net metering programmes in 2016.[65] In Arizona, after an initial rejection of calls to remove net metering, regulators ended the state's retail net metering programme, transitioning new solar customers to a reduced incentive programme with rates to be decided by the state's public utility commission.[66] In Australia, New South Wales revised its existing programme to move from its FIT to net metering for household solar systems.[67]

Regulatory policies that require the deployment of renewable power capacity – the most common of which are Renewable Portfolio Standards (RPS) – continued to be used worldwide in 2016, although the pace of implementation has slowed notably in recent years. At the national level, for the second year in a row, no new RPS policies were introduced in 2016. ***(→ See Reference Table R21.)***

At the sub-national level, however, RPS trends are more dynamic. In the United States, 29 of 50 states, the District of Columbia and 3 territories had targets set under RPS by year's end. In 2016, the general roll-back of state RPS targets was largely reversed, with more-ambitious RPS policy mandates adopted in the US Commonwealth of the Northern Mariana Islands, the District of Columbia and the states of Illinois, Maryland, Michigan, Minnesota, New York, Ohio, Oregon, Rhode Island and Vermont.[68] In Ohio, the first state to freeze its RPS policy, an extension of the freeze that had been in place since 2014 was rejected in 2016, restoring the original policy.[69]

In addition to regulatory policies, several countries provided public funds through grants, loans or tax incentives to drive investment in renewable energy deployment. In early 2016, India launched a 30% capital subsidy for rooftop solar PV installations backed by USD 750 million (INR 50 billion) to fund the new programme; the fund is expected to support 4,200 MW of new capacity.[70] The Republic of Korea pledged to invest USD 36 billion in clean energy by 2020, with 79% of the funds earmarked for deployment of renewable energy and 11% for energy storage.[71] As of end-2016, Sweden removed its tax on solar production in order to advance the national target of 100% renewable electricity by 2040.[72]

Many such incentives have been reduced or eliminated in recent years in response to tightening fiscal budgets and/or falling technology costs. Significant examples from 2016 include the Netherlands, which plans to phase out subsidies over the coming decades (despite these plans, in 2016, a 33% increase in the government's budget for support to renewable technologies was announced), and the United States, which rolled back support for a number of renewable technologies previously supported by the Production Tax Credit.[73]

At the sub-national level, Alberta (Canada) introduced a renewable energy credit funded through the province's carbon tax on large industrial carbon emitters.[74] In the United States, Florida removed property taxes from solar PV panels installed at businesses and manufacturing facilities, and Wisconsin authorised USD 7.7 million for rebates for small-scale, customer-based projects, including solar, geothermal, biogas, biomass and small-scale wind power for both power and non-power uses.[75]

Globally, the development and deployment of supporting technologies such as energy storage and smart grid systems drew increased focus from policy makers at the national and state/provincial levels. *(→ See Enabling Technologies chapter.)* To advance these technologies, many governments are adapting mechanisms that long have been used for the promotion of power generation technologies (including a mix of incentives and regulatory support), as well as newer mechanisms such as tenders, often through direct calls for their integration with renewable technologies.

For example, in 2016, Germany enacted a USD 31.5 million (EUR 30 million) programme to provide loans and grants to support residential solar PV systems combined with battery storage.[76] India made multiple commitments to energy storage, calling for its first bid for solar energy (300 MW of projects) that mandated the inclusion of a storage component.[77] Suriname similarly held a tender for a solar PV installation including battery storage.[78] The United States also awarded USD 18 million to six solar PV projects that integrate energy storage.[79] In a bid to better integrate renewable power sources in the national electricity mix, Jordan launched the first of three tenders designed to enhance the national transmission network to allow solar and wind power generated in the south to reach population centres in the central and northern areas of the country.[80]

Enabling technologies also continued to receive support through policies not directly tied to renewable energy. Sweden announced support for energy storage and smart grid technologies with investments of USD 5.5 million and USD 1 million (SEK 50 million and SEK 10 million) per year, respectively, with an initial outlay of USD 2.75 million (SEK 25 million) provided to energy storage in 2016.[81] At the sub-national level, the US state of California enacted four new pieces of legislation to promote the deployment of energy storage; the state increased funding and required that investor-owned utilities accelerate the pace of deployment.[82]

In 2016, governments also adopted policies to support the development of domestic renewable energy supply chains. For example, under its FIT, Iran established a 35% premium for solar and wind power plants built using domestic content.[83] Also in 2016, Turkey included a premium of up to 50% higher tariffs under the country's wind power FIT if all turbine components are made in the country, and adopted a 50% tariff on solar panel imports.[84] For the first time in the country, a local content requirement also was applied to tender specifications for the Karapinar solar PV project, for which it is anticipated that 75% of

i Opponents of net metering often claim that it increases costs for customers not generating their own power and that net metering policies should be adjusted to better distribute the costs of grid operation.

module components will be manufactured locally.[85] In India, the government plans to support the development of its domestic solar panel manufacturing industry through a USD 3 billion (INR 210 billion) Prayas initiative of government incentives.[86]

During the year, policy makers expanded support for renewable deployment specifically for low-income communities. In 2016, for the first time, the US federal government launched an initiative to promote solar power and energy efficiency for low- and moderate-income Americans.[87] Also during the year, Mexico instituted a USD 106 million initiative, supported by the International Finance Corporation, to finance the construction of solar-powered energy-efficient houses in low-income communities.[88]

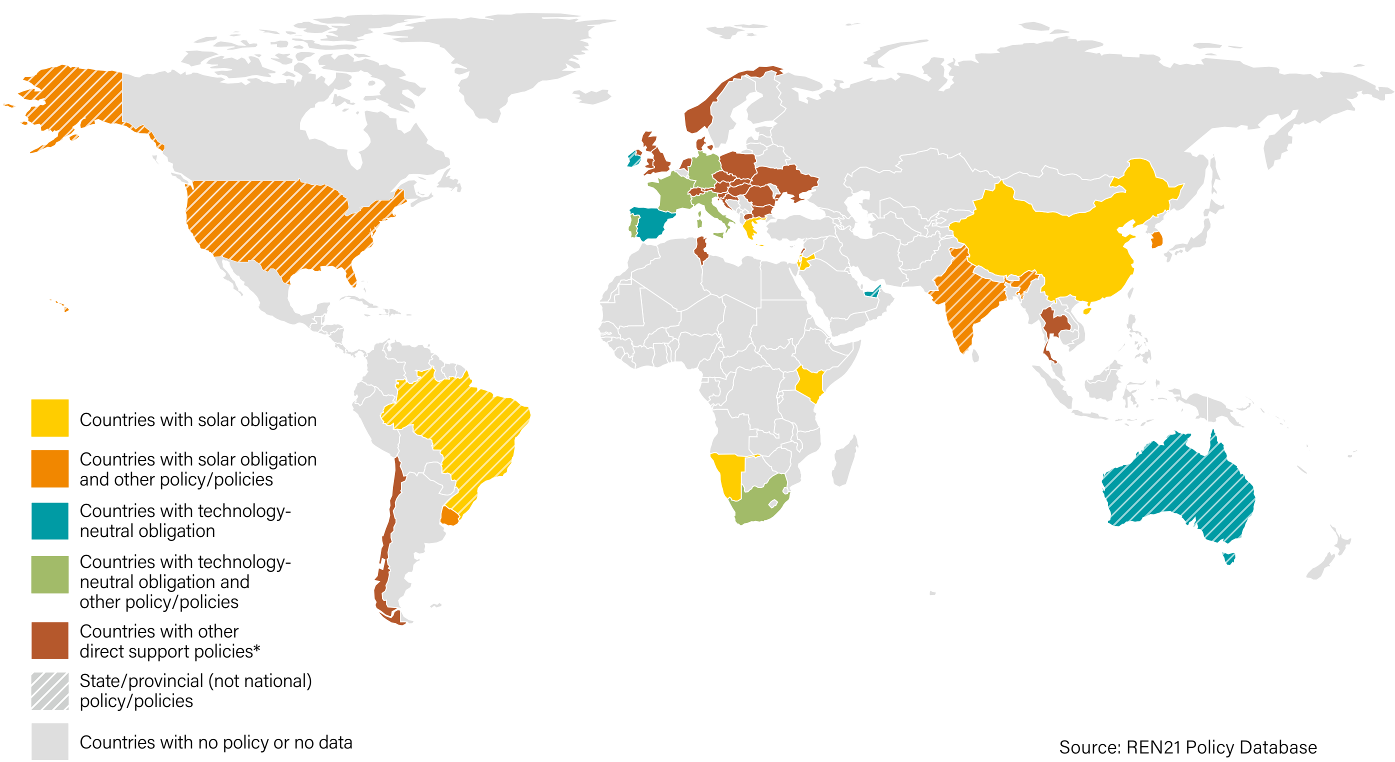
Most policies targeted towards low-income populations have occurred at the sub-national level in the United States. As of 2016, programmes to expand access to renewable energy for low-income communities existed in California, Massachusetts and the District of Columbia, and 12 states had community net metering programmes to help low-income residents access solar PV by allowing the benefits of solar PV to be extended to renters and not only property owners.[89] New state initiatives during the year included New York's USD 3.6 million in funding to support solar PV deployment in low-income communities, and Illinois' Future Energy Jobs Bill, which also promotes solar PV deployment for low-income communities.[90]

RENEWABLE HEATING AND COOLING

Although renewable energy technologies in the power sector continue to receive the most attention from policy makers, some countries are taking measures to increase the deployment of technologies in the renewable heating and cooling sectors as well in order to achieve energy security goals (for example, in the EU) or greenhouse gas emission reduction goals, among others.[91] Despite these efforts, the unique and distributed nature of the heating and cooling market continued to present challenges to policy makers during 2016. High upfront investment costs and competition with low-cost fossil fuels remained impediments to the deployment of renewable heat.[92]

As in the power sector, renewable heating and cooling technologies generally are promoted through a mix of targets, regulatory policies and public financing. During 2016, most government support for the renewable heating and cooling sector was provided through financial incentives in the form of grants, loans, rebates or tax incentives aimed at increasing deployment and, in some cases, incentivising further technological development. Countries also have adopted regulatory mandates, which often are enacted through building codes or, as in some US states, through the inclusion of renewable heat in RPS policies. *(→ See Figure 47 and **Reference Table R23.**)* Although far less

Figure 47. Countries with Renewable Energy Heating and Cooling Policies, 2016



Source: REN21 Policy Database

* Indicates countries with other policies that directly support renewable heating and cooling technologies, including rebates, tax credits, FITs, tenders, etc. *(→ See Table 3.)*

Note: Figure shows countries with direct support regulatory policies and financial incentives for renewable heating and cooling technologies. Countries are considered to have policies when at least one national-level policy is in place; these countries may have state/provincial-level policies in place as well. Diagonal lines indicate that countries have no policies in place at the national level but have at least one policy at the state/provincial level.

common than in the power sector, some governments have used FITs, including the United Kingdom's Renewable Heat Incentive (RHI), and tendering mechanisms, such as those held in South Africa in 2016, to support deployment of renewable heating and cooling technologies.

These policies have continued to focus on the promotion of heating and cooling technologies in the buildings sector and, in many cases, include linkages to energy efficiency policies.[93] *(→ See Energy Efficiency chapter.)* The development of targeted mechanisms to overcome technical barriers to the promotion of renewable heating and cooling in industry – for example, R&D policies to help renewable technologies meet the technical standards (temperature, pressure, quantity) required by industrial consumers – remained a challenge for policy makers during the year.[94]

Europe is the largest producer of renewable heat worldwide and continues to be a global leader in the use of policies to advance the deployment of renewable heating and cooling technologies.[95] In September 2016, the European Parliament adopted a resolution on renewable heating and cooling following the EC's *An EU Strategy on Heating and Cooling* designed to promote the adoption of energy efficiency measures and to provide a framework for policy makers to better integrate renewable heating and cooling into the buildings, industry and electricity sectors.[96] The parliamentary resolution called on EU member states to phase out older, inefficient, fossil fuel-based boilers and recommended the adoption of financing support mechanisms for renewable heat.[97]

At the national level in Europe, Bulgaria re-launched an energy efficiency loan scheme supported by the European Bank for Reconstruction and Development that provides support to a wide range of efficiency improvements and solar water heaters.[98] Hungary expanded policy support to the heating and cooling sector through two rounds of tenders and offered new preferential loans in support of municipal renewable heating and cooling projects.[99] Italy's financial support scheme for up to 40% of the capital costs of renewable heating and cooling installations was revised following limited participation of the public buildings sector compared with extensive participation of the commercial sector. The revised policy increased the capacity limit for eligible installations by 150% and expanded incentives by linking payments to anticipated yield as well as to project size.[100]

Elsewhere in Europe, the former Yugoslav Republic of Macedonia allocated a new round of subsidies covering up to 30% of the cost of installing solar water heaters under its existing support scheme.[101] In the Netherlands, a new building energy support scheme introduced grants for biomass boilers and solar thermal systems (and heat pumps).[102] Portugal adopted two new incentive mechanisms to promote energy efficiency in the buildings sector, including grants for up to 60% of the cost of solar thermal systems in residential buildings and up to 35% in commercial buildings.[103] Romania relaunched a subsidy scheme providing incentives of USD 700-1,870 (RON 3,000-8,000) for the installation of solar thermal systems (and heat pumps).[104] The Slovak Republic adopted a new grant scheme promoting solar thermal systems (and heat pumps).[105]

Despite the positive developments in 2016, policy uncertainty affected the renewable heating and cooling sector in several

countries in Europe. The United Kingdom released plans in early 2016 to remove solar thermal support from its RHI in an effort to "promote value for money", but later reversed this action under pressure from industry groups.[106] In Northern Ireland, the non-domestic RHI was heavily criticised for over-subsidising fuel use and, as a result, was closed to new applications in February 2016.[107] In Switzerland, canton adoption of the national model building energy regulations (including a 10% renewable requirement for heating system retrofits) was delayed in many regions of the country.[108] Similarly, the Swiss Harmonised Incentive Model (including calls for incentives of up to 20% of the total investment cost of solar thermal systems) has been confronted with competing financial policy priorities, forcing some cantons to pledge to end incentives entirely.[109]

Africa also was among the most active regions in renewable heat policy in 2016. Bids for South Africa's long-delayed solar water heater supply, delivery and warehousing tender closed in January 2016.[110] Lesotho, Mozambique and Zimbabwe continued to develop policy for renewable heat in 2016, following early actors on the continent such as Namibia and South Africa.[111]

Elsewhere, Chile extended to 2020 a tax credit for commercial solar thermal systems approximately two years after the original credit expired, including retroactive support for systems installed during the lapse.[112] India enacted new loan incentives designed to help solar process heat developers finance the upfront costs of project development. This new policy builds on an existing 30% subsidy available to developers later in the project development cycle and on a long-term loan programme that offers preferential rates for deployment of solar thermal systems.[113]

The United States extended tax credits for solar thermal heat systems through 2021 and awarded grants through the SunShot Initiative to six R&D projects that aim to reduce the cost of concentrating solar collectors and the energy they generate, with some of the research designed to increase the supply of renewable process heat in the country.[114] The federal tax credit for biomass stoves in the United States was allowed to expire as scheduled at year-end 2016.[115] At the state level, New York State extended its Clean Heating Fuel Tax Credit incentivising the use of biodiesel in heating oil through 2020.[116]

TRANSPORT

Policy support for improving the sustainability of the transport sector traditionally has occurred in two key areas: increasing energy efficiency *(→ see Energy Efficiency chapter)* and expanding the use of biofuels in road transport, although there also is growing interest in electric vehicles (EVs) *(→ see Enabling Technologies chapter)* and in advanced biofuels for aviation and maritime transport. Strong policy support has allowed the renewable transport sector to weather some of the difficulties posed by low international oil prices. However, the reduced price competitiveness of renewable fuels has created investment challenges and has limited discretionary biofuel blending where not mandated.[117]

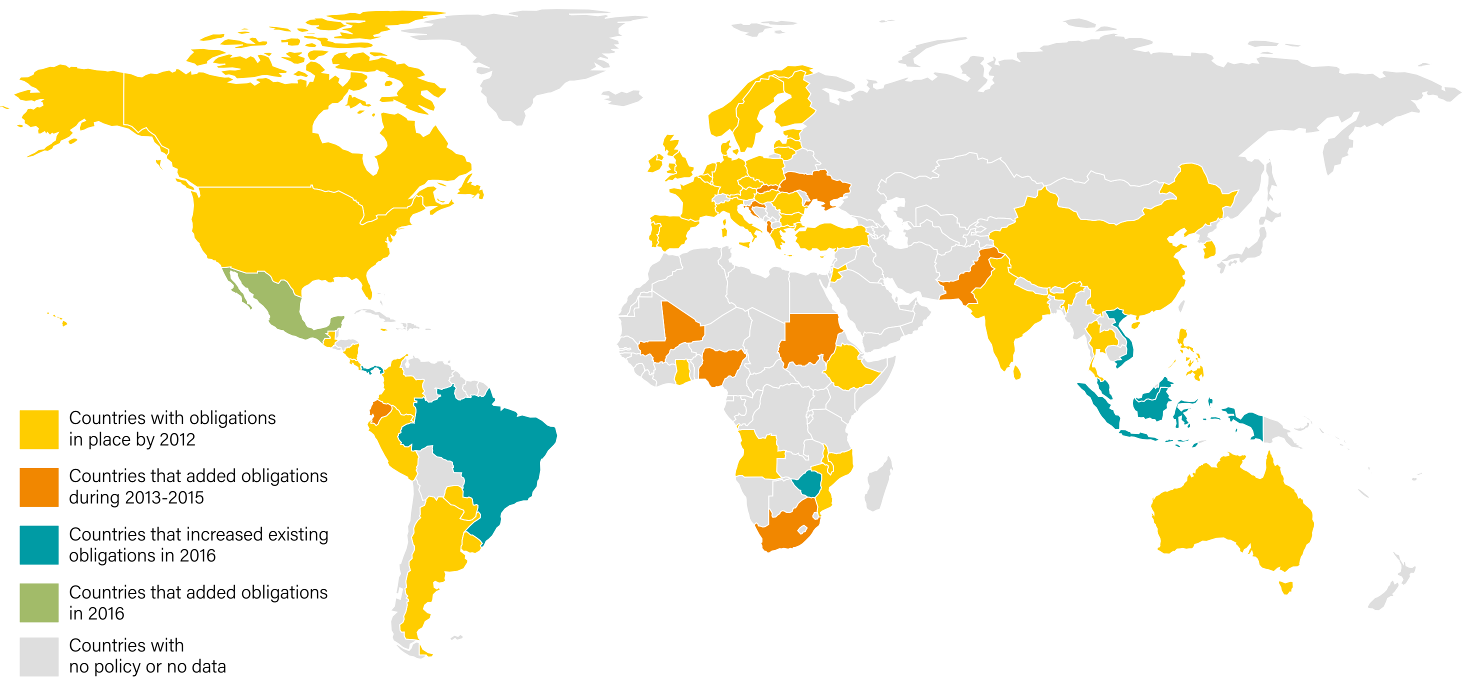
The policy debate over the sustainability of first-generation biofuels continued in 2016; there was a resurgence of the food versus fuel debate, particularly in Argentina, following the rising price of soy oil during the year.[118] In Europe, the new package of clean energy and emissions reduction goals provided guidance on biofuels use. Specifically, the plan calls for a gradual reduction in the share of food-based biofuels in transport fuel, from 7% of transport fuel consumption in 2021 to 3.8% in 2030; "low-emissions" fuels, including renewable electricity and advanced biofuels, are targeted to increase from 1.5% in 2021 to 6.8% in 2030.[119] In Canada, a set of guiding principles for sustainable biofuels was released.[120]

Despite ongoing debates over biofuel production and use, biofuel support policies continued to be adopted during 2016. Biofuel blend mandates and financial support for biofuel blending programmes continued to be the most common forms of support for renewable energy in the transport sector.[121] *(→ See Figure 48 and **Reference Table R25.**)*

In 2016, biofuel blending policy was particularly active in North America. The United States released 2017 blending mandates under its Renewable Fuel Standard, requiring the blending of 73 billion litres (19.3 billion gallons) of renewable fuels, including 16.2 billion litres (4.3 billion gallons) of advanced biofuels and 1.2 billion litres (311 million gallons) of cellulosic biofuels. The United States also established a mandate for blending 7.9 billion litres (2.1 billion gallons) of biomass-based diesel in 2018.[122] Canada announced its intention to adopt a national clean fuels standard, building on sub-national blend mandates already in place in 5 of the country's 10 provinces.[123]

Elsewhere in 2016, Mexico mandated the blending and sale of E5.8 outside of the three metropolitan areas of Guadalajara, Mexico City and Monterrey, where ethanol blending was initially piloted.[124] Argentina enacted a B10 and E10 mandate and announced plans for an E26 mandate to be enacted in 2017; Malaysia increased its B7 mandate to B10; and Indonesia increased its B5 mandate to B20.[125] India set goals of E22.5 and B15 through a new policy that promotes the use of non-conventional biofuel feedstocks (for example, biodiesel from bamboo, rice straw, wheat straw and cotton straw, and ethanol from molasses).[126] Panama's

Figure 48. Countries with Biofuels Obligations for Transport, 2016



Source: REN21 Policy Database

Note: Figure shows countries with biofuels obligations in the transport sector. Countries are considered to have policies when at least one national-level policy is in place; these countries may have state/provincial-level policies in place as well. Bolivia, the Dominican Republic, the State of Palestine and Zambia added obligations during 2010-2012 but removed them during 2013-2015.

ethanol mandate increased to E10; Vietnam established an E5 mandate; and Zimbabwe returned its blend mandate to E15 after a temporary reduction to E5 due to a lack of supply.[127] At the sub-national level, Queensland (Australia) mandated that fuel retailers with 10 or more locations in the province sell specifed shares of renewable blended fuel.[128] The mandate has been supported by a government-backed educational campaign, E10 OK, that promotes the use of biofuels and allows motorists to check the compatibility of their cars for E10.[129] In the United States, Minnesota's B10 mandate that is scheduled to increase to B18 by 2018 was upheld in court after having been challenged by multiple fossil fuel industry associations as being incompatible with the federal Renewable Fuel Standard.[130]

New financial incentives also were introduced in 2016 to promote biofuel production and consumption, biorefinery development and R&D into new technologies. Argentina extended tax exemptions for biodiesel production through 2017, Sweden introduced tax cuts on both ethanol and biodiesel, and Thailand provided subsidies to support a trial programme for the use of B20 in trucks and B10 for military and government use.[131] At the US state level, Hawaii introduced a tax credit for biofuel producers, and Iowa extended biodiesel and ethanol tax credits through 2025.[132] Incentives to the biofuels sector also were rolled back in 2016. Argentina increased taxes on biodiesel exports, Brazil's tax exemption on ethanol was allowed to expire at year's end, and, after being extended in late 2015, the biodiesel tax credit in the United States expired at year-end 2016.[133]

The year also brought increased policy support for the development and use of advanced biofuels. At the international level, the 191 member states of the International Civil Aviation Organization agreed in November to establish a global market-based measure to reduce the sector's CO_2 emissions, which includes specifications for advances in the production and use of sustainable aviation fuel.[134] Nationally, Denmark set a mandate requiring that advanced biofuels represent 0.9% of transport fuel use by 2020.[135] Australia awarded a USD 1.75 million (AUD 2.4 million) grant to develop and construct a biocrude and biofuel laboratory in Queensland, potentially leading to the capability of producing renewable diesel and jet fuel from plant material.[136] The United States launched the Sustainable Biofuels Innovation Challenge to stimulate the development of advanced fuels, announced USD 90 million in funding for biorefineries capable of creating fuel from non-food domestic biomass, and provided separate funding for the development of a demonstration-scale facility capable of producing renewable diesel and renewable jet fuel from industrial waste gases.[137]

Despite increasing attention to advanced biofuels, use of these fuels in the aviation, rail and maritime transport sectors has largely been left out of broader strategies to advance the use of bioenergy in the transport sector. For example, jet fuel is not recognised under the California Low Carbon Fuel Standard, although its inclusion was under consideration as of year-end 2016.[138] Nonetheless, some plans or policies were launched in 2016 that will support the integration of renewable energy in these sectors. For example, India launched its Green Port Initiative, which aims to install wind and solar power systems at major ports across the country.[139]

Few policies directly link electric vehicles to renewable energy at the national or state/provincial level despite the fact that policy support for EVs has been on the rise. *(→ See Enabling Technologies chapter.)* The potential interplay of renewable energy and EVs in transforming transport energy use is gaining political attention.[140]

CITY AND LOCAL GOVERNMENTS

Municipal policy makers play an increasingly important role in promoting the use of renewable energy. This is true for two reasons: 1) more and more policy makers at the local level are setting targets and enacting policies to advance renewables in their cities and towns, and 2) population growth combined with urbanisation has resulted in ever-greater demand for energy services in municipalities and has raised their share of the world's energy consumption. In 2014, cities accounted for 65% of global energy demand, up from approximately 45% in 1990.[141]

Each city has a unique set of resources and pattern of energy use and therefore presents its own unique challenges and opportunities for policy makers. For example, cities such as New York (United States), London (United Kingdom) and Seoul (Republic of Korea) use much of their energy in the buildings and transport sectors, whereas other cities including Shanghai (China) and Kolkata (India) have large industrial sectors that account for the majority of their energy use.

Throughout 2016, the number of cities committed to transitioning to 100% renewable energy in total energy use or in the electricity sector continued to grow. This trend has continued to spread across the globe, with some cities, such as Burlington, Vermont (United States) and more than 100 communities in Japan having already achieved their 100% goals.[142] ***(→ See Reference Table R26.)*** The Australian Capital Territory set a goal of 100% renewable energy by 2020.[143] In the United States, Boulder (Colorado), Salt Lake City (Utah) and St. Petersburg (Florida) joined cities such as San Diego (California), San Francisco (California) and Burlington with targets to achieve 100% renewable energy or electricity.[144] Los Angeles, the second largest US city, directed its municipal utility to determine how to move to 100% renewable electricity, although no specific target was established by year's end.[145]

Several other large cities set less ambitious but still significant targets in 2016, building on the actions of a host of cities with similar targets. ***(→ See Reference Table R26.)*** Calgary (Canada) pledged to power all government operations on renewable energy by 2025.[146] Tokyo (Japan) committed to meeting 30% of electricity demand with renewables by 2030.[147] Cape Town and the Nelson Mandela Bay Metropolitan Municipality (South Africa) set goals of sourcing up to 20% and 10% of renewable electricity, respectively, by 2020 to increase energy security.[148] New York City set targets for 1 GW of solar power capacity by 2030 and 100 MWh of energy storage by 2020.[149] New York City, California and Massachusetts are the three US jurisdictions that had established targets for energy storage by year's end.[150]

A number of cities have established their targets through the carbon*n* Climate Registry (cCR), a global platform designed for cities to publicly and regularly report climate actions. As of 2016 the cCR had registered 237 renewable energy targets including 36 commitments to 100% renewables.[151]

In 2016, municipal policy makers continued to make use of their purchasing and regulatory authorities to spur deployment within their jurisdictions. Government purchasing authorities have the power to transition public transportation fleets to clean fuel or EVs, or to install solar panels on municipal buildings. Municipalities also face many unique challenges, such as the lack of capital needed to finance large infrastructure projects.

Municipal governments have the power to set local building codes, mandate the use of solar water heaters or enact energy efficiency standards. Additional regulations can mandate the collection of energy sector data, helping to improve future energy policy and planning efforts.[152] In 2016, Santa Monica (California) mandated the installation of solar PV rooftop systems for all new buildings and passed a law requiring all new single-family homes to qualify as zero net energy, consuming only as much energy as they produce.[153] San Francisco mandated the use of solar energy, either solar PV or solar thermal heating systems, in new commercial and residential buildings, becoming the largest city in the United States to institute such a mandate as well as the first city in California to allow such a requirement to be met through the deployment of solar thermal systems.[154]

Several city governments also implemented mandates specific to renewable heating and cooling in 2016, joining cities such as Barcelona (Spain), São Paulo (Brazil) and Shenzen (China) as well as 903 municipalities in Italy with existing mandates.[155] Cities also have focused on linking renewable energy to district heating and cooling networks.

In 2016, Oslo (Norway) committed to phasing out fossil fuel heating in homes and offices in favour of renewable heat sources by 2020.[156] New York City mandated the blending of biodiesel into heating oil in the city, with the required share increasing from 2% in 2016 to 5% by October 2017, 10% by 2025 and 20% by 2034.[157] Through the NYC Retrofit Accelerator, New York City also encourages fuel switching away from natural gas for heat and hot water, favouring heat pumps and biofuels by providing information to consumers, including access to both public and private finance.[158]

In the transport sector, Oslo (Norway) pledged to power its public bus fleet with renewable energy by 2020 as part of the city's "climate budget".[159] Reykjavik (Iceland) set a goal to fuel all vehicles (public and private) in the city with renewable energy by 2025.[160] In the United States, Seattle's publicly operated Seattle-Tacoma Airport became the first airport in the world to seek to supply airport-wide access to bio-jet fuel, and Sacramento County (California) began fuelling its liquefied natural gas trucks with biogas.[161] In Mumbai (India), the ethanol import tax was eliminated in an effort to better align with a desire for increased national ethanol use and to reduce local pollution in the city.[162]

Cities continued to collaborate in 2016 to achieve their renewable energy and climate mitigation goals. During the year, the C40 Cities initiative brought together leaders of 90 of the world's largest cities to launch a pathway for cities to meet the goals of the Paris Climate Agreement.[163] The Covenant of Mayors for Climate & Energy attracted another 600 members in 2016, increasing the total number of signatories to more than 7,200 communities with a combined population of 225 million citizens.[164] The group is now committed to increasing energy efficiency and renewable energy deployment to reduce emissions 40% by 2030 (based on each member's Baseline Emission Inventory).[165]

At COP22 in Marrakech, in late 2016, local and regional leaders representing 114 countries launched the Marrakech Roadmap for Action, in part to mobilise the financing needed to make renewable energy infrastructure investments in cities around the world.[166] Also at COP22, a new Covenant of Mayors in sub-Saharan Africa was launched to catalyse municipal-level action on energy access and climate change mitigation and adaptation.[167] At the Habitat III conference in late 2016, countries around the globe adopted the New Urban Agenda, which establishes a roadmap for guiding sustainable urban development over the next 20 years.[168] Under these initiatives, cities have adopted their own unique commitments and strategies for renewable energy deployment.

Table 3. Renewable Energy Support Policies

COUNTRY	Renewable energy targets	Renewable energy in INDC or NDC	REGULATORY POLICIES: Feed-in tariff/ premium payment	Electric utility quota obligation/ RPS	Net metering	Transport obligation/mandate	Heat obligation/ mandate	Tradable REC	Tendering[i]	FISCAL INCENTIVES AND PUBLIC FINANCING: Investment or production tax credits	Reductions in sales, energy, VAT or other taxes	Energy production payment	Public investment, loans, grants, capital subsidies or rebates
HIGH INCOME COUNTRIES													
Andorra			○									○	
Australia	○	○	R*	○	★*	R*	●	○	H*				○[6]
Austria	○		○			○		○		○			○
Bahrain	○	○											○
Barbados[1]	R	○			○						○		○
Belgium	○			●	●	○		○	X	○	○		●
Canada	R*	○	R*	●	●	○			H*	○	○		○
Chile	○	○		○	○			○	H	R[6]	○		○
Croatia	○		○			○							○[6]
Cyprus	○		○		○	○			X				○
Czech Republic	○		★			○		○		○	○		○[6]
Denmark	○		R		○	R		○	H	○	○		○[6]
Estonia	○		○			○						○	○
Finland	R		○			○		○			○	○	○
France	R		R			○	○	○	H	○	○		○[6]
Germany	○		R			○	○	○	H	○	○		R[6]
Greece	○		R	○	R	○	○	○	★	○	○		○
Hungary	○		○			○			★[6]		○		○[6]
Ireland	○	○	○			○	●	○	X				
Israel	○	○	○	○	○		○		H		○		○
Italy	○		○		○	○	○	◊	X	○	○		R[6]
Japan	○	○	R					○	H		○		○
Korea, Republic of	R			○	○	○	○	○		★	○	○	R[6]
Kuwait	○	○							X				
Latvia	○		○		○	○			X		○		
Liechtenstein			○										
Lithuania	○		○	○		○					○		○
Luxembourg	○		○			○							○
Malta	○		○		○						○		○
Netherlands	○		○		○	○		○	X	○		○	R[6]
New Zealand	○	○			●								○
Norway	R	○		○		○		○	X		○		○[6]
Poland	○		R	○		○		○	H		○		○[6]
Portugal[2]	○		○	○		○	○	○			○		R
Qatar	○	○							X				
San Marino		○	○										
Saudi Arabia	R	○							★				
Seychelles	○	○			○					○	○		○
Singapore	R	○			○				X				○
Slovak Republic	○		○			○		○			○		R[6]
Slovenia	○		R		★			○	R	○	○		○[6]
Spain[3]	○					○	○	○	H	○		○	○[6]
Sweden	○		○	○		○		○		○	R		R
Switzerland	○		○				○	○			○		○[6]
Trinidad and Tobago	○	○								○	○		
United Arab Emirates	○	○		●	●		●		H*			●	●
United Kingdom	○		R[6]	○		○		○			○	○	R[6]
United States[4]	R*		●	R*	R*	R	●	●		R[6]	○		R[6]
Uruguay	○	○	◊		○	○	○		X		○	○	○[6]

○ EXISTING NATIONAL (could also include sub-national)
● EXISTING SUB-NATIONAL (but no national)
★ NEW (one or more policies of this type)
◊ Removed

R REVISED (one or more policies of this type)
R* REVISED SUB-NATIONAL
H TENDERS HELD IN 2016, AS IN PAST YEARS
H* SUB-NATIONAL TENDERS HELD IN 2016

i Tendering column includes all countries that have held tenders. Countries that held tenders in 2016 are denoted with "H", and historical tenders where no tender was held in 2016 are denoted with "X".

Table 3. Renewable Energy Support Policies (continued)

COUNTRY	Renewable energy targets	Renewable energy in INDC or NDC	REGULATORY POLICIES							FISCAL INCENTIVES AND PUBLIC FINANCING			
			Feed-in tariff/ premium payment	Electric utility quota obligation/ RPS	Net metering	Transport obligation/mandate	Heat obligation/ mandate	Tradable REC	Tendering[i]	Investment or production tax credits	Reductions in sales, energy, VAT or other taxes	Energy production payment	Public investment, loans, grants, capital subsidies or rebates
UPPER-MIDDLE INCOME COUNTRIES													
Albania	O		O	O		O		O	X	O	O	O	O
Algeria	O	O	O						X			O	O
Angola		O				O							O
Argentina	R	O	O	O		R			X	O	R	O	O
Azerbaijan	R	O											O
Belarus	O		O	O							O		O
Belize	O	O							X				
Bosnia and Herzegovina	O	O	O						X				
Botswana	O										O		O
Brazil	O	O			R	O	●		R	O	O		O
Bulgaria	O		O			O							R[6]
China	R	O	R	O		●	O		H	O	O	O	O
Colombia	R				O	O				O	O		O
Costa Rica	R	O	O		R	O			X		O		
Dominican Republic	R		O		O				X	O	O		O
Ecuador	O	O	O			O			X		O		O
Fiji	R	O								O	O		
Grenada	R	O			O						O		
Guyana	O	O									O		
Iran	O	O	R							O		O	O
Iraq	O	O							H				
Jamaica	R	O			O	O			X	O	O		
Jordan	O	O	O		O	O	O		H		O		O
Kazakhstan	O	O	O					O					O
Lebanon	R	O			O						O		O[6]
Libya	O										O		
Macedonia, FYR of	O		O										R[6]
Malaysia	R	O	O	O		R					O		O
Maldives	R	O	O						X				
Marshall Islands	R	O									O		
Mauritius	O	O							X		O		O
Mexico	R				O	★			H	O			O
Montenegro	O	O	O										
Namibia	O	O					O						
Palau	R	O		O									
Panama	O	O	O		O	R			H	O	O	O	
Paraguay	O	O				O					O		
Peru	O	O	O	O	O	O			H		O		O
Romania	O			O		O		O					R[6]
Russian Federation	O	O	O						X				O
Serbia	O		O										O
South Africa	R	O		O		O	O		H[6]		O		O
St. Lucia	R	O			O						O		
St. Vincent and the Grenadines[1]	O	O			O								
Suriname		O			★				★				
Thailand	R	O	O			O					O	O	R[6]
Turkey	O	O	R			O			H				O

Note: Countries are organised according to annual gross national income (GNI) per capita levels as follows: "high" is USD 12,476 or more, "upper-middle" is USD 4,036 to USD 12,475, "lower-middle" is USD 1,026 to USD 4,035 and "low" is USD 1,025 or less. Per capita income levels and group classifications from World Bank, "Country and Lending Groups", http://data.worldbank.org/about/country-and-lending-groups, viewed March 2017. Only enacted policies are included in the table; however, for some policies shown, implementing regulations may not yet be developed or effective, leading to lack of implementation or impacts. Policies known to be discontinued have been omitted or marked as removed or expired. Many feed-in policies are limited in scope of technology.

Source: See endnote 1 for this chapter.

Table 3. Renewable Energy Support Policies (continued)

COUNTRY	Renewable energy targets	Renewable energy in INDC or NDC	REGULATORY POLICIES: Feed-in tariff/ premium payment	Electric utility quota obligation/ RPS	Net metering	Transport obligation/mandate	Heat obligation/ mandate	Tradable REC	Tendering[i]	FISCAL INCENTIVES AND PUBLIC FINANCING: Investment or production tax credits	Reductions in sales, energy, VAT or other taxes	Energy production payment	Public investment, loans, grants, capital subsidies or rebates
LOWER-MIDDLE INCOME COUNTRIES													
Armenia	○	○	○		○								
Bangladesh	R	○							X		○		○
Bolivia	○	○	○	○	○	○					○	○	○
Cabo Verde	R	○			○				X	○		○	
Cameroon	○	○									○		
Côte d'Ivoire	○	○							X		○		
Egypt	○	○	R		○				X		○		○
El Salvador		○							H	○	○	○	○
Ghana	R	○	○	○	○	○		○			○		○
Guatemala	R	○			○	○			H	○	○		
Honduras	R	○	○		○				H	○	○		
India	R	○	R*	○	●	R	●	○	H	○	○	○	R[6]
Indonesia	○	○	R	○		R			H	○	○		○
Kenya	R	○	R		○		○		X		○	○	○
Kosovo	○		R										
Kyrgyzstan				○							○		○
Lesotho	○	○			○				X	○		○	○
Micronesia, Federated States of	○	○			●								
Moldova	○		○										○
Mongolia	R	○	○						X		○		
Morocco	R	○			○				H				○
Myanmar	○	○									○		
Nicaragua	○		○			○				○	○		○
Nigeria	R	○	○	○		○			★		○		○
Pakistan			R		○	○		○			○		○
Palestine, State of[5]	R		○		○				★		○		
Philippines	R	○	R	○	○	○			X	○	○	○	○
Sri Lanka	R	○	○	○	○	○					○	○	○
Sudan	R	○				○							
Syria	○		○		○				X	○			
Tajikistan	○	○	○								○		○
Tunisia	R	○			○						○		○[6]
Ukraine	○	○	R		○	○					○		○[6]
Uzbekistan									X				
Vanuatu	R	○	○								○		
Vietnam	R	○	○	○		R		○		○	○		○
Zambia		○							★		○		○

○ EXISTING NATIONAL (could also include sub-national)
● EXISTING SUB-NATIONAL (but no national)
★ NEW (one or more policies of this type)
◊ Removed
R REVISED (one or more policies of this type)
R* REVISED SUB-NATIONAL
H TENDERS HELD IN 2016, AS IN PAST YEARS
H* SUB-NATIONAL TENDERS HELD IN 2016

i Tendering column includes all countries that have held tenders. Countries that held tenders in 2016 are denoted with "H", and historical tenders where no tender was held in 2016 are denoted with "X".

Table 3. Renewable Energy Support Policies (continued)

COUNTRY	Renewable energy targets	Renewable energy in INDC or NDC	REGULATORY POLICIES: Feed-in tariff/ premium payment	Electric utility quota obligation/ RPS	Net metering	Transport obligation/mandate	Heat obligation/ mandate	Tradable REC	Tendering[1]	FISCAL INCENTIVES AND PUBLIC FINANCING: Investment or production tax credits	Reductions in sales, energy, VAT or other taxes	Energy production payment	Public investment, loans, grants, capital subsidies or rebates
LOW INCOME COUNTRIES													
Burkina Faso	★	O							X	O	O	O	
Ethiopia	R	O				O					O		O
Gambia	R	O									O		
Guinea	O	O									O		
Haiti	R	O											O
Liberia	O	O									O		
Madagascar	R	O									O		
Malawi	R	O					O		★		O		O
Mali	O	O				O					O		O
Mozambique	O	O				O					O		O
Nepal	R	O	O					O	X	O	O		O
Niger	R	O									O		
Rwanda	R	O	O						X	O	O		O
Senegal	R	O	O	O	O				X		O		
Tanzania	R	O	O								O	O	O
Togo	O	O									O		
Uganda	O	O	O						X		O		O
Zimbabwe		O				R					O		O

[1] Certain Caribbean countries have adopted hybrid net metering and feed-in policies whereby residential consumers can offset power while commercial consumers are obligated to feed 100% of the power generated into the grid. These policies are defined as net metering for the purposes of the GSR.

[2] FIT support removed for large-scale power plants.

[3] Spain removed FIT support for new projects in 2012. Incentives for projects that previously had qualified for FIT support continue to be revised.

[4] State-level targets in the United States include RPS policies.

[5] The area of the State of Palestine is included in the World Bank country classification as "West Bank and Gaza".

[6] Includes renewable heating and/or cooling technologies.

Note: Countries are organised according to annual gross national income (GNI) per capita levels as follows: "high" is USD 12,476 or more, "upper-middle" is USD 4,036 to USD 12,475, "lower-middle" is USD 1,026 to USD 4,035 and "low" is USD 1,025 or less. Per capita income levels and group classifications from World Bank, "Country and Lending Groups", http://data.worldbank.org/about/country-and-lending-groups, viewed March 2017. Only enacted policies are included in the table; however, for some policies shown, implementing regulations may not yet be developed or effective, leading to lack of implementation or impacts. Policies known to be discontinued have been omitted or marked as removed or expired. Many feed-in policies are limited in scope of technology.

Source: See endnote 1 for this chapter.

06

In an energy system, **STORAGE** can be seen as a source of generation as well as demand, offering the possibility to bridge periods of over- and under-production of electricity from variable renewable energy resources. Energy storage solutions include pumped storage, batteries, flywheels and compressed air energy storage.

Salem Smart Power Center – Storage capacity: 5 MW lithium-ion battery, 1.25 MWh energy - Portland, Oregon, USA

06 ENABLING TECHNOLOGIES AND ENERGY SYSTEMS INTEGRATION

This marks the first instalment of a chapter in the Global Status Report *devoted to enabling technologies and energy systems integration. The purpose is to convey information on current developments in various energy technologies, infrastructure, markets and institutional frameworks that advance and facilitate expanded deployment of renewable energy. Due to the emerging linkages between the advancement of various enabling technologies and continued growth in renewables, the GSR examines major themes and developments in this area.*

The remarkable growth in renewable energy production in recent years has been concentrated in the power sector; meanwhile, the heating and cooling and transport end-use sectors have not seen commensurate growth. Most power sector growth has occurred among the variable renewable energy technologies (wind power and solar PV) raising concerns about potential challenges of integrating large shares of variable generation into existing power systems. Against this backdrop, certain enabling technologies – along with improvements in energy infrastructure, energy markets and related institutional frameworks – can serve two synergistic purposes: creating new conduits for renewable energy to reach all end-use sectors, and facilitating the successful integration of ever-growing shares of variable renewable electricity generation.

Enabling technologies can take many forms. For the purpose of this chapter, they are technologies that share the potential to facilitate and advance the deployment and use of renewable energy, and include:

- End-use technologies (e.g., electric vehicles and heat pumps)
- Energy storage (e.g., pumped storage; home-, commercial- or grid-scale batteries; thermal storage)
- Demand-side energy management technologies (e.g., energy management systems in buildings; interruptible industrial load)
- Energy supply and delivery management technologies (e.g., advanced distribution network management and systems control options).[1]

Overall, enabling technologies comprise both the physical infrastructure and the automation technology required to support, for example, greater systems integration, data collection and dissemination of system resources, and effective and efficient demand response. This can enhance the function and efficiency of energy systems and thereby facilitate greater deployment and use of renewable energy.

This chapter reports on current developments for three types of enabling technologies: energy storage, heat pumps and electric vehicles (EVs). None of these technology groups has been developed for the specific purpose of facilitating wider deployment of renewable energy. For instance, energy storage historically has been deployed for use in consumer goods (e.g., mobile phones), in modern manufacturing (for applications where uninterrupted power is critical) and to support large-scale grid power management (i.e., via pumped storage).[2] Heat pumps have been a primary option to improve efficiency in electrified water and space heating. EVs have been pursued largely for their potential to improve local air quality and to reduce the direct use of fossil fuels in the transport sector.[3]

Endnotes: see full version online at www.ren21.net/gsr

These technologies present significant opportunities to bring additional benefits by creating new markets for renewable energy in buildings, industry and transport. For example, electrification of vehicles not only reduces local air pollution, but also allows for rapidly growing renewable power technologies to displace fossil fuels in a sector where renewables other than biofuels previously were barred from entry. Air quality is enhanced further, along with other benefits of expanded renewables deployment. Heat pumps allow renewable power to substitute for fossil fuels in buildings and industrial heat applications, and energy storage solutions help to balance grid-connected renewable energy supply against energy demand and facilitate off-grid renewable energy deployment.[4]

In addition to their potential to create new or expanded markets for renewable energy, enabling technologies can help better accommodate rapidly growing shares of variable renewable electricity generation. Power systems have always required flexibility to accommodate ever-changing electricity demand, system constraints and supply disruptions, but growing shares of variable generation may require additional flexibility from the broader energy system.[5] *(→ See Feature chapter.)* This includes flexible generation; load response from energy consumers; coupling of the electric, thermal and transport sectors; improved delivery infrastructure; and enhanced energy markets and associated institutions. The increased integration of the electricity sector with thermal applications in buildings and industry and with transport is one such approach, as is increased use of energy storage.[6]

While enabling technologies in their own right may present new opportunities for renewable energy, a wide range of additional considerations needs to be explored to promote broader energy system integration. These considerations span various technical, regulatory and market elements that may help to unlock greater synergies between renewable energy generation and various enabling technologies, possibly allowing more optimal outcomes, and they pertain to the following areas[7]:

Market design frameworks that allow both the proper valuation of and compensation for enabling technologies. Enabling technologies can provide a range of services and benefits to individual consumers, energy providers and the energy system as a whole, helping to balance supply and demand, to promote the stability of the power grid and to provide backup energy during power outages or energy shortages. However, there may not be a market framework in place either to establish the economic value of such services or to compensate the owner of the enabling technology once such value is established. This may reduce the attractiveness of investment in enabling technologies.

Legal and regulatory frameworks that allow the participation of enabling technologies, as well as the monetisation of their services. Depending on the jurisdiction, the participation of enabling technologies may not be allowed without changes to laws, regulations and grid codes. For instance, while an individual electric vehicle may be used for backup power during an outage, it may not be permitted to sell power into an electricity market.

Sufficient availability and access to system data, and appropriate legal safeguards thereof. A healthy market for enabling technologies likely will require some level of access to consumer and grid data, such that utilities and possibly other parties may pursue the most valuable opportunities and promote economically efficient allocation of resources. This requires finding a balance between consumer privacy and protection of critical infrastructure data, with the objective of forming an efficient, dynamic and open market.

Adequate technology for grid operators to gather, process and act on system data in real-time and to reliably control and dispatch enabling technology installations from a distance. To maximise the effectiveness and efficiency of enabling technologies, it is necessary to know their moment-by-moment availabilities and capabilities and to understand how best to use them. An infrastructure that can support bi-directional information exchange is required in order to feed a continuous stream of data about the conditions of the power system as a whole, including the availability of enabling technology installations (individual or aggregated) to respond to automated commands based on real-time, system-wide resource optimisation.

ENERGY STORAGE

Energy storage has long been used for a variety of purposes, including to support the overall reliability of the electricity grid, to help defer or avoid investments in other infrastructure, to provide backup energy during power outages or other energy shortages, to allow energy infrastructure to be more resilient, to support off-grid systems and to facilitate energy access for under-served populations. In 2016, a primary driver for advances in energy storage was the demand for battery storage in EVs.[8]

Energy storage technologies can capture energy during periods when demand or costs are low, or when electricity (or heat) supply exceeds demand, and can surrender stored energy (electric or thermal) when demand or energy costs are high. Storage can provide system benefits and flexibility to customers, system managers and utilities and can be applied from the household level (behind the meter) to utility-scale. Storage also can participate in a range of market segments, particularly in power markets, acting as a direct energy provider to the broader system, as hardware to support energy delivery or as a supplementary system for individual households or businesses.[9] *(→ See Figure 49.)* Many ownership models are possible (e.g., utility, third-party, customer level), along with a diverse mix of corresponding business and financing models to promote growth.[10] A number of different energy storage technologies exist and are under development, and their characteristics (response time, discharge time, output capacity and efficiency) and functions vary widely. As of 2016, most electric energy storage capacity relied on pumped storage[i],

Figure 49. Storage Applications in Electric Power Systems

Source: See endnote 9 for this chapter.

the oldest and most mature electricity storage option, as well as the largest in scale (per system).[11] Other electricity storage technologies include batteries (electro-chemical), flywheels and compressed air (both electromechanical). Thermal energy storage, which stocks heating or cooling for later use (e.g., molten salt, ice storage, etc.) also is present in some markets and can serve both thermal applications and electricity by conversion.[12] Only pumped storage is a highly mature technology; all others are undergoing development and transition. The potential for abundant, low-cost energy storage offers the prospect of reconceptualising how energy systems are planned and operated.

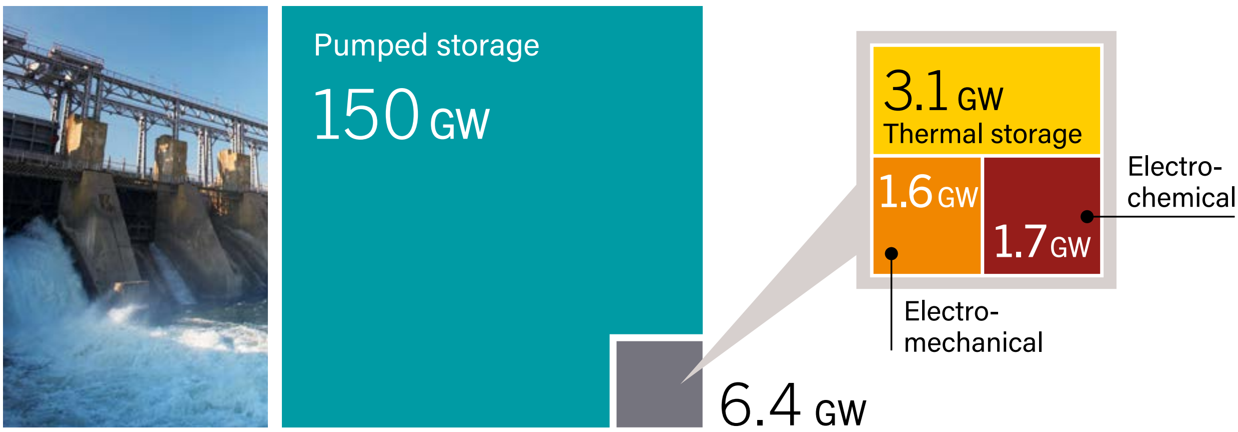
ENERGY STORAGE MARKETS

Global grid-connected and stationary energy storage capacity in 2016 totalled an estimated 156 GW[ii], with pumped storage hydropower accounting for the vast majority.[13] *(→ See Figure 50.)* More than 6 GW of pumped storage capacity was commissioned in 2016, for a year-end total of approximately 150 GW.[14] *(→ See Hydropower section in Market and Industry Trends chapter.)* The rest of this section focuses on energy storage other than pumped storage.

About 0.8 GW of new advanced energy storage capacity became operational in 2016, bringing the year-end capacity total to an estimated 6.4 GW.[15] Most of the growth was in battery (electro-chemical) storage, which increased by 0.6 GW for a total of 1.7 GW.[16] Lithium-ion batteries comprised the majority of new capacity installed.[17] The remaining additions were mainly in the form of thermal storage, which was up by 0.2 GW (mostly molten salt storage at CSP plants), for a year-end total of 3.1 GW.[18] Very little electro-mechanical storage was added in 2016, with the total remaining at 1.6 GW.[19] Emerging technologies such as conversion of surplus electricity to hydrogen or other gases are in the earlier stages of development and demonstration and have not yet seen large deployments.

The United States added the most new non-pumped storage capacity in 2016 (0.3 GW), followed by the Republic of Korea (0.2 GW) and by Japan, Germany and South Africa (0.1 GW each).[20] The United States also had the most non-pumped energy storage capacity (1.5 GW) at year's end, followed by Spain, Germany and Chile. For stationary battery storage alone, the United States was in the lead, followed by the Republic of Korea, Japan, Germany, Italy and Chile.[21] *(→ See Figure 51.)*

Figure 50. Global Grid-Connected Energy Storage Capacity, by Technology, 2016

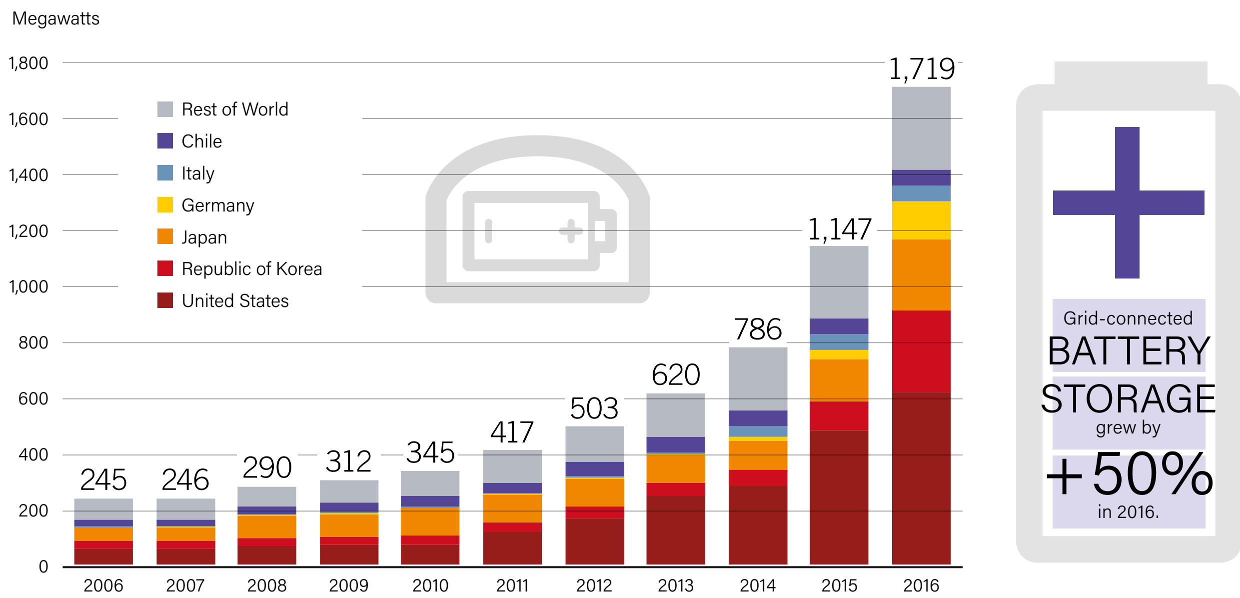


Source: See endnote 13 for this chapter.

i Pumped storage hydropower involves pumping water to a higher elevation to store its potential kinetic energy until the energy is needed. Pumped storage can be implemented in a stand-alone (closed-loop) application or as part of a conventional reservoir hydropower facility (open loop). Without pumping capability, a conventional reservoir hydropower facility can serve as storage only in the context of deferred generation, meaning that generation can be held off to accommodate other generation (such as solar PV and wind power), but excess grid power cannot be captured for storage.

ii This total aims to include all storage with the exception of off-grid storage or batteries in EVs, but it may exclude some thermal storage in district heating systems.

Figure 51. Global Grid-Connected Stationary Battery Storage Capacity, by Country, 2006-2016



Source: See endnote 21 for this chapter.

The 0.3 GW of non-pumped storage capacity added in the United States during 2016 included 0.1 GW of molten salt thermal storage at a CSP plant in Nevada, with the remainder being mostly battery storage, comprising primarily lithium-ion technology.[22] A large portion of the battery storage additions was installed in California in anticipation of an electricity shortfall due to a natural gas leak.[23] By one estimate, about 20% of new US battery storage capacity was in residential and commercial behind-the-meter installations.[24]

The Republic of Korea's additions (0.2 GW) in 2016 were all in the form of electro-chemical storage, bringing the national total to 0.3 GW.[25] The electric utility deploying the technology noted the importance of owning and operating emission-free resources to support its frequency control markets.[26]

Deployment of energy storage capacity also is rising rapidly in Japan, where more than 0.1 GW was brought online in 2016 for a year-end total of 0.25 GW.[27] Following the March 2011 earthquake, Japan's government began to explore options to increase power system reliability and cross-regional co-ordination of the electric grid through market liberalisation.[28] Energy storage has been deployed to provide flexibility to the country's rapidly increasing output of variable renewable energy (particularly solar PV).[29]

In Europe, Germany saw the largest additions of non-pumped storage during 2016, with 36 MW of large-scale projects commissioned for a year-end total of 1.1 GW.[30] The country's residential storage market (behind the meter) is expanding as a growing share of solar PV systems is paired with battery storage; rising from 14% of PV systems in 2014 to more than half of new installations in 2016.[31] An estimated 25,355 home energy storage systems were installed in Germany during 2016, accounting for about 80% of Europe's annual market.[32]

Also in Europe, a 20 MW battery storage project was installed in the Netherlands in 2016 as a replacement for a natural gas peaker generation plant.[33] The United Kingdom committed to significant additional future capacity when National Grid (the owner and operator of the transmission grid in England and Wales) procured 0.2 GW of Enhanced Frequency Response services through an auction in mid-2016; all winning bids were in the form of storage solutions that are to be implemented in 2017–2018, at a total cost of USD 81 million (GBP 66 million).[34]

China has relatively little storage capacity to date, beyond pumped storage. However, this could soon change due to a pilot programme, launched in 2016, to address curtailment of solar and wind power in three of the country's northern regions. This programme is designed to allow energy storage to provide services such as peak shaving and frequency regulation and to receive payment for services provided.[35]

Australia, with one of the world's highest penetrations of residential solar PV, is a small but rapidly expanding market for small-scale, behind-the-meter battery storage systems.[36] Battery storage systems are being used to increase on-site use of distributed generation. Rising electricity prices, falling costs of solar PV systems and declining feed-in-tariffs have combined to drive Australia's market for residential battery systems in conjunction with solar PV.[37] Many solar suppliers have begun to offer battery solutions as part of their solar installations, and the market is growing rapidly from a small base.[38] In 2016, the annual residential storage market grew 13-fold, with nearly 7,000 systems installed.[39]

While most advanced storage capacity added in 2016 was in the form of batteries (electro-chemical), thermal storage is playing an increasingly important role alongside CSP plants. In South Africa, 0.1 GW of molten salt thermal storage came into operation during 2016 at two CSP plants, providing several hours of plant operating capacity.[40] China also added a small amount of CSP-linked storage capacity.[41] *(→ See CSP section in Market and Industry Trends chapter.)*

Seasonal storage for heat generated by renewable energy for district heating systems (heat is fed in the summer, taken out in winter) continued to be used in several European countries and in Canada in 2016.[42] Such systems often are combined with the electric grid, using excess electricity for stored heat.[43]

ENERGY STORAGE INDUSTRY

The year 2016 was characterised by the diversification of utilities, renewable energy companies, vehicle manufacturers and oil and gas companies into the storage industry in order to capture rapidly growing markets. For example, Innogy SE, the renewable energy subsidiary of German utility RWE, took over the solar and energy storage business of Belectric Solar & Battery, and Total (France) acquired a majority stake in Saft Groupe (France).[44]The year also was marked by the expansion of product options and manufacturing capacity, increased pairing of storage with other systems (including solar PV and wind power) and ongoing advances in a range of storage technologies.

As of 2016, Panasonic (Japan) dominated the production of lithium-ion batteries for EVs and other applications, with double the output of its nearest competitor.[45] The company collaborates with Tesla (United States) through the latter's US-based Gigafactory, which started mass production of lithium-ion batteries in late 2016.[46] Other leading manufacturers of batteries for EVs include Samsung SDI and LG Chem (both Republic of Korea).[47] Chinese manufacturers are rapidly gaining market share, including BYD and Contemporary Amperex Technology, which reportedly benefit from preferential domestic treatment over their three Japanese and Korean competitors, which are pursuing battery manufacturing in China.[48]

In the power sector, several companies advanced new home storage options to compete in this rapidly growing market. For example, Daimler AG (Germany) started delivery of its Mercedes-Benz stationary residential energy storage units using lithium-ion batteries that were originally designed for automotive use, and committed to mass development of a lithium-ion battery line in California.[49] Germany's second largest utility, E.ON, launched a residential solar-plus-storage option in its home country.[50] Sonnen (Germany) launched a home battery for self-consumption in the United States, priced at 40% below the company's existing residential system.[51] In the first half of 2016, Sonnen held a 23% market share across Australia, Europe and the United States, followed by LG Chem (Republic of Korea) and Deutsche Energieversorgung.[52]Numerous partnerships were launched or announced to develop or distribute solar-plus-storage solutions during the year.[53] For example, solar PV inverter manufacturer Sungrow (China) and Samsung (Republic of Korea) launched a joint venture to provide complete energy storage systems.[54] US-based solar technology company Enphase Energy joined Tesla, LG Chem and others in the battery storage market in Australia in response to the country's surge in rooftop solar power.[55] In addition, wind turbine manufacturer Envision (China) and GE Ventures (United States), among others, acquired stakes in Germany's Sonnen to increase their presence in fast-growing energy storage markets in Australia, Europe and the United States.[56]

Several utility-scale renewable energy-plus-storage plants were completed in 2016, including Tesla's first solar-plus-storage installation in the United Kingdom and a Sungrow facility in China.[57] Renewable Energy Systems (United States), an international wind and solar power developer, has begun diversifying into large-scale storage and had built 70 MW of storage capacity in North America by early 2016.[58] In May of that year, solar PV developer SkyPower (Canada) and BYD announced an agreement to bid for up to 750 MW of solar-plus-storage capacity in India's upcoming tenders.[59] E.ON continued to expand its industrial-scale battery technology operation during the year and announced plans in early 2017 for two projects (totalling nearly 20 MW of storage) at its existing wind farms in Texas.[60]

Also in 2016, German flywheel developer Stornetic presented an energy storage solution for wind farms that allows operators to balance output fluctuations over the long term and that could enable wind farms to provide grid services.[61] The company also launched a 1 MW flywheel storage unit, quadrupling the output of its machine, and commenced a joint project with EDF (France) on advanced smart grid storage solutions.[62] In late 2016, Stornetic announced that it had optimised its EnWheel system for transport use, enabling operators to store the braking energy of trains to power acceleration for departure from stations.[63]

Large increases in manufacturing scale, improvements in storage capacity and density, and reductions in material costs are working to push down the costs of batteries and other storage technologies.[64] Between 2010 and 2015, the average price of lithium-ion batteries used in EVs fell 65%, to USD 350 per kWh.[65] As of late 2016, lithium technology prices were as low as USD 1,600 to USD 1,900 per kW installed when deployed on a large scale (e.g., comparable to a 100 MW natural gas-fired power plant).[66]

Lead-acid batteries, which remain common for off-grid installations, have experienced an increase in lifespan through the integration of carbon. This advance has reduced the costs of lead-acid batteries dramatically.[67] The costs of alternative chemistry batteries also have declined in recent years, due mostly to falling subcomponent costs and longer operating lives; these advances, in turn, have unlocked additional services and applications. For flow batteries, technology advancements are resulting in longer operating ranges (discharge time), and the introduction of larger-scale manufacturing is driving down prices.[68] The costs of thermal and non-battery storage technologies, such as compressed air, vary widely; however, all have seen steady cost reductions.[69]

Several promising storage options were entering the pilot stage during 2016. The Stored Energy in the Sea project, led by Germany's Fraunhofer Institute for Wind Energy and Energy System Technology, began piloting a novel pumped storage concept for large-scale storage of ocean energy. Researchers estimate that the concept, which uses water pressure to drive electro-mechanical pump components housed in submerged storage units, could deliver cycle efficiency and levelised costs of storage per kWh similar to conventional pumped storage.[70] Also in Germany, GE won a contract to supply wind turbines for Naturstromspeicher Gaildorf, a pilot project combining wind energy and pumped storage. The base of each 3.4 MW turbine will act as a water reservoir; an additional lower reservoir pumped storage facility, which will use Voith (Germany) reversible Francis pump-turbine units, lies 200 metres below in a nearby valley.[71]

ENERGY STORAGE POLICIES

Policies to support deployment of energy storage include policy-driven procurement targets, energy market reforms and utility mandates, as well as financial incentives such as grants, loans and tax credits. Generally, policies target either distributed, customer-sited behind-the-meter storage (residential and commercial) or large-scale utility projects in front of the meter. Few incentives exist, and as of end-2016 only a handful of governments had adopted targets for energy storage. For example, in 2016 New York City set a target of 100 MWh by 2020.[72] However, energy storage is receiving increased attention and support from policy makers and regulators in a number of countries around the world.

To date, mandates for utility-scale capacity have been the most common form of support for energy storage. In the United States, electric utilities in California are required under a 2010 state mandate to procure a total of 1.3 GW of energy storage by 2020; this mandate was expanded by an additional 500 MW of energy storage in 2016.[73] In addition, utilities in southern California were directed by the state's Public Utilities Commission to quickly procure over 60 MW of electricity storage by year's end to overcome an expected electricity shortfall due to a devastating natural gas leak discovered in late 2015.[74]

Other states and territories are following California's lead. Oregon passed legislation in 2015 requiring that the state's main utilities deploy 5 MWh of storage by 2020.[75] In 2016, Massachusetts became the third US state to pass an energy storage mandate.[76] Puerto Rico mandated in late 2013 that renewable energy project developers incorporate energy storage into new projects.[77] In Canada, the province of Ontario has mandated the procurement of energy storage, with most projects designed to provide frequency regulations service or voltage support to improve grid functions; a two-part solicitation in late 2015 resulted in contracts for 50 MW of storage capacity.[78]

In 2016, countries also supported storage through tenders. For example, India called for its first tender for solar energy (300 MW of projects) that mandated the inclusion of a storage component.[79] Suriname also held a tender for a solar PV project that included battery storage.[80]

In part because electricity storage can be considered both generation and load (similar to supply and demand), regulations governing its role and function can differ greatly from one market to the next. To ensure regulatory consistency, in 2016 the EU's Energy Commission proposed a regional definition[i] for energy storage.[81] In some countries, regulatory bodies are clarifying the rules for the participation of energy storage by removing barriers to participation and creating market structures for fast-responding resources. For example, in 2016 the US Federal Energy Regulatory Commission (FERC) began exploring regulations to further reduce market barriers to energy storage solutions.[82] This built upon FERC's 2011 mandate to create compensation mechanisms for fast-response regulation service providers that can support the grid when frequency deviation occurs with either fast-response generation or stored energy.[83]

Some governments are using financial incentives to improve the cost-competitiveness of emerging storage technologies. Germany offers a variety of incentive programmes, including low-interest loans and grants for specific uses, customer segments and storage technologies. In 2016, Germany extended its incentive programmes for residential solar PV-linked storage through 2018.[84] Elsewhere in Europe, Italy provides a tax rebate for battery storage in solar PV systems, and some cantons in Switzerland offer subsidies.[85] Sweden announced support for energy storage and smart grid technologies with investments of USD 5.5 million and USD 1 million (SEK 50 million and SEK 10 million) per year, respectively, with an initial outlay of USD 2.75 million (SEK 25 million) provided to energy storage in 2016.[86]

In Asia, Japan offers a national subsidy for residential batteries, and China has offered significant incentives, such as subsidies and domestic quotas, to spur development of a domestic storage industry.[87] The Republic of Korea pledged in 2016 to invest USD 36 billion in clean energy by 2020, with 79% of the funds earmarked for deployment of renewable energy and 11% for energy storage.[88]

In the United States, an investment tax credit is provided for up to 30% of the value of a qualifying energy storage system.[89] In 2016, the country also awarded USD 18 million to six solar PV projects that will integrate energy storage.[90] At the state level, California's Self-Generation Incentive Program, which provides rebates for customer-sited generation and storage systems installed on the customer's side of the utility meter, allocates 75% of its annual USD 87 million budget to storage technologies and has been vital to the growth of customer-sited storage in the state.[91] New York State offers incentives for commercial and industrial customers to install batteries to reduce peak load.[92]

On a smaller scale, the Australian cities of Adelaide and Melbourne have provided incentives for the installation of solar PV systems plus energy storage to increase self-consumption from solar projects.[93]

i Storage was defined as "the act of deferring an amount of the energy that was generated to the moment of use, either as final energy or converted into another energy carrier". European Commission, *Energy Storage – Proposed Policy Principles and Definition* (Brussels: June 2016), https://ec.europa.eu/energy/sites/ener/files/documents/Proposed%20definition%20and%20principles%20for%20energy%20storage.pdf.

HEAT PUMPS

Heat pumps are used mainly for space heating and cooling of buildings, as well as for some industrial heating and cooling applications. Heat pumps transfer heat from one area (source) to another (sink) using a refrigeration cycle driven by external energy, either electric or thermal. They provide efficient heating, cooling, humidity control and hot water for residential, commercial and industrial applications by drawing on one of three main sources: the ground, ambient air, or water bodies such as lakes, rivers or the sea. Heat pumps also can use waste heat from industrial processes, sewage water and buildings.

Depending on a heat pump's inherent efficiency and on its external operating conditions, it has the potential to deliver significantly more energy than is used to drive it. A modern, electrically driven heat pump under optimal operating conditions (a modest "lift" in temperature from source to sink) can easily deliver three to five units of energy for every one unit of energy that it consumes. That incremental energy delivered is considered the renewable portion of the heat pump output (on a final energy basis)[i]. When the input energy is 100% renewable, so is the output of the heat pump.

HEAT PUMP MARKETS

The scale of the global heat pump market is difficult to assess due to the lack of data and to inconsistencies among existing datasets. Part of the reason for limited and fragmented data on heat pumps may be due to variation in how systems are classified. In moderate climates, where cooling demand is dominant, heat pumps generally are counted as air conditioning equipment, with a side benefit of dehumidification or provision of hot water. In cold climates, the heating service is much more important and thus heat pumps are counted as heating equipment, with cooling and dehumidification considered welcome byproducts.[94]

Air-source heat pumps make up the largest share of the global heat pump market, representing more than 80% of the European market[ii], followed by ground-source heat pumps. The vast majority (90%) of air-source units installed around the world are used primarily for cooling and for dehumidification in mild and warmer climates.[95] However, global data for air-source installations are limited.

Most ground-source heat pumps are used for heating in colder climates, but they also can serve cooling and dehumidification loads.[96] As of end-2014, the global stock of ground-source heat pumps represented an estimated 50.3 GW_{th} of capacity, producing approximately 327 PJ (91 TWh) of output.[97] The largest markets for heat pumps are the United States, China and Europe as a whole, where France, Germany, Italy and Sweden were the most significant national markets in 2016.[98]

Europe's combined heat pump market (for both air- and ground-source) grew by about 12% in 2015 (the most recent year for which data are available), adding 890,000 units for a total of 8.4 million units installed.[99] By the end of 2016, total European installed heat pump capacity reached about 73.6 GW_{th}, producing an estimated 148 TWh of useful energy, of which about 94.7 TWh[iii], or 64%, was derived from ambient air and the ground, and the rest was derived from input energy.[100]

The top 10 markets in Europe account for 90% of the region's sales.[101] As of end-2014, Sweden led the region for ground-source heat pump capacity with a total of 5.6 GW_{th} in operation and 52 PJ (14.4 TWh) of output.[102] Sweden's output implies a utilisation rate (capacity factor) of over 29%, compared to a global average of less than 21% and a US average of less than 13%. Differences in utilisation rates are explained by variations in climate and the sizing of systems (i.e., whether units are sized for heating load only or for peak-cooling load, which may result in oversizing of units for heating load).[103]

In recent years, relatively low oil prices have slowed heat pump sales in some markets, and for ground-source units in particular. In Germany, sales of ground-source heat pumps in 2015 (12,500 units and 22% of the total German heat pump market that year) declined by 8.1% relative to 2014, despite government support programmes. By contrast, air-to-water heat pumps showed a small increase of 1.3% in 2015.[104] Finland also saw mixed results: the overall heat pump market grew 2.4% in 2016, to over 60,000 units, but the growth was all for air-source units. Finland's sales of ground-source systems, which accounted for 14.1% of the heat pump market, declined by 7.8% in 2016.[105]

For the United States, the total market size is uncertain. As of late 2014, the market for ground-source heat pumps was growing at an estimated average rate of 8% annually, and a total of 1.4 million units was in operation, representing 16.8 GW_{th} of capacity and an estimated 67 PJ (18.5 TWh) of output.[106]

China had approximately 11.8 GW_{th} of ground-source heat pumps in place at the end of 2014, producing an estimated 66.7 PJ (14.4 TWh).[107] Although sales of heat pumps (for heating) remain small in China – with fewer than 10,000 units sold in 2015 – they jumped three-fold that year relative to 2014.[108]

Elsewhere in Asia, Japan and the Republic of Korea also are significant heat pump markets. As of 2015, Japan had in place an estimated 100 MW_{th} of ground-source heat pumps.[109] The Republic of Korea had in place nearly 800 MW_{th} of heat pump capacity by the end of 2014.[110] In 2015, the country's stock grew by about 10%, reaching 0.3 million units.[111] It is estimated that the heat pump market share represents 3-4% of the country's 7 million residential, commercial, industrial and public buildings.[112]Demand for heat pumps is spurred by ever-stricter efficiency standards for building envelopes. Well-insulated and

i The total share of renewable energy delivered by a heat pump on a primary energy basis depends on the efficiency of the heat pump and on its operating conditions, as well as on the composition of the energy used to drive the heat pump. A heat pump operating at a performance factor of four, driven by electricity from a thermal plant at 40% efficiency, provides about 1.6 units of final energy for every 1 unit of primary energy consumed (4/(1/0.4) = 1.6).

ii Market data for Europe from the European Heat Pump Association (EHPA), which includes 19 EU countries plus Norway and Switzerland, are indicative for all of Europe. Countries not covered are small or do not have a method to collect data.

iii This is based on an average performance factor of 2.77, which implies that the installed heat pump stock delivers 2.77 units of thermal output for each unit of energy input. EHPA, *European Heat Pump Market and Statistics Report 2016* (Brussels: 2016), http://www.researchandmarkets.com/research/dvqr4b/european_heat.

air-tight buildings can be heated, cooled and dehumidified at relatively low thermal differentials ("lift" from source to sink), creating a particular synergy between heat pumps and efficient building design. Moreover, as building design and construction become more efficient, smaller heat pumps are required, reducing initial system cost and further improving the competitiveness of heat pumps relative to conventional fossil fuel systems. The positive effect of building codes has been seen mainly in new construction; however, building renovations invite the use of heat pumps, either as full replacements or as hybrid solutions that supplement existing heating and cooling systems.[113]

The potential for heat pumps in industrial applications is comparable to that in residential and commercial applications. However, availability of data for the industrial segment is even more limited.

HEAT PUMP INDUSTRY

The industry is characterised by a large number of relatively small entities, although consolidation accelerated in 2016. Manufacturers have pursued acquisitions mainly to gain access to markets and to increase market share, as well as to access know-how and to complement existing product portfolios.

In recent years, the global heat pump industry has grown in scale and scope as major manufacturers from Europe, China and the United States have extended their areas of activity both geographically and sectorally (integrating heating and cooling, as well as ventilation and, increasingly, dehumidification). A typical example is the acquisition of air conditioning and ventilation companies by boiler manufacturers, and vice versa. US and Chinese companies have acquired companies in Europe, and European companies have invested in the United States and Asia.[114] Among the notable developments in 2016, Midea Group (China) acquired an 80% stake in Clivet (Italy), UTC (United States) completed a 70% acquisition of the Italian HVAC company Riello Group S.p.A., and Mitsubishi (Japan) acquired DeLclima (Italy) and its subsidiaries Climavenata and RC Group.[115] Swedish heat pump maker Nibe completed several acquisitions, including US-based Climate Control Group and the heat pump operations of Enertech (United Kingdom).[116]

Other notable trends in the industry include the combination of heat pump technologies with ventilation, and the integration of heat pump technologies and solar PV to increase on-site consumption of distributed generation. Further synergies are suggested by the correlation between solar irradiation and cooling load, and the opportunity to use the "waste" heat from heat pump cooling for domestic hot water production.[117]

Manufacturers of heat pumps and solar PV inverters are co-operating to develop standards that enable a connected and optimised operation of heat pump and solar PV systems. In some instances, heat pumps are being configured to provide demand-response services to "smart" electric grids, in order to take advantage of their inherent operational flexibility.[118] Heat pumps that use water as a thermal medium for heating and cooling employ water storage tanks that can aid in this regard.

Growing market penetration and increasing sales of heat pumps also are resulting in cost reductions for components and systems due to technical progress and economies of scale. A doubling of the installed heat pump stock is expected to result in a 20% cost reduction of heat pumps.[119]

HEAT PUMP POLICIES

In addition to indirect support provided by energy efficiency standards and building codes, there are some limited examples of support policies specific to heat pumps, mostly in the form of fiscal incentives such as grants, loans and tax credits. Drivers for heat pump support policies include improvements in energy efficiency of space heating, increased use of renewable energy and reductions in local air pollution.[120]

Several incentives were adopted in Europe in 2016 to support the use of heat pumps as well as renewable heat technologies. In the Netherlands, a new building energy support scheme introduced grants for heat pumps, as well for biomass boilers and solar thermal systems.[121] Romania relaunched a subsidy scheme providing incentives of USD 700 to USD 1,870 (RON 3,000 to RON 8,000) for the installation of heat pumps (and solar thermal systems), and the Slovak Republic adopted a new grant scheme that promotes heat pumps (and solar thermal systems).[122]

Germany has backed up its commitment to increase its share of renewable energy in the heating market by 2020 to 14% by providing incentives for heat pumps (among other technologies) under its Market Incentive Program. In 2015, the programme provided about USD 13.1 million (about EUR 12 million), which supported the installation of 3,700 heat pumps (equivalent to about 20% of average system cost), about half of which were air-source heat pumps.[123]

Since 2014, the UK Renewable Heat Incentive (RHI) – similar to feed-in tariffs for electricity generation – has provided incentive payments for the heat output of renewable heat technologies, including the renewable portion of heat pump output. Starting in 2017, tariffs paid were set to rise, alongside limits on annual heat demand for eligible residential air- and ground-source systems (20 MWh and 30 MWh, respectively) and a requirement to meter electrical input in all residential systems in order to provide better information on actual system performance.[124]

The United States also has enacted policies to support heat pump markets. For example, a 10% corporate tax credit for ground-source heat pumps was in place as of early 2017, as was an accelerated depreciation scheme for businesses; a 30% federal tax credit for ground-source heat pumps expired at the end of 2016.[125] In addition, many US states offer direct support for ground-source heat pumps in the form of tax incentives, rebates, grants or loans.[126] Through the NYC Retrofit Accelerator, New York encourages fuel switching away from natural gas for heat and hot water, favouring heat pumps and biofuels by providing information to consumers, as well as access to both public and private finance.[127]

In China, the Beijing municipal government began providing a subsidy of approximately USD 3,600 (RMB 25,000) per household to replace 150,000 coal boilers with air-source heat pumps during 2016.[128] The effort was successfully completed at year's end. Tianjin, Shandong and Hebei provinces planned to follow with similar incentives in 2017.[129]

ELECTRIC VEHICLES

Electric vehicles encompass any road-, rail-, sea- and air-based transport vehicles that use electric drive and can take an electric charge from an external source, or hydrogen in the case of fuel cell EVs. Some EV technologies are hybridised with fossil fuel engines (for example, plug-in hybrid electric vehicles, or PHEVs), while others use only electric power via a battery (battery EVs). A third variant uses fuel cells to convert hydrogen into electricity.

Beyond offering the prospect to reduce fossil fuel use in the transport sector, EVs can create a new market for renewable electricity. They can help integrate growing quantities of variable renewable energy by using "smart" EV charging strategies that communicate with grid operators and energy markets to promote flexibility, allowing for the use of generation that otherwise might be curtailed.[130] Also, EVs have the potential to send electricity back to the grid during periods of high demand and to substitute for stand-alone customer-sited electric energy storage.

ELECTRIC VEHICLE MARKETS

Electrification of the transport sector expanded during 2016, enabling greater integration of renewable energy in the form of electricity for trains, light rail, trams as well as two- and four-wheeled EVs. Political interest in electric mobility increased following the 2015 Paris Agreement, which sparked a broader debate on accelerating electrification of the sector.[131]

Global deployment of EVs for road transport, and particularly passenger vehicles, has grown rapidly in recent years. In 2016, global sales reached an estimated 775,000 units, and more than 2 million passenger EVs were on the world's roads by year's end.[132] *(→ See Figure 52.)* The EV passenger car market (including PHEVs) accounted for around 1% of global passenger car sales in 2016.[133] The top five countries for total passenger EV deployment in 2016 were China, the United States, Japan, Norway and the Netherlands; together, they accounted for 78% of the year's global sales.[134] China and the United States are the market leaders in unit sales, while Norway is well ahead of all other countries in terms of market penetration.[135]

China's market has seen dramatic growth in recent years, with EV sales increasing from about 11,600 vehicles in 2012 to more than 350,000 in 2016.[136] China surpassed the United States in 2016 to become the country with the most passenger EVs on its roads, with more than 650,000 units in use by year's end.[137]

In the United States, sales were up 38%, following a decline of more than 5% during 2015 (despite federal and state subsidies) due to the drop in petrol prices.[138] An estimated 159,000 vehicles were added to the nation's fleet in 2016.[139]

In most countries, even those with strong incentives, EVs continue to represent a small share of passenger vehicle sales. Norway is the only market in which EVs have reached a mass market stage, driven by a set of strong government incentives that include EV exemption from sales and registration taxes, as well as the construction of an extensive charging infrastructure.[140] In 2016, EVs represented 29% of new passenger vehicle registrations in Norway, followed by Iceland with a market share of 6%.[141] Because EV sales still depend heavily on incentives, any

disruptions in policy (or changes in fuel costs) can cause large shifts between years, as was seen in 2015 in the Netherlands, where an announced incentive reduction for PHEVs caused a jump in demand, followed by a sharp contraction in market share in 2016.[142]

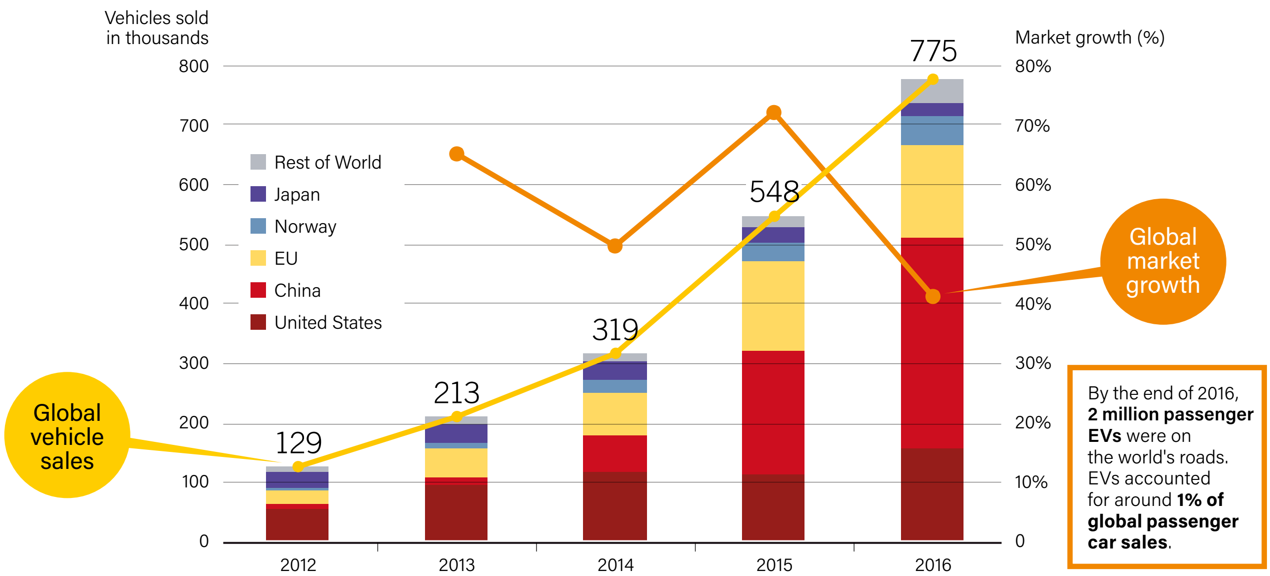
Although electrically driven passenger cars have experienced the most rapid market growth in recent years, EVs also come in the form of trains, trams, buses, two- and three-wheeled vehicles and others, including some marine vessels. In Europe, some 5,500 electric buses were on the road as of end-2016, around 90% of which were connected via overhead wire, and China also appears to have a robust and rapidly growing market for electric buses.[143] In most other countries, cities and transit companies are experimenting with only several units at a time. China also was home to an estimated 235 million electric two-wheelers based on lead-acid battery technology in 2015.[144]

Beyond the primary motivations to date for electrification of transport – reduced fossil fuel use and local air pollution – several countries, municipalities, EV manufacturers and electric utilities are experimenting with "smart" charging and vehicle-to-grid technologies that will enable EVs to contribute to grid storage, particularly from variable renewable energy sources. The Netherlands is becoming an international leader in the use of variable renewables for EV charging, or "smart charging". By late 2016, 325 Dutch municipalities, several companies, universities and grid operators had joined the Living Lab Smart Charging platform, with the ultimate goal of ensuring that all EVs in the country are powered by solar and wind energy. The Living Lab, supported by the Dutch government, is converting existing charging stations and installing thousands of new "Smart Charging Ready" charging points, which are used for research and testing, with the aim of developing international standards based on the programme's findings and innovations. As part of this effort, the Lombok neighbourhood of Utrecht partnered with vehicle manufacturer Renault (France) to test the vehicle-to-grid concept, using EVs as solar power storage for reinjection to the grid when the sun is not shining.[145]

Significant challenges remain to scaling up markets for EVs. Some of the most important include vehicle range, limited availability (in most locations) of charging infrastructure, and a lack of uniform charging standards.[146] As of 2016, there were three primary plug types for rapid charging of EVs: the CHAdeMO network, which works only with Asian-made vehicles; the SAE Combo plug, which fits in German and some US-made vehicles; and Tesla's Supercharger network, which fits only Tesla vehicles.[147] These potential standards all compete in the marketplace.[148] Regulatory issues surrounding charging infrastructure also remained a barrier to electrification of the transport sector during 2016.[149]

With such rapid growth in the EV market, electricity use for transport is growing as well. By one estimate, full electrification of

Figure 52. Global Passenger Electric Vehicle Market (Including PHEVs), 2012-2016



Source: See endnote 132 for this chapter.

the entire European car fleet in operation in 2015 would consume about 800 TWh of electricity annually, which would represent a 24.3% increase in electricity demand that year.[150] With a fleet of this scale, uncontrolled vehicle charging could exacerbate load peaks on the regional power grid by a significant margin. Conversely, if vehicle charging were shifted to off-peak hours, and if it managed to coincide with renewable power generation, the increase in electricity demand associated with EVs could be accommodated.[151]

ELECTRIC VEHICLE INDUSTRY

By the end of 2016, the global market leader among passenger EV manufacturers was China-based BYD, which sold 100,000 vehicles during the year and achieved a 13% global market share.[152] The company started as a battery manufacturer in 1995 and is a relative newcomer in the automotive industry.[153] Renault-Nissan (France-Japan) sold about 86,000 EVs in 2016, and as of August that year it was the leader in cumulative sales, with a total of 350,000 units.[154] This was followed by Tesla (United States) with around 76,000 EVs sold, and BMW (Germany) with 62,000 units sold.[155]

Several long-established vehicle manufacturers have realigned their strategies, with plans to increase the share of EVs in their future sales. In 2016, Volkswagen Group (Germany), announced plans to bring more than 30 pure-electric models to market and to sell 2-3 million EVs annually by 2025, equivalent to 20-25% of its total projected sales.[156] As part of this strategy, the company plans to develop battery technology as a new core competency and has expressed interest in building its own battery factory.[157] Daimler AG (Germany) announced in 2016 that it would invest USD 10.5 billion (EUR 10 billion) in EVs, and the company expects to have 10 different models by 2022.[158]

The emergence of electric drives as an alternative to internal combustion engines has opened opportunities for new entrants to the automotive market. For example, Tesla and BYD quickly became leaders in EV manufacturing; Tesla was founded as an EV company in 2003, and BYD began the same year as a battery manufacturer.[159] Apple (United States) also is investing in EVs, spending more on R&D in recent years for vehicles and related services than it did on several other Apple products combined.[160]

In addition, several other global consumer electronic companies have announced their interest in entering the EV market; in China alone, some 200 mostly small companies were reported to be developing and marketing EVs as of late 2016.[161]

Driving range continues to be perceived as a relative handicap for EVs, but manufacturers continue to advance battery technologies to increase range. In 2016, for example, two mid-priced battery-EV models from Renault-Nissan and General Motors (United States) entered the market with ranges of more than 300 kilometres each.[162] In addition, several companies announced plans to launch vehicles with equal or greater range in the coming years. By late 2016, nearly 500,000 reservations had been made for Tesla's Model 3 (with a presumed range over 300 kilometres), which the company claims will enter production in 2017.[163] Also in 2016, Daimler AG announced its EQ battery EV, which has a range of up to 500 kilometres and is slated to launch before the end of the decade, and Volkswagen Group introduced a concept e-Golf model with a range of up to 600 kilometres to come on the market in 2020 at a similar cost to its diesel-based equivalent.[164]

The electric vehicle industry is assuming an active role in addressing the shortage of charging facilities. In Europe, the EV charging infrastructure has expanded rapidly, from 30,000 stations in 2014 to 100,000 stations in 2016, including 10,000 fast-charging stations. In late 2016, auto manufacturers BMW Group (Germany), Daimler AG, Ford Motor Company (United States) and Volkswagen Group announced a joint venture to deploy, starting in 2017, a network of high-powered 350 kW charging stations in Europe to enable long-range travel for EVs.[165] This charging capacity is more than double the 2016 capability of Tesla Superchargers and allows EVs with a range of 400 kilometres to reach a full charge in 12 minutes.[166] In the United States, in 2016 and early 2017, Nissan and BMW announced plans to install fast-charging stations across the country that will be equipped to work with both CHAdeMO and SAE Combo connectors.[167] US electric utilities have joined the effort to expand charging infrastructure, but some have been blocked by regulators over concerns about who should pay for it.[168]

Reducing battery costs is an important driver for EV market development, although few manufacturers have provided details on these costs. Also relevant to overall battery costs, and to EV competitiveness in general, are the trends towards longer battery lifetimes and higher energy storage densities.[169] General Motors announced in 2016 that its battery cell cost for the Chevrolet Bolt was a surprisingly low USD 145 per kWh, whereas an expert had estimated the price at USD 215 per kWh.[170] As of early 2017, battery sizes for small and mid-sized battery EVs ranged from 30 kWh up to a maximum of 60 kWh (for the Chevrolet Bolt), and Tesla was offering up to 100 kWh battery capacity. Manufacturers have been taking advantage of lower battery prices to increase the range of EVs.[171]

Beyond passenger cars, work continued on development of EVs for public transit and freight transport. Siemens (Germany) made advances with its long-distance pure-electric trucks, while companies in California, Singapore and Switzerland explored the potential of autonomous electric buses.[172]

Exploration of methods to integrate renewable energy into charging stations for electric cars expanded in 2016, although many projects are pilot or demonstration, and integration remains relatively small scale. In 2016 installation of what is reportedly the world's first solar controlled, bi-directional charging station for EVs was completed in Utrecht, the Netherlands, as part of that country's Living Lab programme.[173] Even where renewable energy is not directly available, some EV service providers (e.g., car sharing companies in the United Kingdom and the Netherlands) have begun offering a provision for buying renewable electricity.[174] Renewables also are being used to charge public transit systems. In 2016, Chile announced that Santiago's subway system (the second largest in Latin America, following Mexico City's) will be powered mostly by solar PV (42%) and wind energy (18%) as of 2018.[175]

In addition, an increasing number of companies was working in 2016 to integrate renewable energy technology directly into vehicles. For example, Hanergy Holding Group (China) introduced four concept EVs that use solar power to extend their range, with plans to produce the vehicles commercially within three years.[176] Uganda launched Africa's first solar-powered bus (battery electric with solar extending the range); an Australian company announced plans to launch a solar-powered jeepney for use in the Philippines; and an inexpensive solar-powered three-wheeled ambulance was set to provide service to rural areas of Bangladesh before the end of 2017.[177] Also in 2016, a solar-powered aircraft, the Solar Impulse 2, successfully completed an around-the-world flight after a 16-month voyage.[178]

ELECTRIC VEHICLE POLICIES

The drivers for enacting policies to support EV use are varied. They include enhancing energy security, reducing transport-related carbon emissions and increasing opportunities for sustainable economic growth.[179] For cities in particular, EV support policies aim to reduce local air pollution and thereby to improve public health.[180]

Several countries, states and provinces have issued targets for electric vehicles. In many instances these are articulated in terms of "zero-emission vehicles" (ZEVs[i]), which is largely synonymous with EVs, including PHEVs. The international ZEV Alliance, comprising several European countries and North American states and provinces, announced in late 2015 a common goal to achieve zero emissions for all new cars by 2050.[181]

Within a shorter time frame, the Netherlands set targets in 2016 for 10% of new cars to be EVs by 2020, 50% by 2025 and 100% by 2035.[182] Norway is committed to all new passenger cars, city buses and light vans being ZEVs by 2025.[183] In April 2015, the country met its initial target – to reach 50,000 ZEVs – three years early.[184] In the United Kingdom, all new cars and vans must be ZEVs by 2040, with the goal that nearly all cars and vans on the road by 2050 will be ZEVs.[185]

In Asia, India aims to have 6 million EVs (including hybrids) on the road by 2020 under its National Electric Mobility Mission.[186] China's Technical Roadmap for Energy Saving Vehicles, issued in October 2016, set a target for 7% EV sales by 2020 and 40% EV sales (an estimated 15 million units) by 2030.[187] The country also has a target for the development of charging infrastructure, aiming for 12,000 charging stations across China to serve 5 million EVs by 2020.[188]

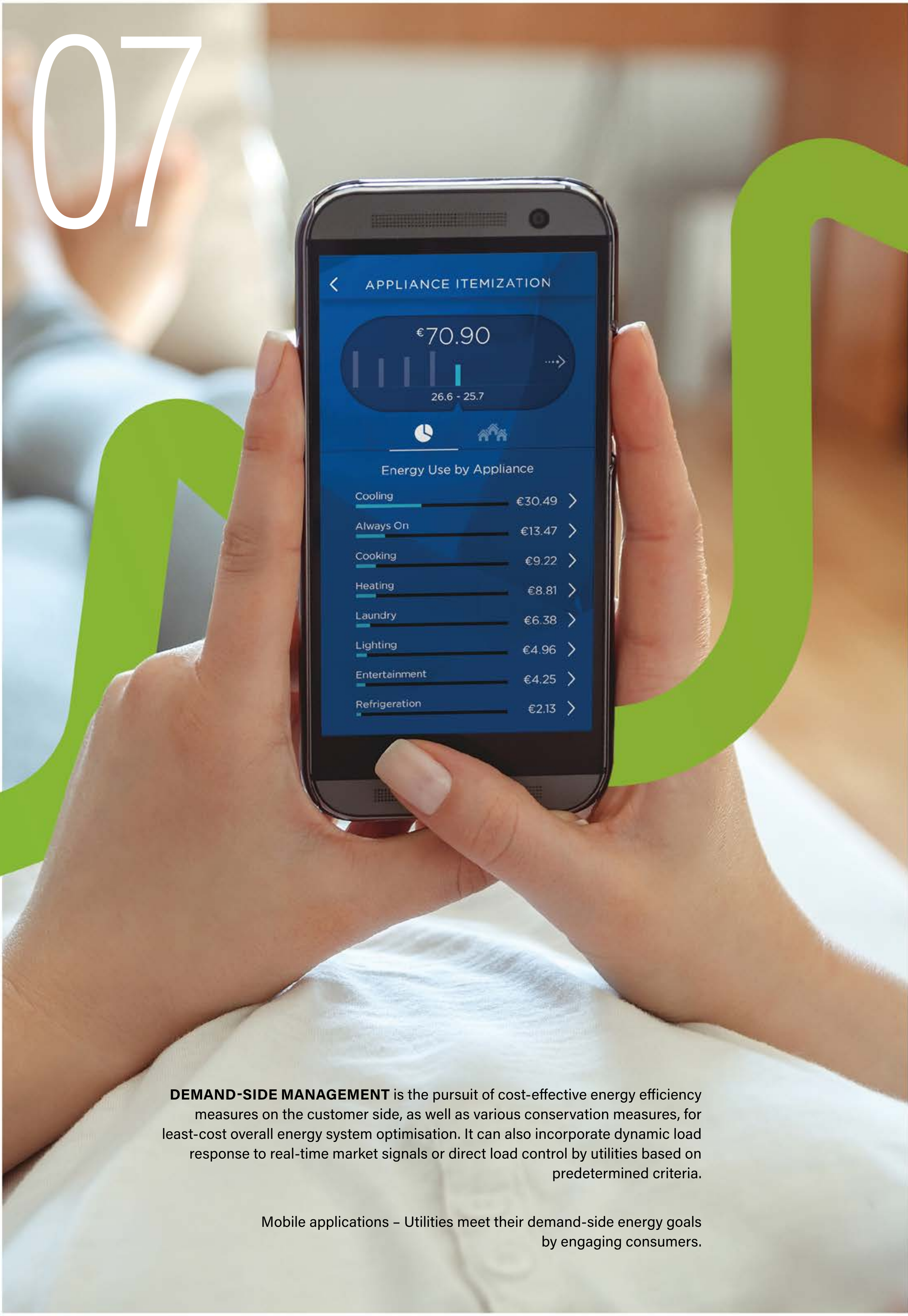
In the United States, California and several other states require ZEVs to make up around 15% of new car sales by 2025.[189] California also requires that the renewable energy share of hydrogen for vehicles increase to 33% by 2022.[190]

Fiscal incentives also are being used to advance EV use. In Europe, Germany launched a support scheme for EVs in 2016 that includes purchase grants and funding to expand recharging infrastructure, and, as of early 2017, Austria offered a purchase premium for EVs charged with 100% renewable electricity.[191] In Asia, Japan offers subsidies for the purchase of low-emissions vehicles, including EVs.[192] During 2015, China spent USD 4.5 billion in subsidies for the purchase of EVs, with plans to gradually phase out the programmes by 2021.[193] While China's policy has increased sales substantially, there have been reports of widespread cheating.[194] The country also has invested significant funds in creating fully integrated domestic manufacturing companies over the years.[195]

Some cities are developing zero-emission (at the tailpipe) transport strategies. Amsterdam in the Netherlands has committed to becoming a zero-emission city by 2025; starting in 2018, it will replace all 200 public transit buses with electric buses. In addition, the city aims to replace 4,000 taxis with ZEVs under the Clean Taxis for Amsterdam covenant, and similar agreements are in place with freight and delivery companies.[196] In China, Taiyuan became the country's first city to replace its entire taxi fleet with EVs and the city funded a network of 1,800 charging stations.[197] By late 2016, at least 14 Chinese cities, including Beijing and Shanghai, offered subsidies to encourage development of charging stations.[198] In addition, EVs in Beijing are exempt from restrictions on internal combustion vehicles, which are not permitted to drive one day per week and for which new licence plates are restricted and allocated by lottery.[199]

i The term "zero-emission vehicle" is largely synonymous with EV under the California (US) regulations and includes plug-in electric as well as battery-electric vehicles (and hydrogen fuel cell vehicles). Therefore, ZEVs are generally not zero-emission vehicles "at the tailpipe" or by primary energy source (grid power), but they have the potential to be virtually zero-emission if powered by renewable energy.

07



DEMAND-SIDE MANAGEMENT is the pursuit of cost-effective energy efficiency measures on the customer side, as well as various conservation measures, for least-cost overall energy system optimisation. It can also incorporate dynamic load response to real-time market signals or direct load control by utilities based on predetermined criteria.

Mobile applications – Utilities meet their demand-side energy goals by engaging consumers.

07 ENERGY EFFICIENCY

GLOBAL OVERVIEW

Many policy makers consider energy efficiency to be a priority for achieving various energy goals, including improved energy security and energy access, reduced air pollution and fuel poverty, employment growth and industrial competitiveness.[1] Moreover, scenarios for achieving CO_2 emissions reductions recognise that energy efficiency will play a critical role.[2] Energy efficiency also has significant synergies with renewable energy; together they can achieve more than the sum of their parts[i]. For example, energy savings help renewable energy to meet a higher share of energy demand at a lower cost and open up new markets. Shifting from thermal power to non-thermal renewables also improves primary energy efficiency.

Energy efficiency policies are the main driver of investment in energy efficiency, with innovations in technology and finance also playing important roles. Thus, despite lower oil prices in 2015 and much of 2016, households, businesses and governments continued to invest strongly in energy efficiency.[3]

Due to a lack of precise indicators of energy efficiency, energy intensity often is used as a proxy for energy efficiency trends, even though it also is affected by structural changes in the economy and by changes in the energy mix. Primary energy intensity is measured as total primary energy supply (TPES) per unit of gross domestic product (GDP). Alternatively, final energy intensity is measured as total final consumption[ii] (TFC) per unit of GDP. TFC intensity may better reflect trends in end-use energy efficiency than TPES intensity because it excludes losses in power generation or fuel conversion.[4] However, primary energy data usually are available earlier and generally are more reliable. Also, TPES intensity is more relevant to monitoring overall energy demand and related greenhouse gas emissions.

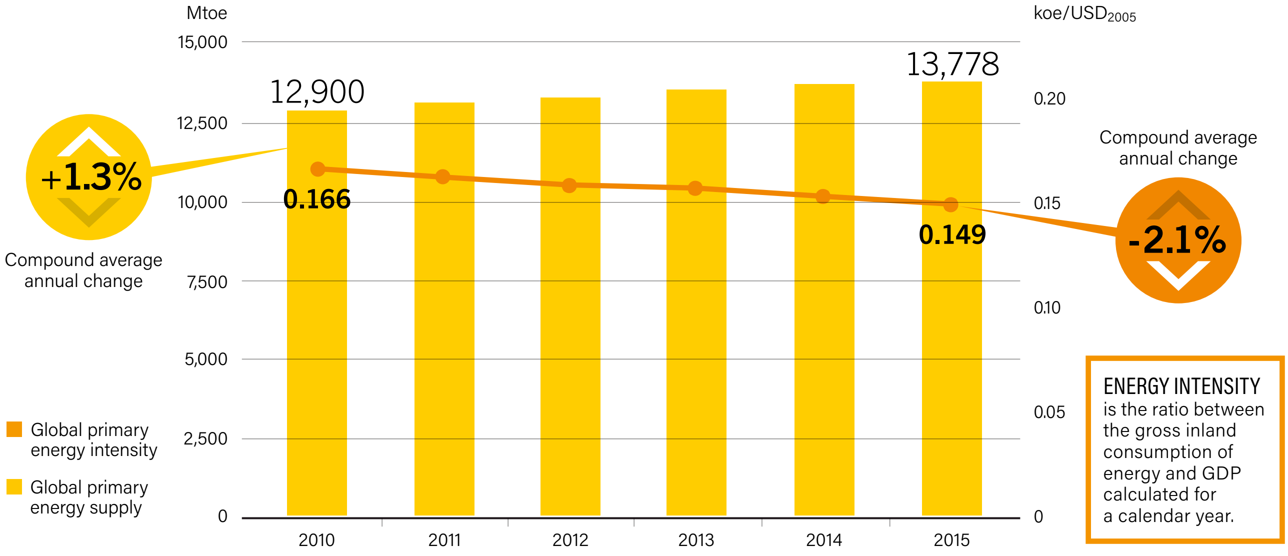
In 2015, global primary energy intensity improved by 2.6%.[5] That is the average rate that needs to be achieved between 2010 and 2030 to meet the Sustainable Development Goal 7 target of doubling the rate of improvement in energy efficiency.[6] However, between 2010 and 2015, energy intensity declined by only 10.2% overall – an average annual rate of 2.1%.[7] Over the same period, TPES grew by 1.3% per year, amounting to a total increase of 6.8%.[8] *(→ See Figure 53.)*

Energy intensity, whether primary or final, varies widely among regions and countries. In 2015, primary energy intensity improvements were less marked in developed economies than in developing and emerging economies, most of which are still

i Renewable energy and energy efficiency are twin pillars of a sustainable energy future. Synergies exist between the two across numerous sectors. This means that the interaction of renewables and energy efficiency can result in an outcome greater than the sum of the parts. In recognition of the important linkages between renewable energy and energy efficiency, there has been a dedicated chapter on energy efficiency in the GSR since 2015. *(→ See Feature in GSR 2012 for more on renewable energy–energy efficiency synergies.)*

ii Total final consumption includes energy demand in all end-use sectors, which include industry, transport, buildings (including residential and services) and agriculture, as well as non-energy uses, such as the use of fossil fuel in production of fertiliser. It excludes international marine and aviation bunkers, except at the global level, where both are included in the transport sector. IEA, *Energy Efficiency Market Report 2016* (Paris: 2016), p. 18, https://www.iea.org/eemr16/files/medium-term-energy-efficiency-2016_WEB.PDF

Figure 53. Global Primary Energy Intensity and Total Primary Energy Supply, 2010-2015



Note: Dollars are at constant purchasing power parities.

Source: See endnote 8 for this chapter.

growing rapidly and have more efficiency potential remaining. For example, China's primary energy intensity improved by 5.8% in 2015 as the country's TPES increased by 0.9% (the lowest rate since 1997), even as GDP grew by 6.9%.[9] India's economy also has become steadily less energy-intensive over the past decade.[10] Brazil, on the other hand, has experienced rising primary energy intensity since 2012, and energy intensity of electricity generation in Vietnam increased by 70% between 2004 and 2014 (driven in part by a rising share of coal-fired power generation).[11]

High levels of primary energy intensity are due to some combination of: a relatively large share of energy-intensive economic activities, the use of less energy-efficient technologies, under-utilisation of power generation capacity, and a relatively large share of thermal power generation, in particular coal. For example, China's primary energy intensity decline in recent years is due in large part to structural changes in the economy away from heavy industry and towards services and high value-added manufacturing (in line with China's overall growth policy), as well as towards a more low-carbon energy mix.[12] China's 13th Five-Year Plan aims to lower coal's 2020 share of primary energy from 62% to 58%.[13] Structural change has been important for reducing energy intensity in several other countries as well, including the United States and Canada.[14]

Total final consumption in member countries of the Organisation for Economic Co-operation and Development (OECD) as a whole peaked in 2007.[15] Isolating energy efficiency from activity and structural effects requires detailed data that are not always available. Nevertheless, decomposition analysis of IEA countries for which data are available finds that, in 2015, energy efficiency was responsible for more than 80% of the downward pressure on energy consumption.[16]

Global TPES in 2014 (the most recent data available) was 13,699 million tonnes of oil equivalent (Mtoe), of which nearly 38% was allocated to power generation.[17] Global TFC in 2014 was 9,425 Mtoe; of this total, more than 32% was consumed in buildings, 29% in industry and nearly 28% in transport, with the remainder consumed in other sectors and for non-energy applications. Electricity makes up a portion of final energy use in all end-use sectors, and energy efficiency in power generation must be gauged in terms of its primary energy use. By contrast, the efficiency of end-use sectors is better measured in the context of final energy use.

The next few sections examine primary energy efficiency in the generation of electricity, followed by efficiency of final energy use in the buildings, industry and transport sectors. The chapter also covers recent trends and developments in energy efficiency investment and finance, as well as policies and programmes.

ELECTRICITY GENERATION

Primary energy efficiency in the power sector can be improved mainly by shifts in the energy mix and by improving the efficiency of electricity generation technologies. Further efficiency gains can be achieved through combined heat and power (CHP), which captures waste heat for thermal applications, as well as through reduced transmission and distribution losses.

Thermal power plants convert only about one-third of their energy inputs to electricity (38% on average for OECD generation), while conversion losses for non-thermal renewable energy such as hydro, wind or solar power are low and generally are not accounted for in energy balances.[18] Therefore, achieving greater shares of non-thermal renewable power increases primary energy efficiency.

The efficiency of electricity generation ranges from about 30-35% in the Russian Federation and the Middle East to almost 55% in Latin America, where a significant share of electricity is generated by hydropower. Electricity generation efficiency improved between 2000 and 2014 in all regions except Latin America, where it declined by 0.6% because hydropower output declined and was replaced by fossil fuel generation.[19] In Europe and North America, efficiency improved with rising shares of natural gas and increasing use of CHP.[20]

In addition to fuel switching, the efficiency of the electricity generation sector can improve through advances in the efficiency of generation technologies themselves. The efficiency of fossil fuel power plants increased in all regions between 2000 and 2014. Gas-fired plants experienced the highest rate of improvement, with the increase in efficiency exceeding 20% in North America and Africa.[21]

Energy also is lost through electricity dissipation in the grid and through non-technical losses. In 2014, global transmission and distribution losses averaged 8.6%, with lower rates in developed regions and far higher losses in some developing countries.[22] More-efficient transformers and cables can reduce transmission and distribution losses, as can demand management and automation. In some circumstances, increased use of distributed energy can reduce transmission and distribution losses by producing electricity closer to where it is used. Non-technical losses may be addressed through better management of the grid and billing system.[23]

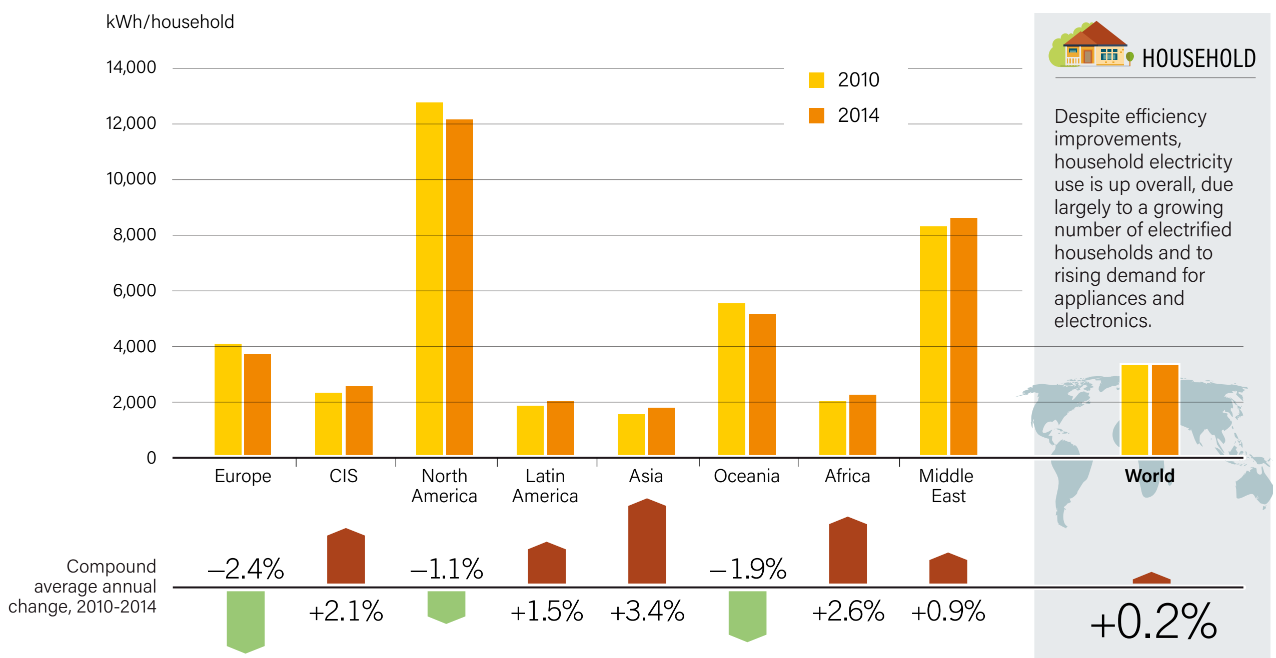
BUILDINGS

Buildings account for nearly one-third of global TFC, of which almost three-quarters is consumed in residential buildings, with the remainder used in commercial facilities (services).[24] The largest portion of TFC in the sector comes in the form of electricity (30%), followed closely by modern and traditional uses of biomass for heating and cooking (29%), and by natural gas (21%).[25] Efficiency of energy use in buildings is affected by building envelopes, design and orientation, as well as by the efficiency of energy-consuming devices, including climate control systems, lighting, appliances and office equipment. Energy intensity per square metre in the buildings sector has improved in many regions, but not rapidly enough to offset the doubling of floor area since 1990.[26]

Markets for more-efficient building materials, technologies and equipment are growing worldwide, both for renovation and new construction. The largest market is in Europe, where it is driven by building energy codes and energy prices. North America and Oceania are major markets as well.[27] Net zero energy buildings (NZEBs) take fullest advantage of the synergies between energy efficiency and renewable energy by facilitating the use of on-site renewable energy in meeting building energy loads *(→ see, for example, heat pumps in the Enabling Technologies chapter)*. The number of NZEBs remains small but continues to rise, particularly in Europe but also in the United States and Canada.[28]

The buildings sector accounts for around half of world electricity demand.[29] In residential buildings, global average electricity consumption was nearly flat between 2010 and 2014 (0.2% average annual increase).[30] In North America, Europe and the Pacific, electricity consumption per household declined between 2010 and 2014, in part a result of improved energy efficiency. These declines were outweighed by increases elsewhere.[31] *(→ See Figure 54.)*

Figure 54. Average Electricity Consumption per Electrified Household, Selected Regions and World, 2010 and 2014



Note: Dollars are at constant purchasing power parities.

Source: See endnote 31 for this chapter.

Electricity demand for appliances has been increasing steadily for decades, due largely to a rapid increase in units per household, in addition to the growing number of electrified households. In developed countries, TFC growth for appliances has slowed significantly over the past decade as markets for some products have approached saturation and as energy efficiency has increased.[32] However, energy efficiency improvements have not yet cancelled out growing demand for some categories, such as mobile phones, televisions and networked devices.[33]

The market share of efficient lighting solutions also is growing rapidly, as a result of declining light-emitting diode (LED) prices, international initiatives, green procurement policies and policies to phase out incandescent lamps.[34] Smart lighting controls have the potential to improve the energy efficiency of lighting systems even further.

Energy efficiency in the service (commercial) sector can be indicated by the ratio of electricity consumption to value-added in commercial activity, in constant purchasing power parity (PPP). Between 2010 and 2014, the electricity intensity of the service sector declined in every region except the Middle East and Latin America.[35] *(→ See Figure 55.)*

As with other sectors, the energy intensity of services is the product of several factors. These include structural changes within the sector (e.g., between more energy-intensive sub-sectors, such as hospitals, and less energy-intensive ones, such as warehouses) and across the economy, the growth of building size relative to sector GDP, and the uptake of more-efficient technologies.[36]

INDUSTRY

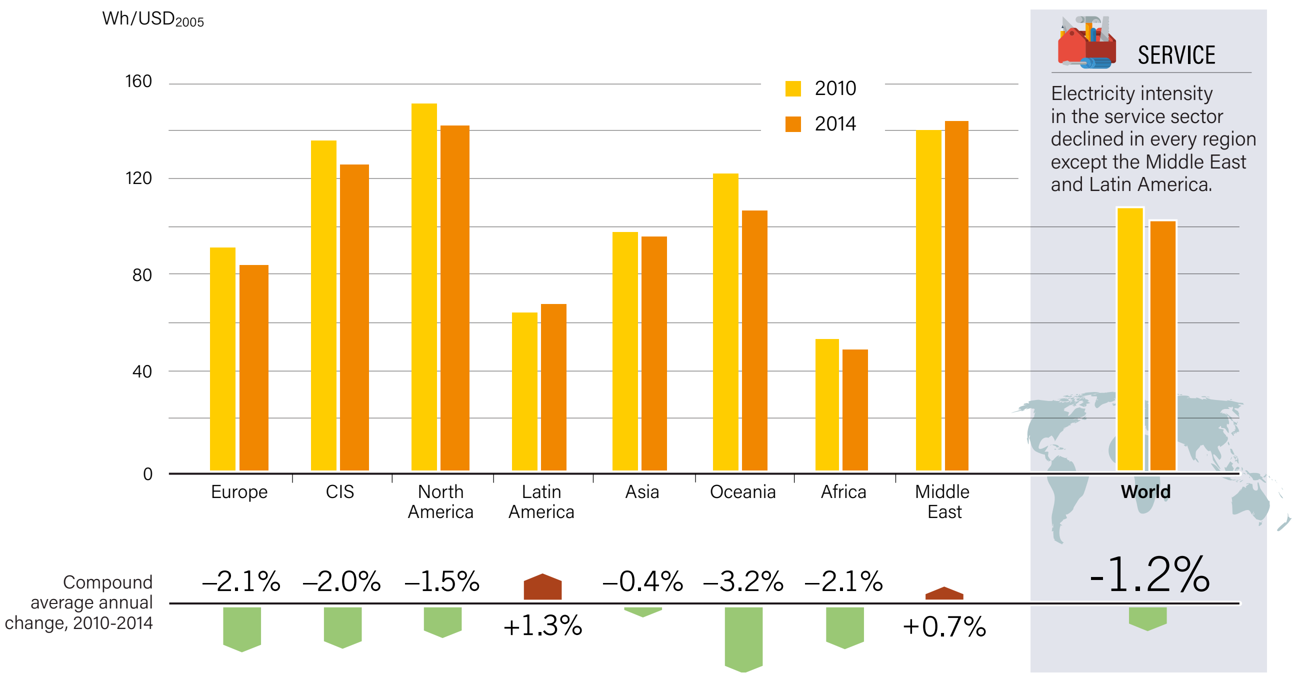
The ratio of industry TFC to industry value-added (PPP) is an indicator of the intensity of the industry sector as a whole. It can be improved by structural changes, such as displacement of heavy industry, higher utilisation rates of equipment during a period of strong economic activity, or growth in less energy-intensive sub-sectors, as well as improvements in energy efficiency.[37] Measures of industrial energy intensity based on physical production would be better but require data that often are lacking.

Between 2010 and 2014, TFC intensity of the global industrial sector decreased by an average of 1.5% annually and improved in all regions, with the fastest improvement observed in Asia.[38] *(→ See Figure 56.)*

In China, structural changes in energy-intensive sectors in recent years have tended to balance each other out.[39] However, structural change is expected to be an important factor influencing energy use.[40] India, driven by policy (e.g., Make in India), is seeing growth in the manufacturing sector. A focus on manufacturing brings economic benefits but also tends to increase the energy intensity of the economy, making energy efficiency improvements all the more important.[41]

Industrial energy efficiency can be influenced by changes in industrial processes and also by changes in capacity utilisation. For example, the energy intensity of the steel sector of the EU worsened after 2007 due to the economic recession, in large part because the energy consumption of steel-producing equipment did not decline in proportion to lower utilisation of plant capacity.[42]

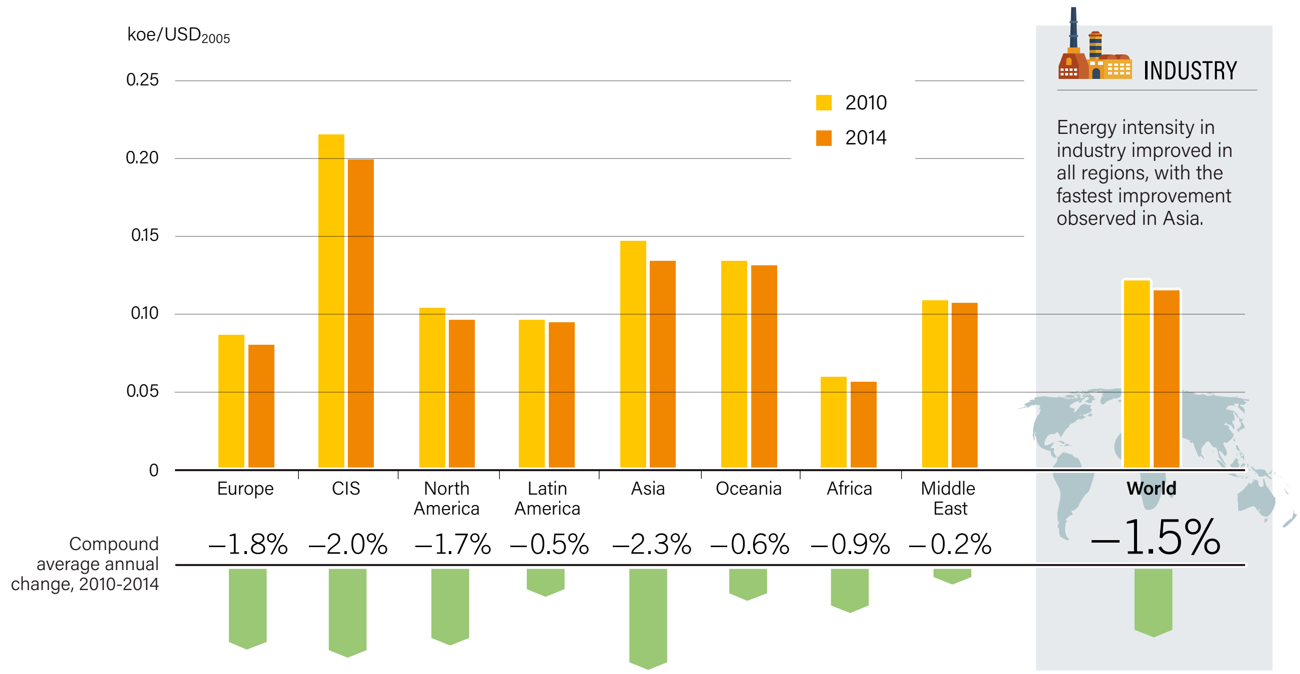
Figure 55. Electricity Intensity of Service Sector, Selected Regions and World, 2010 and 2014



Note: Dollars are at constant purchasing power parities.

Source: See endnote 35 for this chapter.

Figure 56. Energy Intensity of Industry, Selected Regions and World, 2010 and 2014



Note: Dollars are at constant purchasing power parities.

Source: See endnote 38 for this chapter.

In general, varying performance by the steel sectors of different countries is explained in large part by their process mixes. For example, the use of electric-arc furnaces in steel production and recycling requires two to three times less energy than the oxygen process.[43]

TRANSPORT

There is significant untapped energy efficiency potential in the transport sector. The energy intensity of the sector is affected by energy efficiency improvements within transport modes (rail, road, aviation, shipping) and by shifts between transport modes (e.g., from private car use to public transport, from road freight to rail). Between 2010 and 2014, the final energy intensity[i], of world transport overall declined by an annual average of 2.5%, driven mostly by advances in road transport.[44] Most regions saw an improvement over the four-year period, except for Africa (1.3% annual growth) and Latin America (virtually unchanged).[45]

Road transport accounts for 75% of transport energy use.[46] Improvements in the global average fuel economy (fuel used per unit of distance) of light-duty vehicles averaged 1.5% per year for the decade 2005-2015, slowing gradually to 1.1% in 2015.[47] Improvements in OECD and EU countries have slowed after relatively rapid improvement of 2.8% annually between 2008 and 2010, falling to 0.5% in 2015.[48] Conversely, annual improvements in non-OECD countries accelerated from 0.3% annually between 2008 and 2010, to 1.6% in 2015.[49]

Progress has been much slower in the freight sector than for passenger vehicles, due to a relative lack of fuel economy standards. Heavy-duty vehicles make up only 11% of the world's vehicle fleet, yet they consume around half of all transport fuels.[50]

Electric vehicles, including plug-in hybrid vehicles, can drive improvements in fuel economy on a final energy basis.[51] As the share of non-thermal renewable energy in electricity increases, the contribution of such vehicles to primary energy efficiency will increase as well. However, because the share of EVs is still extremely small, advances in internal combustion efficiency are still a critical component of energy efficiency improvements in road transport.[52] *(→ See Electric Vehicles section in the Enabling Technologies chapter.)*

Aviation accounts for about 13% of fossil fuel use in transport worldwide.[53] Aviation fuel efficiency can be increased through operational measures such as reducing the weight of on-board equipment and through improved aircraft design and materials. Shipping consumes about 4% of total transport energy use.[54] Technology and supply chain innovation can deliver savings in that sector.[55]

The efficiency of transport also is improving through the spread of more sustainable modes such as electric trams and bus rapid transit (BRT). By early 2016 at least 200 cities had BRT systems, transporting more than 33 million passengers per day.[56] The BRT system in Bogota (Colombia) replaced ageing public buses with more efficient models, delivering 47% savings in fuel consumption.[57]

i This is defined as energy use in transport per unit of GDP. A more direct indicator of transport efficiency might be defined in terms of energy use per passenger-kilometre and energy per cargo-tonne-kilometre, but aggregated global data across all transport segments are not available.

FINANCE AND INVESTMENT

In 2015, global incremental[i] investments in energy efficiency in buildings, industry and transport increased by 6%, to USD 221 billion.[58] The buildings sector led with an estimated 53% of the total, followed by transport (29%) and industry (18%).[59] Investments in energy-efficient assets and technologies yield estimated two- to four-fold returns in lifetime cost savings.[60] Most energy efficiency investments are made using the cash and savings of individuals and businesses, or directly from public money.[61] The remainder is financed primarily by traditional commercial banks through loans and leases. Increasingly, however, financing is coming from other sources, including dedicated national energy funds, green banks, development finance institutions (DFIs) and green bonds.

As of 2016, at least 40 countries had dedicated energy efficiency funds, led by Germany's development bank KfW.[62] During the year, new facilities were established in Poland, where a multistakeholder partnership set up a residential buildings energy efficiency financing facility of USD 214 million (EUR 200 million), produced a benchmarking report on operating costs in commercial buildings and created a platform for public-private dialogue and action; and in Latvia, which established an energy efficiency fund as part of its law to implement the Energy Efficiency Directive.[63] In addition, Ukraine worked to develop an Energy Efficiency Fund for district heating and related energy efficiency activities. An amount of USD 31 million was allocated to the fund, and additional monies totalling up to USD 110 million were expected to come from international partners; the fund was scheduled to start operations in 2017.[64]

Green banks at the national level (e.g., United Kingdom) and sub-national level (e.g., the US states of Connecticut and New York) continued to scale up their lending in 2016, and more than a dozen banks were operational around the world by year's end.[65] These banks have a strong focus on energy efficiency, and they provide funds – as well as advice and clarity on default risk – for programmes in areas such as energy efficiency retrofits and street lighting.[66]

DFIs also play an important role in energy efficiency investment by providing loans, guarantees, credit lines and other products. In 2015, multilateral development banks invested an estimated USD 2.9 billion in energy efficiency (a slight drop relative to 2014).[67] DFIs undertook a number of significant initiatives in 2016 as well.

In 2016, the Green Climate Fund allocated USD 378 million to support sustainable energy financing (including energy efficiency and renewable energy) by the European Bank for Reconstruction and Development (EBRD) in Armenia, Egypt, Georgia, Jordan, Moldova, Mongolia, Morocco, Serbia, Tajikistan and Tunisia.[68] In November, the EBRD announced a USD 35 million expansion of the Kyrgyz Sustainable Energy Financing Facility, alongside grants from the EU, to improve energy and resource efficiency.[69] An EBRD-arranged USD 122 million (EUR 116 million) package will allow the CEZ utility in Bulgaria to upgrade distribution infrastructure, which will reduce grid losses.[70]

In addition, the EBRD and the European Investment Bank (EIB) announced loans of USD 49 million (EUR 46.5 million) to Tunisia for the state utility to improve the efficiency of the country's transmission infrastructure.[71] The EIB approved two lending programmes under the European Fund for Strategic Investments for nearly zero energy buildings (nZEBs) in Finland, for a total of USD 337 million (EUR 320 million).[72] Also in 2016, the EIB confirmed its contribution of an additional USD 26 million (EUR 25 million) to the Green for Growth Fund, to support energy efficiency and renewable energy projects across North Africa as well as in Jordan, Lebanon and the State of Palestine.[73]

The Asian Development Bank announced plans to loan India USD 200 million to install energy-efficient water pumps for farms and millions of LEDs via a public-private joint venture.[74] The African Development Bank approved a USD 948 million (EUR 900 million) loan for Algeria to improve the efficiency of its energy sector and to promote renewable energy. The AfDB also approved USD 19 million for energy sector reform in Madagascar, including improvements to efficiency of the country's electricity production.[75] Also in 2016, the International Finance Corporation (IFC) offered technical assistance to Belgrade (Serbia) to boost the energy efficiency of public buildings, district heating and street lighting.[76]

In recent years, green bonds have emerged as a substantial source of capital for energy efficiency projects. As of November 2016, 19.6% of projects financed by green bonds were for energy efficiency improvements.[77] DFIs have dominated the financing of such improvements through the issuance of green bonds. During the first half of 2016 alone, the IFC issued USD 1 billion of green bonds to fund projects in 22 countries, with green banking and green buildings being the two largest sectors.[78] However, utilities and other businesses, local authorities, commercial banks, universities and governments are playing an increasingly important role. Luxembourg and Nigeria both announced forthcoming issuances, and the governments of France and Poland issued green bonds in December 2016 and January 2017, respectively.[79] Also in 2016, the US state of California was the lead investor in a USD 200 million, two-year green bond issued by the International Bank for Reconstruction and Development.[80]

The G20 Energy Efficiency & Finance Task Group began to mobilise policy makers and financial institutions in 2016, notably by developing a set of voluntary energy efficiency investment principles to enhance capital flows.[81] In addition, the EU launched an initiative to improve transparency and reduce risk for energy efficiency investors: the De-risking Energy Efficiency Platform (DEEP) is an online database that contains more than 7,800 industrial and buildings-related projects.[82]

i Incremental investment in energy efficiency is the additional cost of energy-efficient goods compared with goods of average efficiency. IEA, *Energy Efficiency Market Report 2016* (Paris: 2016), p. 91, https://www.iea.org/eemr16/files/medium-term-energy-efficiency-2016_WEB.PDF

POLICIES AND PROGRAMMES

Throughout 2016, governments at the regional, national, state and local levels continued to expand and strengthen their policies to improve energy efficiency in the buildings, industry and transport sectors. Drivers for such policies include increasing energy security, advancing economic growth and competitiveness, reducing fuel poverty and mitigating climate change.[83] In developing countries, increased efficiency can make it easier to provide energy services to those who lack access.[84] Energy efficiency policies – including targets and plans; standards, labels and codes; monitoring and auditing programmes; mandates; and fiscal incentives – aim to address a number of barriers to accelerating energy efficiency actions. These include a lack of knowledge and capacity, energy subsidies and regulatory barriers, and misplaced incentives[i] across different stakeholders.[85]

Targets help guide policy development and benchmark policy implementation. They vary in their time horizons, geographical areas, definitions, sectors and levels of ambition. Targets are articulated in terms of energy savings or reductions in energy consumption, improvements in energy intensity, or sales or dissemination of more energy-efficient products. Many targets do not provide sufficient detail regarding how or by when they are to be achieved, and many countries (developing and emerging economies, in particular) do not report regularly on progress towards national goals.

During 2015 and 2016, there was a surge in the adoption of energy efficiency targets, especially in developing and emerging economies.[86] Of the 140 countries that had ratified the Paris climate change agreement and submitted Nationally Determined Contributions as of late March 2017, 107 mentioned energy efficiency, including both the United States and China.[87] Among all NDCs submitted by developing and emerging economies, 79 included energy efficiency targets.[88] Brazil, for example, pledged a target of 10% efficiency gains in the electricity sector by 2030 in its NDC.[89] Members of the Association of Southeast Asian Nations (ASEAN) set a target to reduce energy intensity by 20% in 2020 compared to 2005.[90]

By end-2016, at least 137 countries had enacted some kind of energy efficiency policy, and at least 149 countries had enacted one or more energy efficiency targets. Of these countries, 48 enacted a new or revised policy in 2016, and 56 countries adopted a new target in 2015 or 2016.[91] *(→ See Figures 57 and 58.)*

China has strengthened its policy framework for achieving energy savings in successive Five-Year Plans. The 13th Five-Year Plan (2016-2020) targets, by 2020, a 15% energy intensity improvement (relative to 2015 levels) and 560 Mtoe of energy savings annually.[92] Economic restructuring is planned to make up 65% of the targeted energy savings; energy efficiency improvements are to deliver the rest.[93]

Norway presented a new energy policy that targets an energy intensity improvement of 30% between 2015 and 2030.[94] In late 2016, Belarus called for energy efficiency improvements at all stages of energy supply as part of its effort to increase national energy security, and in early 2016 the country approved a state energy policy for 2016-2020 that includes energy-saving targets and programmes.[95]

Energy efficiency targets were adopted at the regional level as well. In late 2016, the European Commission published a new

i Misplaced incentives occur if those who make decisions about investing in energy efficiency improvements are different from those who benefit from the resulting energy savings.

Figure 57. Countries with Energy Efficiency Targets, 2016

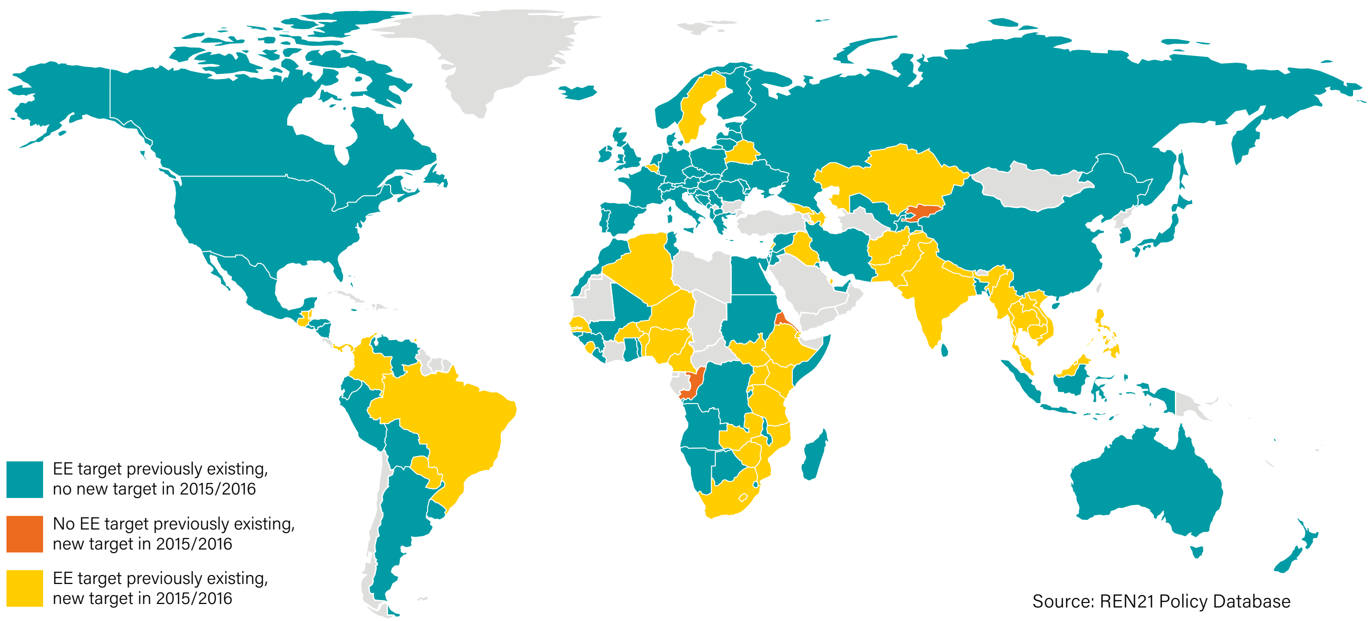
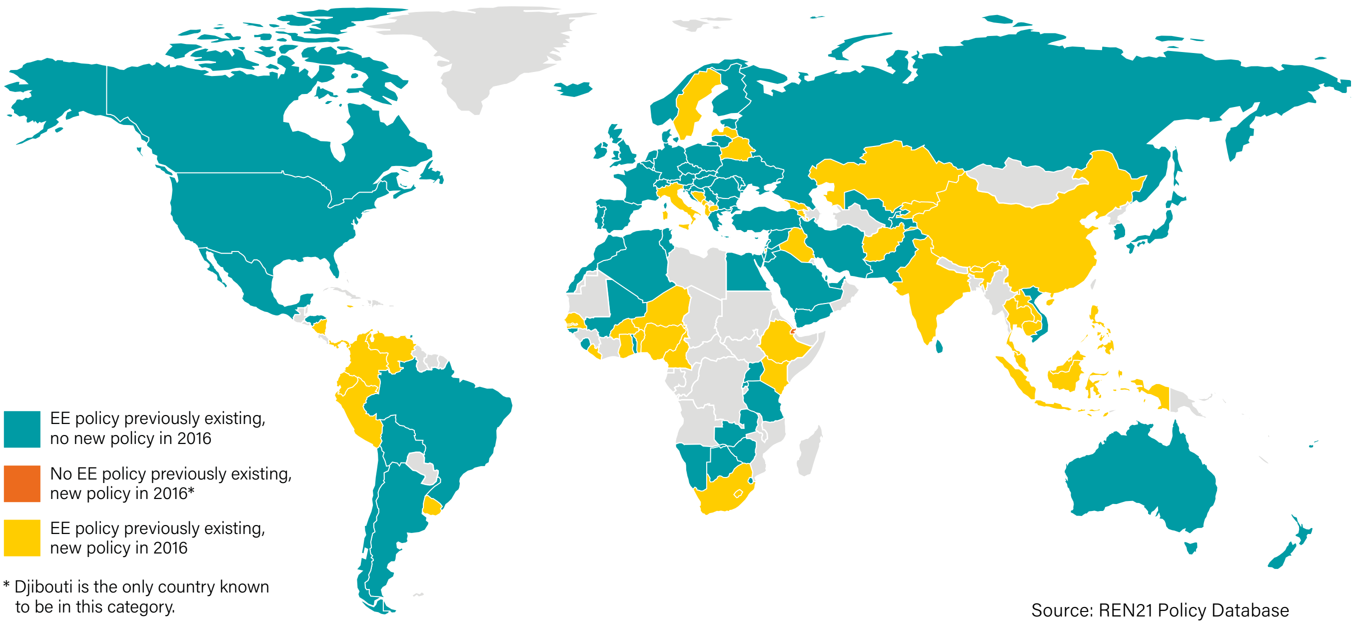


Figure 58. Countries with Energy Efficiency Policies, 2016



package of energy policy proposals that includes a binding 30% energy savings target by 2030.[96] The EU's previous (non-binding) target called for 27% energy savings by 2030 relative to 1990, which the region is on track to meet.[97] European policy makers also have adopted an "Efficiency First" principle, which prioritises cost-effective end-use efficiency improvements over supply-side expenditures.[98]

A large number of energy efficiency targets are articulated in National Energy Efficiency Action Plans (NEEAPs) in the EU but also in other Eastern European and African countries.[99] For example, Nigeria published its NEEAP in July 2016, and efforts were under way during the year to co-ordinate NEEAPs (and National Renewable Energy Action Plans) across Africa.[100]

Targets that address more than one end-use sector are the most common, yet many new sector-specific targets are being adopted. For example, India aims to replace 770 million incandescent lamps with LED bulbs by 2019; as of March 2016, the programme was running in 12 states, and over 170 million LEDs had been sold.[101] Uganda and other countries have similar LED distribution programmes and targets.[102] In mid-2016, as part of Japan's effort to achieve its NDC commitments, the country announced its aim to make more than half of new built-to-order homes zero energy by 2020, and the government is providing subsidies to advance that goal.[103]

Many other countries have targets for both renewable energy and energy efficiency, often defined through roadmaps and national action plans.[104] As of 2016, at least 103 countries addressed energy efficiency and renewable energy within the same government agency, and an estimated 81 countries had policies or programmes that combine them.[105]

To achieve their targets, governments are introducing new regulations or updating existing ones to drive efficiency improvements in all economic sectors. For example, in late 2016, the US state of Illinois introduced new electricity demand reduction mandates for utilities as part of the state's Renewable Portfolio Standard.[106] In 2016, the European Commission proposed an update to the EU Energy Efficiency Directive that included measures to ensure that new proposed energy efficiency targets (30% improvement by 2030) are met.[107] Several governments in Europe and elsewhere – including China, India and the Australian state of Victoria – have experimented with the use of tradable certificates to meet energy efficiency mandates or targets.[108] Design challenges with such schemes include verification and risk of leakage.[109]

In 2016, several countries advanced building codes, which generally establish minimum energy efficiency standards to guide construction or retrofit. For example, Norway and the US state of Alabama introduced building codes with tighter energy efficiency requirements.[110] By year's end, Indonesia was in the process of developing a Green Building Code, and several West African countries were implementing building energy codes in accordance with a directive of the Economic Community of West African States (ECOWAS).[111] At the local level, the city of Santa Monica (United States) approved a mandate requiring that all new single-family homes qualify as zero net energy.[112] As of early 2017, at least 139 building energy codes were in place worldwide, including many at the sub-national level.[113]

Standards and labelling programmes also are used to move markets towards more-efficient appliances and equipment. As of 2015, 30% of final energy demand globally was covered by mandatory efficiency policies, up from 11% in 2000; the average performance requirements of such policies have increased by 23% over the last decade.[114] More than 50 types of commercial, industrial and residential appliances and equipment were covered by such programmes in more than 80 countries by 2015.[115]

In the transport sector, fuel economy standards are helping to advance the energy efficiency of passenger vehicles. By one estimate, car fuel economy standards worldwide saved 2.3 million barrels of oil per day in 2014, or 2.5% of global oil demand, assuming that efficiency would have remained stagnant in the absence of new standards.[116] At least eight countries (Brazil, Canada, China, India, Japan, Mexico, the Republic of Korea and the United States) plus the EU have established fuel economy standards for passenger and light-commercial vehicles as well as light trucks.[117]

While most efficiency standards in the transport sector focus on light-duty vehicles, China, Japan and the United States also have set fuel economy standards for heavy-duty vehicles.[118] In 2016, the United States announced a new regulation for medium- and heavy-duty trucks, and China was updating its fuel consumption regulations for heavy-duty vehicles.[119] As of 2015, Canada and Japan had implemented efficiency regulations for heavy-duty vehicles.[120]

Monitoring and auditing energy use helps governments and businesses establish a basis for energy management systems in buildings and industry. Energy audits analyse energy flows within a building, process or system to identify ways to reduce energy use without negatively affecting output. Audits are mandatory for EU Member States as part of their implementation of the Energy Efficiency Directive.[121] In addition, many developing and emerging economies, such as Mali and Morocco, require energy audits for large industrial energy users.[122] Singapore requires more than 165 energy-intensive industrial companies to implement energy management programmes.[123]

The need for careful design and monitoring of standards and labelling programmes can pose challenges in implementation, particularly where adequate funding and policy support are lacking. For instance, Uganda has Minimum Energy Performance Standards (MEPS) for five product groups (refrigerators, air conditioners, motors, lighting and freezers) but has had difficulty implementing and enforcing them because the country lacks funding, personnel and testing equipment.[124]

Fiscal incentives – including rebates, tax reductions and low-interest loans – also have been employed to stimulate energy efficiency improvements. In 2016, for example, Ireland implemented a three-year Warmth & Wellbeing pilot scheme with a budget of approximately USD 21 million (EUR 20 million) to provide home energy efficiency improvements for people living in energy poverty and suffering from chronic respiratory diseases.[125]

Further, reductions in subsidies for fossil fuels, while politically difficult, make energy efficiency improvements (and renewable energy deployment) more attractive and reduce the burden on national budgets. Conversely, greater energy efficiency can make subsidy reform more feasible.[126] By the end of 2016, more than 50 countries had committed to phasing out fossil fuel subsidies under G20 and Asia-Pacific Economic Cooperation (APEC) processes.[127]

In addition to government policies and programmes, several collaborative activities to advance energy efficiency were undertaken by the international community during 2016. The SEforALL Global Energy Efficiency Accelerator Platform developed implementation projects in 110 countries.[128] In addition, the Global Fuel Efficiency Initiative continued its work with developing countries to develop appropriate national approaches and targets for improved car-fleet fuel economy.[129]

The Building Efficiency Accelerator held events in several cities in 2016, including Belgrade (Serbia), Bogota (Colombia), Da Nang (Vietnam), Eskisehir (Turkey) and Rajkot (India). Each city will be supported in 2017 to develop and implement at least one policy and one project on energy efficiency in buildings, to track progress and to share lessons learned.[130]

The District Energy in Cities Initiative, co-ordinated by the UN Environment Programme and launched in 2015, aims to double the rate of energy efficiency improvements for heating and cooling by 2030.[131] In 2016, the initiative worked in several countries, including Bosnia and Herzegovina, Chile, China, India and Serbia.[132] New funding announced by Italy in 2016 will be used to expand the initiative to Africa.[133]

Non-governmental organisations, the private sector, and regional and local entities have become an intrinsic part of the policy-making process, and cities are among the front runners.[134] City authorities play a growing role in accelerating energy efficiency, in some countries moving faster than national administrations. For example, local energy efficiency activity is growing in the United States, with seven cities passing energy benchmarking and transparency laws in 2016.[135] Cities also continue to co-operate internationally through initiatives such as Habitat III's New Urban Agenda and organisations such as ICLEI-Local Governments for Sustainability, the Compact of Mayors and C40.[136]

Cities account for 65% of world energy consumption and for more than half of world population.[137] In general, urbanisation has been a driver of improved energy efficiency because connectivity and density lead to benefits of scale and specialisation.[138] Where appropriate, district heating and cooling systems allow greater energy efficiency and penetration of renewables than is possible for a single building. However, challenges remain as urbanisation continues, particularly in Africa where many cities may be vulnerable to sprawl and where infrastructure development may be lagging.[139]

08

Coupling of the electricity, thermal (heating and cooling) and transport sectors can improve flexibility in the power system by adding dynamic demand and storage for electricity. For example, charging of electric vehicles can be timed to coincide with peak variable generation, and heating systems can incorporate thermal storage for added flexibility.

Solar PV charging station for electric cars – Malibu, US

08 FEATURE: DECONSTRUCTING BASELOAD

Markets for solar PV and wind power are expanding rapidly in many regions of the world due to declining costs and to a variety of benefits and opportunities that these technologies can provide. Some countries already meet significant shares of their electricity demand with these variable renewable resources.

While power systems have always had to accommodate variability in both supply and demand, the growing adoption of variable renewable energy (VRE) is changing how power systems are planned, designed and operated. This is because the variability of output from solar and wind power means that more flexibility is required from the rest of the power system, including generating resources, distribution networks and even electricity consumers.

In areas where demand is growing (notably in developing economies), there is an opportunity for new and less-established power systems to grow in concert with higher shares of renewable generation as more flexible systems are developed. It is already possible to avoid lock-in of traditional "baseload" generation by using VRE to provide low-cost energy access and while avoiding costly investments in traditional, and less flexible, generation and grid infrastructure.

In all contexts, a shift away from the traditional "baseload thinking" in power system planning and operations will facilitate optimal integration of growing shares of VRE while providing on-demand, reliable and affordable electricity.

POWER SYSTEMS: TRADITIONAL DESIGN

Both traditional, centralised power systems and distributed, often renewable, energy systems strive to balance the supply and demand of electricity at all times. Their primary objective is to provide access to reliable electricity services at a reasonable price. Traditionally, centralised power systems use electric power facilities classified into three general, and sometimes overlapping, categories[i]:

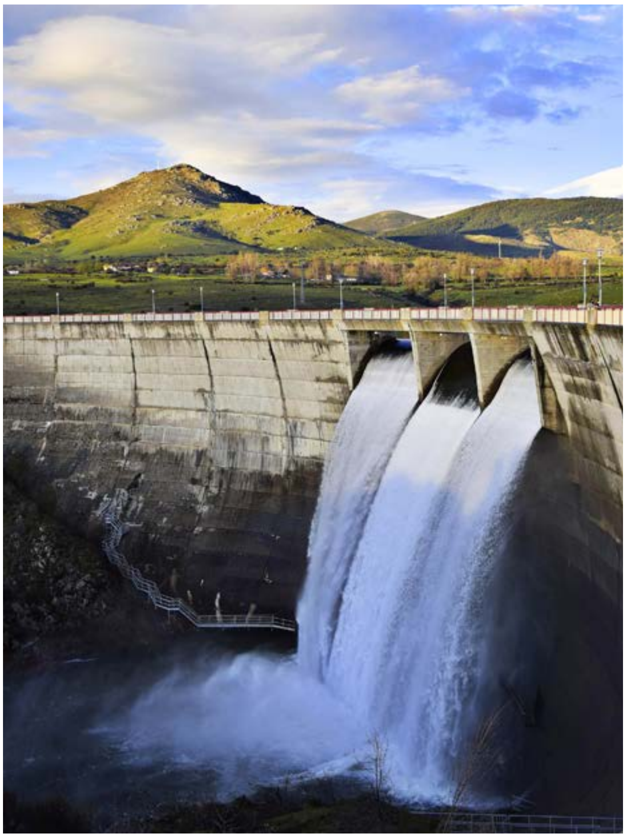
1. **Baseload generation** – Generators such as coal, nuclear and large hydropower facilities are optimised for operation at full output with minimal interruption to meet the minimum level of load[ii] over a given period of time (days, weeks or months). The cost characteristics of traditional baseload generators can vary somewhat, but they typically have relatively high capital costs and relatively low variable costs. This means that these systems achieve their lowest average cost of energy if they are run continuously at full output. Baseload is usually considered an inflexible class of generation, meaning that output cannot be adjusted quickly up or down, with the exceptions of hydropower and geothermal power. The term baseload is an economic paradigm that has been in existence for many decades, but its usefulness is beginning to change in some regions, as explored below.

2. **Intermediate or mid-merit generation** – This includes natural gas combined-cycle generation and sometimes hydropower capacity that is able to adjust power output up or down in response to fluctuating demand.[1] The generators supplement power that is provided by baseload generation. This class of generators is typically designed for frequent flexible operations and may be more expensive to operate than baseload because variable costs (e.g., fuel) may be higher, but also because all costs are spread out over fewer hours of the year.

3. **Peaking generation** – These are generators such as gas- or oil-fired turbines, or diesel generators, that are called on infrequently to meet peak load during periods of very high demand or extreme weather events. They also may be used when other generators or transmission lines are unavailable due to unforeseen outages. These generators are often relatively inefficient and the most expensive form of generation per unit of output, but they are used for short-term and incidental operation because their high variable costs are offset by low capital costs compared to plants optimised for full-time operation.

Demand has always been variable and to some degree unpredictable due to weather and uptake of emerging technologies. To a lesser degree, supply also has been variable given that generators or transmission lines can go offline unexpectedly, even in the most advanced power systems. In the face of this demand and supply variability, system operators have used flexible generation (and flexible demand to a lesser extent) to keep supply and demand in balance. In other words, large, generally inflexible baseload plants such as coal and nuclear have always been complemented by flexible generation in order to meet time-variable demand.

In countries with less mature power systems and/or rapidly growing economies, the demand for electricity may be more difficult to predict in advance because usage patterns are less established and consumers may tend to use more electricity as they add new electrical devices to their homes and businesses. Supply-side variability also may be more pronounced in such countries. Load shedding, or an interruption of energy supply to certain areas in response to balancing challenges, is more common in developing countries. In response, back-up generators are used frequently, and in some cases daily.[2] Where reliable electricity infrastructure is lacking, introducing flexibility to enable higher shares of VRE can help alleviate pressure on strained power systems, and offer better service to customers as demand grows.



i Generators also must supply "ancillary services" such as voltage support and various forms of reserve capacity to fine-tune the matching of supply and demand and to ensure reliability. For more on ancillary services, see, for example, Martin Beck and Marc Sherer, "Overview of Ancillary Services", Swiss Grid, 4 December 2010, http://tinyurl.com/gu5zx4u, and Eric Ela, Michael Milligan and Brandon Kirby, *Operating Reserves and Variable Generation* (Golden, CO: National Renewable Energy Laboratory (NREL), 2011), http://www.nrel.gov/docs/fy11osti/51978.pdf.

ii Load in this context refers to the total amount of electricity demand from all industrial, commercial and residential sources at any given moment.

WHAT IS CHANGING?

Around the world, markets for variable solar and wind power are expanding rapidly for a variety of reasons. These generation sources represent myriad benefits that set them apart from their traditional counterparts. For example, they draw on local resources, can be installed quickly in centralised or decentralised configurations, do not necessarily rely on existing infrastructure (and, unlike traditional systems, are not hampered by a lack of existing infrastructure), do not emit greenhouse gases or other pollutants during generation and generally require little water to operate. Due to their decentralised nature, they also may improve system security in the face of extreme events. In many regions of the world, VRE is now the lowest-cost source of newly constructed power generation available, thanks to rapidly declining capital costs and zero fuel costs.[3]

Subsequent to the growth of VRE in many locations, traditional baseload generators are beginning to lose their economic advantage and may no longer be the first to dispatch energy[i]. This means that once wind or solar power plants are put in service, all else being equal, it is most cost-effective to use all of the energy that they produce, within the bounds of system constraints, and as long as the additional system costs[ii] are not excessive.

With VRE providing increasing amounts of first-in-line generation, several key aspects of power system operation and planning will change:

- As the lowest marginal-cost form of energy on the system, VRE generation in most circumstances will be used when it is available, even if the next cheapest (in terms of marginal cost) generator must reduce its output.
- In established power systems, the market share for traditional baseload generators as providers of bulk energy will decline as operators opt instead for least-cost VRE generation. This, in turn, will make near-constant operation less viable if all VRE is to be effectively utilised, further reducing the cost-competitiveness of baseload generation relative to VRE. Under certain circumstances, traditional baseload generators may begin to operate in a fashion similar to intermediate providers by ramping their output more frequently, to the extent that plant-specific economics and technical constraints allow, raising their average cost per unit of output.[4]
- The remaining energy demand beyond that met by VRE (i.e., residual load) will be more variable, due to the impacts of variable wind and solar generation. Generators that must serve this more variable residual load will be required to operate more flexibly than under the old paradigm.[5] *(→ See Figure 59.)*

In less-developed power systems, integrating flexibility into power system planning will enable higher shares of VRE up-front and reduce the need for traditional, near-constant, baseload operation.

SYSTEM-WIDE FLEXIBILITY

Many technologies and approaches exist to increase flexibility on both the demand and supply sides of power generation.[6] Options such as improved VRE forecasting, use of shorter system dispatch intervals[iii], co-ordination and trade of electricity supply across larger balancing areas[iv] and electricity storage can increase system flexibility.[7] *(→ See Storage section in Enabling Technologies chapter.)* In many countries, grid operators also have used increasingly sophisticated forms of demand response, or incentives that influence customers to shift their use of power to minimise the cost of keeping supply and demand in balance[v,8]

Variable renewable energy systems themselves also can provide flexibility. Operators and regulators are increasingly requiring the use of VRE technology features that provide services to the grid.[9] In Germany, for example, many solar PV systems are required to use smart inverters that ensure ongoing operation in the event of a grid disturbance.[10] Characteristics of VRE power purchase agreements also are evolving in many settings to promote more flexible power systems and to limit curtailment of excess energy generated by VRE.[11]

Conventional generation and certain hydropower resources can be equipped with advanced technologies to provide additional flexibility in electricity supply. In Canada, for example, a coal generating station that originally was designed to provide baseload generation was successfully retrofitted to decrease minimum generation levels and to cycle on and off up to four times per day.[12] Hydropower plants can incorporate variable speed technology, which increases flexibility by allowing power regulation in different modes of operation.[13] One such plant began operation in India in 2016.[14]

i As a result, traditional generators may face concerns of revenue sufficiency, or lost revenue, in systems that see growing shares of near-zero marginal cost VRE. See Bethany Frew et al., *Revenue Sufficiency and Reliability in a Zero Marginal Cost Future* (Golden, CO: NREL, 2016), http://www.nrel.gov/docs/fy17osti/66935.pdf.

ii Additional system costs may include balancing costs (adjustments of dispatchable power plants that respond to short-term variability of VRE), grid costs (that can include additional transmission) and costs related to any back-up capacity that may be required. Falko Ueckerdt et al., "System LCOE: What are the costs of variable renewables?" *Energy*, vol. 63 (15 December 2013), pp. 61–75, http://www.sciencedirect.com/science/article/pii/S0360544213009390. Such costs of integration are highly location-specific – they depend on available power system resources as well as on the characteristics and penetration levels of the specific VRE being used. D. Lew et al., *The Western Wind and Solar Integration Study Phase 2* (Golden, CO: NREL, 2013), http://www.nrel.gov/docs/fy13osti/55588.pdf.

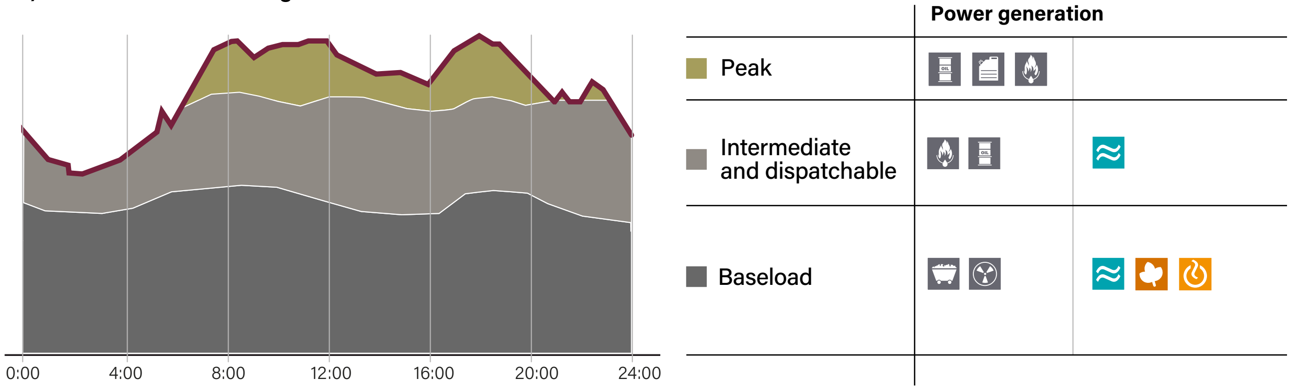
iii Dispatch intervals refer to the time between each new market auction. Shorter dispatch intervals allow dispatch to adjust to renewable variations more quickly and accurately, reducing balancing needs. See Eric Martinot, "Grid integration of renewable energy: flexibility, innovation and experience", *Annual Review of Environment and Resources*, vol. 41 (2016), pp. 223-51, http://www.annualreviews.org/doi/abs/10.1146/annurev-environ-110615-085725.

iv A balancing area in this context refers to a system of power generation and transmission within the jurisdiction of a single authority.

v The simplest form of demand response is to shed load or to dictate when customers can consume. More advanced methods apply price incentives to encourage a shift of consumption to periods of relatively low demand.

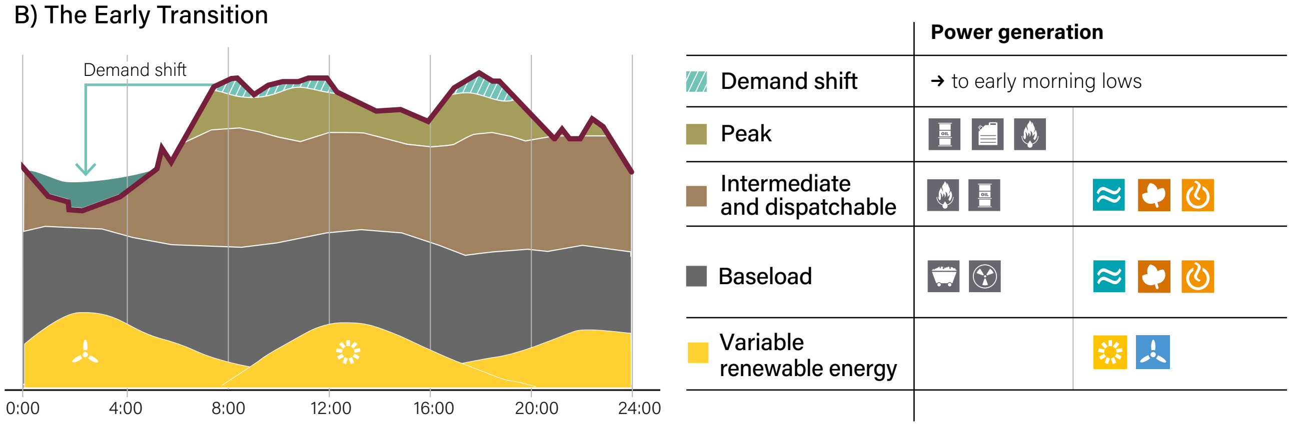
Figure 59. Conceptual Progression from the Baseload Paradigm to a New Paradigm of 100% Renewable Electricity

A) The Baseload Paradigm



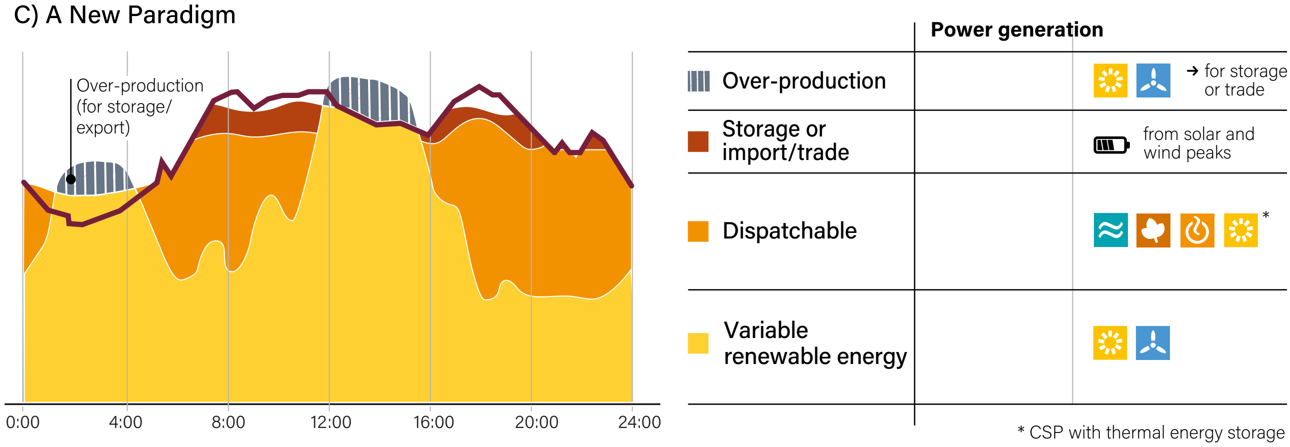
In the early stages of progression to larger shares of variable renewable generation, power systems make some adjustments in their grid operations, develop forecasting systems for renewable energy production, and introduce improved control technology and operating procedures for efficient scheduling and dispatch.

B) The Early Transition



In the late stages of progression towards fully renewable power systems, variable renewable power will be integrated through advanced resource forecasting, grid reinforcements and strengthened interconnections, improved information and control technologies for grid operations, widespread deployment of storage technologies, greater efficiency and scope of demand response, and coupling of electricity, heating and cooling, and transport sectors.

C) A New Paradigm



* CSP with thermal energy storage

Table 4. Overview of Approximate Impacts and Responses to Rising Shares of Variable Renewable Energy

	Share of generation by variable resources				over 50%
Impacts	**No noticeable impacts.**	Small increase in supply variability and uncertainty is **noticeable** at the system operations level. Limited impact on operations of individual power plants.	Growing supply variability and uncertainty has **significant impacts** at the system operations level. Noticeable impact on operations of some power plants.	Elevated supply variability and uncertainty has **major impacts** at the system operations level. Noticeable impact on operations of virtually all power plants.	Structural surplus of VRE generation and seasonal energy imbalances.
Response Requirements	No additional measures.	Some adjustments in system operations and grid infrastructure.	Significant changes to system operations. Greater flexibility of supply and demand. Some grid reinforcement for voltage and frequency stability.	Major changes to system operations. Significant additional flexibility of supply and demand. Significant grid reinforcement for voltage and frequency stability.	Additional steps to manage supply and demand imbalances.
RESPONSES Resource forecasting		■	■ ■	■ ■ ■	■ ■ ■
Grid operations		■	■ ■	■ ■ ■	■ ■ ■
Storage			■	■ ■	■ ■ ■
Demand management			■	■ ■	■ ■ ■
Grid reinforcement			■	■ ■	■ ■ ■
Sector coupling				■	■ ■ ■
Examples of Technological and Operational Responses	Gathering information about grid conditions and planning, including technical standards, for future growth in VRE.	Establishing a renewable energy production forecast system. Introducing improved control technology and operating procedures for efficient scheduling and dispatch of system resources.	Managing variability through advanced resource forecasting, improved transmission infrastructure and a significantly more dynamic operation of a growing number of dispatchable system resources. Co-ordination across control areas with the aid of improved information and control technology, and strengthened transmission interconnections.	Improving significantly the efficiency and scope of demand response with better information and control technology. Deploying significant additional advanced storage on the grid and behind the meter for energy balancing and for voltage and frequency support.	Sector coupling – electrification of heating, cooling and transport as a daily, weekly and even seasonal buffer for VRE generation. Converting electricity into chemical forms that can be stored (e.g., hydrogen).
Countries with This Range of VRE Penetration	Indonesia, Mexico, South Africa	Australia, Austria, Belgium, Brazil, Chile, China, India, the Netherlands, New Zealand, Sweden	Germany, Greece, Italy, Portugal, Spain, the United Kingdom, Uruguay	Denmark, Ireland	

Note: This table represents generalisations. Various impacts and priorities for technological and operational responses will vary by system and will not be confined to a single path.

Source: See endnote 20 for this chapter.

The appropriate selection or mix of these flexibility options will depend on local circumstances. Ireland, for example, has limited opportunities for electricity trade, yet it relies on wind power for approximately one-quarter of its total electricity generation.[15] Similarly, ERCOT, the power system operator in the US state of Texas, has very limited capability to import or export power to other interconnections, but generates far more wind energy than any other US state.[16] Both Ireland and Texas rely on other sources of flexibility, including flexible generation, state-of-the-art wind forecasting and transmission expansion. Uruguay, which supplies 22% of its annual electricity with wind, relies on reservoir hydropower and interconnection with grids of neighbouring countries to provide flexibility.[17] As the penetration of VRE increases, different power systems can employ a combination of flexibility options that are most appropriate and cost-effective under their different institutional, technological and economic contexts.

Based on different mixes of these flexibility mechanisms, VRE has already been integrated in 10 countries above double-digit shares of annual electricity generation without compromising the reliability of electricity supply.[18] The ease of grid integration will vary from country to country.[19] Typically, as the range of VRE penetration increases, so does the impact on power systems, requiring different prioritisation of response options to ensure adequate levels of flexibility.[20] *(→ See Table 4.)*

Where electricity systems are developing, the most attractive option (in terms of both cost and practicality) may be to deploy infrastructure and operations with the flexibility necessary to handle high shares of VRE.

A NEW PLANNING PARADIGM

In all contexts, power system planning plays a major role in setting the trajectory of electricity sector development. Where resources are strong, incorporating high shares of VRE alters planning in un-served and underserved areas because this removes constraints to build new generation capacity in geographic proximity to the existing power system; instead, new capacity can be placed where it makes sense to best serve new and existing customers. In such cases, distributed and VRE systems offer cost-competitive and often more immediate options for providing energy services.[21]

Traditional planning typically has been capacity-based, determining how many baseload, intermediate or peaking units are needed to meet projected energy demand in the future. As the penetration of higher shares of VRE increases, a different type of planning paradigm is required – one that takes into consideration the various costs and benefits derived from solar and wind power generation as well as the operational demands of VRE on system flexibility.[22] In such a new, VRE planning paradigm, power system planners are able to identify the least-cost energy mix while maintaining the reliability of future energy supply.

Integrated Resource and Resiliency Planning (IRRP), sometimes known as Integrated Resource Planning, is a robust framework for identifying the optimal mix of where, how much and what types of power system resources will enable lowest-cost power sector development in the long term while also achieving goals related to reliability, climate, energy access and economic development.[23] IRRPs are common among utilities in developed countries, and utilities in developing countries such as South Africa and Ghana are currently developing new IRRPs.[24] IRRP modelling can integrate emerging best practices for demand response and for managing increasing shares of VRE, including high-quality representation of VRE resource potential, technical and financial implications of distributed VRE, transmission planning, and emerging technologies and operational practices for greater flexibility.[25]

THE ONGOING TRANSITION AWAY FROM BASELOAD

Countries in which high shares (20-40%) of VRE have been integrated (e.g., Denmark, Germany, Portugal, Uruguay and Cabo Verde) have demonstrated the shift away from the traditional baseload paradigm.[26] In Denmark and Germany, interconnection with other European grids has helped to support peaks of 140% and 86.3%, respectively, of electricity generation from renewable energy.[27] Cabo Verde, which supplies 25% of electricity with wind energy, plans to build an additional 20 MW of pumped storage capacity to help manage expanding renewable energy capacity on the island.[28]

Countries in which power demand is currently unmet or growing rapidly may face different conditions for integrating VRE into their power systems than developed countries, where demand for power is typically flat or declining. However, there may be administrative or institutional barriers that inhibit the development of more flexible systems. For example, power systems in developing countries may have baseload generators with mandated generation minimums and limited capital to expand transmission networks, and they may face decisions about extending the grid into new areas versus building mini-grids.[29]

Electric power facilities are long-term investments that involve complex supply chains and employ many people and therefore are subject to system inertia and related institutional, political and cultural barriers.[30] Vested interests in the conventional baseload power system and lack of understanding of and education in new approaches and technological advancements are preventing many countries from moving towards higher shares of VRE, even when variable renewables might help reduce the overall cost of energy provision and improve the quality of energy services. Immature or poorly functioning institutions also can cause difficulties in both developed and developing countries, albeit to different extents.[31]

A range of planning, operational and institutional changes to the power system can be pursued to promote overall least-cost operation and investment strategies while preserving reliability.[32] These strategies can also improve reliability and cost effectiveness in systems that are less developed, regardless of renewable energy penetration. As VRE resources and other enabling technologies – including storage, demand response and efficiency improvements – continue to achieve more favourable cost and performance characteristics, the incentive to deploy them will continue to increase, moving both new and existing power systems further from the baseload paradigm.

Table R1. Global Renewable Energy Capacity and Biofuel Production, 2016

	ADDED DURING 2016	EXISTING AT END-2016
POWER GENERATION (GW)		
Bio-power	5.9	112
Geothermal power	0.4	13.5
Hydropower	25	1,096
Ocean power	~0	0.5
Solar PV	75	303
Concentrating solar thermal power (CSP)	0.1	4.8
Wind power	55	487
HEATING/HOT WATER (GW_{th})		
Modern bio-heat	5	311
Geothermal direct use	1.3	23
Solar collectors for water heating[1]	37	456
TRANSPORT FUELS (billion litres per year)		
Ethanol production	0.04	98.6
Biodiesel production	2.17	30.8
Hydrotreated vegetable oil (HVO)	0.9	4.9

[1] Additions are net and do not include air collectors.

Note: Numbers are rounded to nearest GW/GW_{th}/billion litres, with the exceptions of numbers <15, which are rounded to first decimal point, and transport fuels; where totals do not add up, the difference is due to rounding. Rounding is to account for uncertainties and inconsistencies in available data. Data reflect adjustments to year-end 2015 capacity data (particularly for bio-power and hydropower). For more precise data, see Reference Tables R2-R9, Market and Industry Trends chapter and related endnotes.

Source: See endnote 1 for this section.

Table R2. Renewable Electric Power Global Capacity, Top Regions/Countries[1], 2016

TECHNOLOGY	Global	BRICS[2]	EU-28	China	United States	Germany	Japan	India	Italy
	GW			GW					
Bio-power	112	35	37	12	16.8	7.6	4.1	8.3	4.1
Geothermal power	13.5	0.1	0.9	~0	3.6	~0	0.5	0	0.8
Hydropower	1,096	499	127	305	80	5.6	23	47	18.5
Ocean power	0.5	~0	0.3	~0	~0	0	0	0	~0
Solar PV	303	88	106	77	41	41	43	9.1	19.3
Concentrating solar thermal power (CSP)	4.8	0.4	2.3	~0	1.7	~0	0	0.2	~0
Wind power	487	210	154	169	82	50	3.2	29	9.3
Total renewable power capacity (including hydropower)	**2,017**	**832**	**428**	**564**	**225**	**104**	**73**	**94**	**52**
Total renewable power capacity (not including hydropower)	**921**	**333**	**300**	**258**	**145**	**98**	**51**	**46**	**33**
Per capita capacity (kilowatts per inhabitant, not including hydropower)	0.1	0.1	0.6	0.2	0.5	1.2	0.4	0.04	0.6

[1] Table shows the top six countries by total renewable power capacity, not including hydropower; if hydropower were included, countries and rankings would differ somewhat (the top six would be China, United States, Brazil, Germany, Canada and India).

[2] The five BRICS countries are Brazil, the Russian Federation, India, China and South Africa.

Note: Global total reflects additional countries not shown. Numbers are based on best data available at time of production. To account for uncertainties and inconsistencies in available data, numbers are rounded to the nearest 1 GW, with the exception of the following: capacity totals below 20 GW and per capita totals are rounded to the nearest decimal point (except for India, which is rounded to the nearest 0.01 kW). Where totals do not add up, the difference is due to rounding. Capacity amounts of <50 MW (including pilot projects) are designated by "~0." For more precise capacity data, see Global Overview chapter and Market and Industry Trends chapter and related endnotes. Numbers should not be compared with prior versions of this table to obtain year-by-year increases, as some adjustments are due to improved or adjusted data rather than to actual capacity changes. Hydropower totals, and therefore the total world renewable capacity (and totals for some countries), reflect an effort to omit pure pumped storage capacity. For more information on hydropower and pumped storage, see Methodological Notes.

Source: See endnote 2 for this section.

Table R3. Biofuels Global Production, Top 16 Countries and EU-28, 2016

COUNTRY	ETHANOL	BIODIESEL (FAME)	HVO[1]	TOTAL	CHANGE RELATIVE TO 2015
			Billion litres		
United States	58.0	5.5	1.6	**65.1**	2.6
Brazil	27.0	3.8		**30.8**	-1.4
Germany	0.9	3.0		**3.9**	-0.3
Argentina	0.9	3.0		**3.9**	1.0
China	3.2	0.3		**3.5**	no change
Indonesia	0.1	3.0		**3.1**	1.3
Thailand	1.2	1.4	0	**2.6**	0.2
France	0.8	1.5		**2.3**	-0.2
United Kingdom	0.5	0.2	1.6	**2.3**	0.1
Canada	1.7	0.4		**2.1**	0.1
Spain	0.3	1.1		**1.4**	-0.2
Singapore		0	1.2	**1.2**	no change
Poland	0.2	0.9		**1.1**	no change
Belgium	0.6	0.5		**1.1**	-0.1
Colombia	0.4	0.5		**0.9**	-0.1
India	0.9	0		**0.9**	0.2
EU-28	**3.4**	**8.0**	**1.6**	**13.0**	**0.2**
World Total	**98.6**	**30.8**	**5.9**	**135.3**	**2.1**

[1] Hydrotreated vegetable oil

Note: All figures are rounded to the nearest 0.1 billion litres; comparison column notes "no change" if difference is less than 0.05 billion litres; blank cells indicate that no data are available. Ethanol numbers are for fuel ethanol only. Table ranking is by total volumes of biofuel produced in 2016, and not by energy content. Where numbers do not add up, it is due to rounding. Ethanol data were converted from cubic metres to litres using 1,000 litres/cubic metre; biodiesel data were converted from units of 1,000 tonnes using a density value for biodiesel to give 1,136 litres per tonne based on US National Renewable Energy Laboratory, *Biodiesel Handling and Use Guide, Fourth Edition* (Golden, CO: 2009), http://www.biodiesel.org/docs/using-hotline/nrel-handling-and-use.pdf?sfvrsn=4. HVO data were converted from tonnes to litres using a conversion factor of 780 kg/m^3, from Neste Oil, *Hydrotreated Vegetable Oil (HVO) – Premium Renewable Biofuel for Diesel Engines* (Espoo, Finland: February 2015), https://www.neste.com/sites/default/files/image_gallery/renewable_products/neste_renewable_diesel_handbook_german.pdf. Data can vary considerably across sources. For further details, see Biomass Energy section in Market and Industry Trends chapter and related endnotes.

Source: See endnote 3 for this section.

Table R4. Geothermal Power Global Capacity and Additions, Top 6 Countries, 2016

	ADDED 2016	TOTAL END-2016
	MW	GW
TOP COUNTRIES BY ADDITIONS		
Indonesia	205	1.6
Turkey	197	0.8
Kenya	29	0.6
Mexico	15	0.9
Japan	1	0.5
Italy	–	0.9
TOP COUNTRIES BY TOTAL CAPACITY		
United States	–	3.6
Philippines	–	1.9
Indonesia	205	1.6
New Zealand	–	1.0
Mexico	15	0.9
Italy	–	0.8
World Total	**447**	**13.5**

Note: Capacity additions are rounded to the nearest 1 MW, and totals are rounded to the nearest 0.1 GW. Rounding is to account for uncertainties and inconsistencies in available data. For more information and statistics, see Geothermal Power and Heat section in Market and Industry Trends chapter and related endnotes.

Source: See endnote 4 for this section.

Endnotes: see full version online at www.ren21.net/gsr

Table R5. Hydropower Global Capacity and Additions, Top 6 Countries, 2016

	ADDED 2016	TOTAL END-2016
	GW	
TOP COUNTRIES BY ADDITIONS		
China	8.9	305
Brazil	5.3	97
Ecuador	2.0	4
Ethiopia	1.5	4
Vietnam	1.1	16
Peru	1.0	5
TOP COUNTRIES BY TOTAL CAPACITY		
China	8.9	305
Brazil	5.3	97
United States	0.4	80
Canada	–	79
Russian Federation	0.2	48
India	0.6	47
World Total	**25**	**1,096**

Note: Capacity additions are rounded to the nearest 0.1 GW, and totals are rounded to the nearest 1 GW. Rounding is to account for uncertainties and inconsistencies in available data. For more information and statistics, see Hydropower section in Market and Industry Trends chapter and related endnotes.

Source: See endnote 5 for this section.

Table R6. Solar PV Global Capacity and Additions, Top 10 Countries, 2016

	TOTAL END-2015	ADDED 2016	TOTAL END-2016
		GW	
TOP COUNTRIES BY ADDITIONS			
China	43.5	34.5	77.4
United States	26.2	14.8	40.9
Japan	34.2	8.6	42.8
India	5.1	4.1	9.1
United Kingdom	9.7	2	11.7
Germany	39.8	1.5	41.3
Republic of Korea	3.5	0.9	4.4
Australia	4.9	0.9	5.8
Philippines	0.1	0.8	0.9
Chile	0.9	0.7	1.6
TOP COUNTRIES BY TOTAL CAPACITY			
China	43.5	34.5	77.4
Japan	34.2	8.6	42.8
Germany	39.8	1.5	41.3
United States	26.2	14.8	40.9
Italy	18.9	0.4	19.3
United Kingdom	9.7	2	11.7
India	5.1	4.1	9.1
France	6.6	0.6	7.1
Australia	4.9	0.9	5.8
Spain	5.4	0.1	5.5
World Total	**228**	**75**	**303**

Note: Country data are rounded to the nearest 0.1 GW; world totals are rounded to the nearest 1 GW. Rounding is to account for uncertainties and inconsistencies in available data; where totals do not add up, the difference is due to rounding. Data are provided in direct current (DC); data for Canada, Chile, Japan and Spain were converted from official data reported in alternating current (AC) into DC by the sources listed for this table. Data reflect a variety of sources, some of which differ significantly, reflecting variations in accounting or methodology. For more information, see Solar PV section in Market and Industry Trends chapter and related endnotes.

Source: See endnote 6 for this section.

Table R7. Concentrating Solar Thermal Power (CSP) Global Capacity and Additions, 2016

COUNTRY	TOTAL END-2015	ADDED 2016	TOTAL END-2016
		MW	
Spain	2,300	0	2,300
United States	1,738	0	1,738
India	225	0	225
South Africa	100	100	200
Morocco	180	0	180
United Arab Emirates	100	0	100
Algeria	25	0	25
Egypt	20	0	20
Australia	12	0	12
China	0	10	10
Thailand	5	0	5
World Total	**4,705**	**110**	**4,815**

Note: Table includes all countries with operating commercial CSP capacity at end-2016. Several countries with commercial capacity also have pilot or demonstration facilities that are not included in the table. Additional countries that had small pilot or demonstration plants in operation by year's end include Canada (1.1 MW), France (1.6 MW), Germany (1.5 MW), Israel (6 MW), Italy (7 MW), Oman (7 MW) and Turkey (5 MW). National data are rounded to the nearest MW, and world totals are rounded to the nearest 5 MW. Rounding is to account for uncertainties and inconsistencies in available data; where totals do not add up, the difference is due to rounding. For more information, see CSP section in Market and Industry Trends chapter and related endnotes.

Source: See endnote 7 for this section.

Endnotes: see full version online at www.ren21.net/gsr

Table R8. Solar Water Heating Collectors and Total Capacity End-2015 and Newly Installed Capacity 2016, Top 20 Countries

	TOTAL END-2015			GROSS ADDITIONS 2016		
	GW_{th}			MW_{th}		
COUNTRY	**Glazed**	**Unglazed**	**Total**	**Glazed**	**Unglazed**	**Total**
China[1]	309.5	0	309.5	27,664	0	27,664
Turkey	13.6	0	13.6	1,467	0	1,467
Brazil	5.7	3.0	8.7	530	384	913
India[2]	6.3	0	6.3	894	0	894
United States	2.0	15.3	17.3	121	562	682
Germany	12.8	0.4	13.2	521	0	521
Australia	2.4	3.6	6.0	115	266	381
Denmark	0.8	0	0.8	335	0	335
Mexico	1.3	0.7	2.0	180	76	256
Israel	3.2	0	3.2	252	1	253
Greece	3.1	0	3.1	190	0	190
Spain	2.5	0.1	2.6	146	2	149
Italy	3.0	0	3.0	142	0	142
South Africa[3]	0.5	0.7	1.2	37	55	92
Poland	1.4	0	1.4	81	0	81
Austria	3.4	0.3	3.7	78	1	78
Taipei, China	1.2	0	1.2	70	0	70
Switzerland	1.0	0.1	1.1	55	5	59
Japan	2.4	0	2.4	50	0	50
France	1.5	0.1	1.6	46	0	46
Total 20 Top Countries	376.7	24.2	400.9	32,974	1,351	34,324
World Total	**407.7**	**27**	**434.7**	**35,200**	**1,460**	**36,660**

[1] In 2014, China settled on a new methodology for calculating cumulative capacity, which assumes a 10-year lifetime for Chinese-made systems. China and world data reflect this change.

[2] For India, end-of-year capacity data are by fiscal year; new additions in 2016 are by calendar year.

[3] For South Africa, additions in 2016 are assumed to be equivalent to additions in 2015, due to a lack of available data.

Note: Countries are ordered according to newly installed glazed collector capacity in 2016. Data are for glazed and unglazed water collectors excluding air collectors, which added 1,641,518 m^2 to the year-end world total for 2015, and excluding concentrating collectors with 64,596 m^2 additional aperture area. Data are rounded: end-2015 data for individual countries, Total 20 Top Countries and World Total are rounded to nearest 0.1 GW_{th}; additions for individual countries, Total 20 Top Countries and World Total are rounded to nearest 1 MW_{th}. Where totals do not add up, the difference is due to rounding. By accepted convention, 1 million square metres = 0.7 GW_{th}. The year 2015 is the most recent one for which firm global data on total capacity in operation are available.
It is estimated, however, that 456 GW_{th} of solar thermal capacity (water collectors only) was in operation worldwide by end-2016. For more information, see Solar Thermal Heating and Cooling section in Market and Industry Trends chapter and related endnotes.

Source: See endnote 8 for this section.

Table R9. Wind Power Global Capacity and Additions, Top 10 Countries, 2016

	TOTAL END-2015	ADDED 2016	TOTAL END-2016
		GW	
TOP COUNTRIES BY ADDITIONS			
China[1]	129/145.4	19.3/23.4	149/168.7
United States	74	8.2	82.1
Germany[2]	44.5	5	49.5
India	25.1	3.6	28.7
Brazil[3]	8.7	2	10.7
France	10.5	1.6	12.1
Turkey	4.7	1.4	6.1
Netherlands	3.4	0.9	4.3
United Kingdom	13.8	0.7	14.5
Canada	11.2	0.7	11.9
TOP COUNTRIES BY TOTAL CAPACITY			
China[1]	129/145.4	19.3/23.4	149/168.7
United States	74	8.2	82.1
Germany[2]	44.5	5	49.5
India	25.1	3.6	28.7
Spain	23	~0	23.1
United Kingdom	13.8	0.7	14.5
France	10.5	1.6	12.1
Canada	11.2	0.7	11.9
Brazil[3]	8.7	2	10.7
Italy	9	0.3	9.3
World Total	**433**	**55**	**487**

[1] For China, data to the left of the "/" are the amounts officially classified as connected to the grid and operational (receiving FIT premium) by year's end; data to the right are total installed capacity, most, if not all, of which was connected to substations by year's end. The world totals include the higher figures for China. (See Wind Power text and related endnotes for more details.)

[2] For Germany, some onshore capacity was decommissioned/repowered in 2016; number in table is net additions. (See Wind Power text and related endnotes for more details.)

[3] For Brazil, all capacity was commissioned by year's end, but not all was grid-connected.

Note: Country data are rounded to nearest 0.1 GW; world data are rounded to nearest 1 GW. Rounding is to account for uncertainties and inconsistencies in available data; where totals do not add up, the difference is due to rounding or repowering/removal of existing projects. "~0" denotes capacity additions of less than 50 MW. Data reflect a variety of sources, some of which differ quite significantly, reflecting variations in accounting or methodology. For more information, see Wind Power section in Market and Industry Trends chapter and related endnotes.

Source: See endnote 9 for this section.

Table R10. Electricity Access by Region and Country, 2014 and Targets

WORLD/REGION/COUNTRY	ELECTRIFICATION RATE IN 2014	PEOPLE WITHOUT ACCESS TO ELECTRICITY IN 2014	TARGETS
	Share of population with access	Millions	Share of population with access
Africa	**45%**	**634**	
Northern Africa	**99%**	**1.3**	
Sub-Saharan Africa	**35%**	**632**	
Developing Asia	**86%**	**512**	
Latin America	**95%**	**22**	
Middle East	**92%**	**18**	
Africa			
Algeria	100%	0	
Angola	33%	16	→ 100% by 2030
Benin	29%	7	→ 95% by 2025 (urban) → 65% by 2025 (rural)
Botswana[1]	53%	1	→ 100% by 2030
Burkina Faso	18%	14	→ 95% by 2030
Burundi	5%	10	
Cabo Verde	96%	0.2	→ 100% by 2020
Cameroon	62%	9	
Central African Republic	3%	5	→ 50% by 2030
Chad	4%	13	
Comoros	69%	0.2	
Congo	42%	3	
Côte d'Ivoire	62%	8	→ 100% by 2020
Democratic Republic of the Congo	18%	62	→ 60% by 2025
Djibouti	42%	0.5	
Egypt	99%	1	
Equatorial Guinea	66%	0.3	
Eritrea	32%	3	
Ethiopia	25%	73	→ 100% by 2030
Gabon	89%	0.2	
Gambia	45%	1	→ 100% by 2030
Ghana	76%	8	→ 100% by 2030
Guinea	26%	9	→ 50% by 2020
Guinea-Bissau	21%	1	→ 80% by 2030
Kenya	20%	36	→ 100% by 2022
Lesotho	17%	2	→ 40% by 2020
Liberia	10%	4	→ 100% by 2030
Libya	99.8%	0	
Madagascar	13%	21	
Malawi	12%	15	
Mali	26%	13	→ 87% by 2030 → 61% by 2033 (rural)
Mauritania	29%	3	
Mauritius	100%	0	

Table R10. Electricity Access by Region and Country, 2014 and Targets (continued)

WORLD / REGION / COUNTRY	ELECTRIFICATION RATE IN 2014	PEOPLE WITHOUT ACCESS TO ELECTRICITY IN 2014	TARGETS
	Share of population with access	Millions	Share of population with access
Africa (continued)			
Morocco	99%	0.4	
Mozambique	40%	16	
Namibia	32%	2	
Niger	15%	16	→ 65% by 2030
Nigeria	45%	98	→ 75% by 2020 → 90% by 2030
Rwanda	27%	8	→ 100% by 2030
São Tomé and Príncipe	59%	0.1	
Senegal	61%	6	→ 70% by 2017 → 100% by 2025
Seychelles	98%	0	
Sierra Leone	14%	5	→ 92% by 2030
Somalia	15%	9	
South Africa	86%	8	→ 100% by 2019
South Sudan	1%	12	
Sudan	40%	24	
Swaziland[2]	66%	0.4	→ 75% by 2018 → 85% by 2020 → 100% by 2025
Tanzania	30%	36	→ 75% by 2030
Togo	27%	5	→ 82% by 2030
Tunisia	100%	0	
Uganda	19%	31	→ 98% by 2030
Zambia	28%	11	
Zimbabwe	52%	7	→ 66% by 2030 → 90% by 2030 (urban) → 51% by 2030 (rural)
Developing Asia			
Bangladesh	62%	60	→ 100% by 2021
Brunei	100%	0	
Cambodia	34%	10	
China	100%	0	
India	81%	244	→ 100% by 2019
Indonesia	84%	41	
Korea, DPR	26%	18	→ 90% by 2017
Lao PDR	87%	1	
Malaysia	100%	0	
Mongolia	90%	0.3	
Myanmar	32%	36	
Nepal	76%	7	
Pakistan	73%	51	
Philippines	89%	11	

Table R10. Electricity Access by Region and Country, 2014 and Targets (continued)

WORLD/REGION/COUNTRY	ELECTRIFICATION RATE IN 2014	PEOPLE WITHOUT ACCESS TO ELECTRICITY IN 2014	TARGETS
	Share of population with access	Millions	Share of population with access
Developing Asia (continued)			
Singapore	100%	0	
Sri Lanka	99%	0.3	
Thailand	99%	1	
Vietnam	98%	2	
Latin America			
Argentina	96%	1.6	
Barbados	100%	0	
Bolivia	89%	1.2	→ 100% by 2025 (rural)
Brazil	99.6%	0.8	
Chile	100%	0	
Colombia	98%	1.2	→ 97.45% by 2017
Costa Rica	99.5%	0	
Cuba	98%	0.2	
Dominican Republic	97%	0.3	
Ecuador	97%	0.5	→ 98.9% by 2022 (urban) → 96.3% by 2022 (rural)
El Salvador	94%	0.4	
Guatemala	90%	1.7	
Haiti	29%	7.5	
Honduras	89%	0.9	
Jamaica	93%	0.2	
Mexico	99%	3.7	
Nicaragua	76%	1.4	
Panama	91%	0.3	
Paraguay	99%	0.1	
Peru	90%	3	
Suriname	90%	0.1	
Trinidad and Tobago	97%	0	
Uruguay	99%	0	
Venezuela	99.7%	0.1	

Table R10. Electricity Access by Region and Country, 2014 and Targets (continued)

WORLD / REGION / COUNTRY	ELECTRIFICATION RATE IN 2014	PEOPLE WITHOUT ACCESS TO ELECTRICITY IN 2014	TARGETS
	Share of population with access	Millions	Share of population with access
Middle East			
Bahrain	100%	0	
Iran	99%	1.1	
Iraq	98%	0.6	
Jordan	100%	0	
Kuwait	100%	0	
Lebanon	100%	0	
Oman	98%	0.1	
Palestine, State of[3]	99%		
Qatar	100%	0	
Saudi Arabia	99%	0.2	
Syria	93%	1.6	
United Arab Emirates	100%	0	
Yemen	46%	14.2	
Oceania			
Micronesia, Federated States of[4]	55%	0.0	→ 90% by 2020 (rural)
All Developing Countries	**79%**	**1,185**	
World[5]	**84%**	**1,186**	

[1] Botswana had an electricity access target for 2016.

[2] Swaziland data are for 2015.

[3] The State of Palestine rate is defined by the number of villages connected to the national electricity grid.

[4] For the Federated States of Micronesia, rural electrification rate is defined by electrification of all islands outside of the four that host the state capital (which is considered urban).

[5] Includes countries in the OECD and economies in transition.

Disclaimer: The tracking of data related to energy access and distributed renewable energy systems is a challenging process. Discrepancies or inconsistencies with past reporting may be due to improvements in data collection.

Source: See endnote 10 for this section.

Table R11. Population Relying on Traditional Use of Biomass for Cooking, 2014

WORLD/REGION/COUNTRY	RELIANCE ON TRADITIONAL BIOMASS IN 2014	POPULATION	TARGETS
	Share of population	Millions	Share of population with access to clean cooking
Africa	**69%**	**793**	
Sub-Saharan Africa	**81%**	**792**	
Northern Africa	**0.4%**	**0.7**	
Developing Asia	**50%**	**1,875**	
Latin America	**14%**	**65**	
Middle East	**4%**	**8**	
Africa			
Angola	52%	13	100% by 2030
Benin	94%	10	
Botswana	36%	1	
Burkina Faso	95%	17	100% by 2030 (urban) 65% by 2030 (rural)
Burundi	98%	11	
Cabo Verde	30%	0.2	100% by 2020
Cameroon	78%	18	
Central African Republic	97%	5	
Chad	95%	13	
Comoros	74%	1	
Congo	74%	3	
Côte d'Ivoire	81%	18	
Democratic Republic of the Congo	95%	71	
Djibouti	16%	0.1	
Equatorial Guinea	43%	0.4	
Eritrea	63%	3	
Ethiopia	95%	92	100% by 2025
Gabon	19%	0.3	
Gambia	95%	2	100% by 2030
Ghana	82%	22	100% by 2030
Guinea	98%	12	50% by 2025
Guinea-Bissau	98%	2	75% by 2030
Kenya	85%	38	100% by 2022
Lesotho	62%	1	
Liberia	98%	4	100% by 2030
Madagascar	98%	23	
Malawi	97%	16	
Mali	98%	17	100% by 2030
Mauritania	56%	2	
Mauritius	0%	0	
Morocco	2%	0.7	
Mozambique	96%	26	
Namibia	54%	1	
Niger	97%	18	100% by 2030 (urban) 60% by 2030 (rural)
Nigeria	76%	134	
Rwanda	98%	11	100% by 2030
São Tomé and Príncipe	70%	0.1	
Senegal	61%	9	

Table R11. Population Relying on Traditional Use of Biomass for Cooking, 2014 (continued)

WORLD/REGION/COUNTRY	RELIANCE ON TRADITIONAL BIOMASS IN 2014	POPULATION	TARGETS
	Share of population	Millions	Share of population with access to clean cooking
Africa (continued)			
Sierra Leone	98%	6	
Somalia	95%	10	
South Africa	10%	5	
South Sudan	98%	12	
Sudan	69%	27	
Swaziland	61%	1	100% by 2030
Tanzania	96%	50	75% by 2030
Togo	95%	7	80% by 2030
Uganda	98%	37	99% by 2030
Zambia	82%	13	
Zimbabwe	71%	11	
Developing Asia			
Bangladesh	89%	142	
Cambodia	89%	13	
China	33%	453	
India	63%	819	
Indonesia	38%	97	
Korea, DPR	47%	12	
Lao PDR	65%	4	
Mongolia	62%	2	
Myanmar	92%	49	
Nepal	80%	23	
Pakistan	56%	105	
Philippines	54%	54	
Sri Lanka	73%	15	
Thailand	21%	14	
Vietnam	45%	40	
Latin America			
Argentina	0.2%	0.1	
Bolivia	22%	2.3	
Brazil	5%	9.6	
Chile	3%	0.5	
Colombia	13%	6.4	
Costa Rica	5%	0.2	
Cuba	6%	0.7	
Dominican Republic	8%	0.8	
Ecuador	2%	0.4	
El Salvador	18%	1.1	
Guatemala	64%	10.2	
Haiti	92%	9.7	
Honduras	50%	4	
Jamaica	11%	0.3	
Mexico	16%	19.6	
Nicaragua	52%	3.1	
Panama	14%	0.6	

Table R11. Population Relying on Traditional Use of Biomass for Cooking, 2014 (continued)

WORLD/REGION/COUNTRY	RELIANCE ON TRADITIONAL BIOMASS IN 2014	POPULATION	TARGETS
	Share of population	Millions	Share of population with access to clean cooking
Latin America (continued)			
Paraguay	41%	2.7	
Peru	33%	10.2	
Venezuela	7%	2.5	
Middle East			
Iraq	1%	0.2	
Yemen	31%	8.1	
All Developing Countries	**49%**	**2,722**	
World[1]	**38%**	**2,742**	

[1] Includes countries in the OECD and economies in transition.

Disclaimer: The tracking of data related to energy access and distributed renewable energy systems is a challenging process. Discrepancies or inconsistencies with past reporting may be due to improvements in data collection.

Source: See endnote 11 for this section.

Table R12. Programmes Furthering Energy Access: Selected Examples

NAME	BRIEF DESCRIPTION	WEB ADDRESS
ACP-EU Energy Facility	A co-financing instrument that works to increase access to sustainable and affordable energy services in impoverished rural and peri-urban areas of African, Caribbean and Pacific (ACP) countries by involving local authorities and communities.	https://ec.europa.eu/europeaid/regions/african-caribbean-and-pacific-acp-region/acp-multi-country-cooperation/energy_en
Africa-EU Renewable Energy Cooperation Programme (RECP)	A programme that contributes to the African EU Energy Partnership's political targets of increasing renewable energy use and bringing modern access to at least an additional 100 million people by 2020. It provides policy advice, private sector co-operation, project preparation support activities and capacity development.	http://www.africa-eu-partnership.org/en/newsroom/all-news/energy-africa-launch-renewable-energy-cooperation-programme
African Renewable Energy Fund (AREF)	A private equity fund that invests in small to medium-sized renewable energy projects in sub-Saharan Africa, excluding South Africa. It aims to assist governments in meeting their renewable energy and carbon emission targets, while creating jobs.	http://www.afdb.org/en/news-and-events/article/african-renewable-energy-fund-aref-launches-with-100m-committed-capital-12901/
Asian Development Bank – Energy for All Initiative	An initiative that strengthens ADB's investments in energy access. From 2008 to 2016, ADB's aggregate investment in energy access was around USD 7.2 billion, which is expected to benefit 110 million people.	http://www.adb.org/sectors/energy/programs/energy-for-all-initiative
Central America Clean Cooking Initiative (CACCI)	An initiative that aims to help scale up clean cooking solutions in countries such as Guatemala, Honduras, Nicaragua and possibly El Salvador. Activities to be financed by the grant include development of a roadmap to achieve universal clean cooking access by 2030. The roadmap will build on the regional Sustainable Energy Strategy 2020.	https://www.esmap.org/node/4006
CleanStart	Developed by the UN Capital Development Fund and UNDP to help poor households and micro-entrepreneurs access micro-financing for low-cost clean energy. By 2020, it aims to invest USD 26 million in six countries in Asia and Africa, affecting the lives of more than 2.5 million people.	http://www.uncdf.org/en/cleanstart
Energising Development (EnDev)	A multilateral initiative supported by the governments of Australia, Germany, the Netherlands, Norway, Switzerland and the United Kingdom. It operates in 24 countries in Asia, Africa and Latin America with the aim of facilitating the sustainable access to modern energy services for at least 15 million people by the end of 2018. So far, EnDev has facilitated energy access for 14.8 million people.	http://endev.info/content/Main_Page
EU-Africa Infrastructure Trust Fund (ITF)	A fund that combines grants and loans from the EU and its member states and banks to support local infrastructure projects, notably in electricity generation. Since 2007, more than 100 grants have been awarded to support projects for an amount of over USD 690 million (EUR 655 million).	http://www.eu-africa-infrastructure-tf.net/about/index.htm
Global Alliance for Clean Cookstoves (GACC)	A public-private partnership created with the goal of enabling the adoption of 100 million clean and efficient cook stoves and fuels by 2020. GACC uses a market-based approach to bring together diverse groups of actors across government, development, NGOs, academia and the private sector to save lives, improve livelihoods, empower women and protect the environment through initiatives designed to catalyse and champion the sector, mobilise resources, promote standards and testing, and co-ordinate sector knowledge and research.	http://www.cleancookstoves.org/the-alliance/
Global Energy Efficiency and Renewable Energy Fund (GEEREF)	A sustainable development tool sponsored by the EU, Germany and Norway, advised by the European Investment Bank Group. It aims to mobilise public and private capital to support small and medium-sized renewable energy and energy efficiency projects.	http://geeref.com/posts/display/1
Global Lighting and Energy Access Partnership (Global LEAP)	An initiative of the Clean Energy Ministerial that includes more than 10 governments and development partners. It provides support for quality assurance frameworks and programmes that encourage market transformation towards super-efficient technologies for off-grid use, including the Global LEAP Awards for Outstanding Off-Grid Products.	http://globalleap.org/

Table R12. Programmes Furthering Energy Access: Selected Examples (continued)

NAME	BRIEF DESCRIPTION	WEB ADDRESS
Green Climate Fund (GCF)	A fund established in 2010 by 194 countries that are party to the UN Framework Convention on Climate Change that aims to invest in low-emission and climate-resilient development in developing countries. The fund is to mobilise USD 100 billion per year by 2020.	http://news.gcfund.org/
IDEAS – Energy Innovation Contest	A contest, launched in 2009, that supports the implementation of innovative projects in the areas of renewable energy, energy efficiency and energy access in Latin America and the Caribbean by promoting innovative energy solutions that can be replicated and scaled up in the region.	http://www.iadb.org/en/topics/energy/ideas/ideas,3808.html
IRENA – Abu Dhabi Fund for Development (ADFD) Facility	A partnership between IRENA and the ADFD to provide and facilitate finance for renewable energy projects in developing countries. The ADFD provides concessional loans of USD 5 million to USD 15 million to renewable energy projects in developing countries over seven funding rounds of approximately USD 50 million each. The Facility is currently running its fifth round, and since 2012 has allocated USD 189 million to 19 renewable energy projects.	http://adfd.irena.org/
Lighting a Billion Lives	A global initiative launched in 2008, steered by The Energy and Resources Institute (TERI), to facilitate access to clean lighting and cooking solutions for energy-starved communities. The programme operates on an entrepreneurial model of energy service delivery to provide innovative, affordable and reliable off-grid solar energy solutions. As of March 2016, it had facilitated access to clean lighting and cooking solutions for more than 4.5 million people in India, sub-Saharan Africa and South Asia.	http://labl.teriin.org/
Lighting Africa	An IFC and World Bank programme to accelerate the development of sustainable markets for affordable, modern off-grid lighting solutions for low-income households and micro-enterprises across Africa. As of end-2016, Lighting Africa had provided access to clean, safe lighting for more than 20 million people.	http://www.lightingafrica.org/
Lighting Asia	An IFC market transformation programme aimed at increasing access to clean, affordable energy in Asia by promoting modern off-grid lighting products, systems and mini-grid connections. The programme works with the private sector to remove market entry barriers, provide market intelligence, foster business-to-business linkages and raise consumer awareness on modern lighting options. In India alone, Phase I of the programme (2012-2016) enabled energy access for more than 8 million people.	http://www.lightingasia.org/
OPEC Fund for International Development (OFID)	A development aid institution with a 40-year standing and a presence in over 130 countries. It works in co-operation with developing country partners and the international donor community to stimulate economic growth and alleviate poverty. Since 2008, the year that OFID launched its Energy for the Poor Initiative (EPI), energy poverty alleviation has been the primary strategic focus. In June 2012, the OFID Ministerial Council committed a minimum of USD 1 billion to bolster activities under the EPI, and in 2013 it turned this commitment from a one-time obligation to a revolving pledge.	http://www.ofid.org/
Power Africa's Beyond the Grid Initiative	An initiative launched in 2014 focused on unlocking investment and growth for off-grid and small-scale energy solutions on the African continent. Beyond the Grid has partnered with over 40 investors and practitioners that have committed to invest over USD 1 billion into off-grid and small-scale energy. In 2016 alone, through the initiative, the US African Development Foundation (USADF), USAID and General Electric funded more than 30 entrepreneurs working on home and micro-grid energy projects in Africa. In March 2016, Sweden and Power Africa launched the USD 21 million (EUR 20 million) Beyond the Grid Fund for Zambia, which between 2016 and 2018 will support rural energy providers with market-based approaches to expanding energy access. The goal is to provide energy access to 1 million people.	https://www.usaid.gov/powerafrica/beyondthegrid

Table R12. Programmes Furthering Energy Access: Selected Examples (continued)

NAME	BRIEF DESCRIPTION	WEB ADDRESS
Readiness for Investment in Sustainable Energy (RISE)	A World Bank Group project providing indicators that compare the investment climate of countries across the three focus areas of the SEforALL initiative: energy access, energy efficiency and renewable energy.	http://rise.worldbank.org/
Renewable Energy and Energy Efficiency Partnership (REEEP)	An international multilateral partnership that works to accelerate market-based deployment of renewable energy and energy efficient systems in developing countries. REEEP manages several initiatives and programmes which further energy access, including the Power Africa: Beyond the Grid Fund for Zambia, the Kilimo Biashara Sustainable Energy Fund, and the Cambodian Clean Energy Revolving Fund, among others.	http://www.reeep.org/
Scaling Up Renewable Energy in Low Income Countries (SREP)	A Strategic Climate Fund (SCF) programme that was established to expand renewable energy markets and scale up renewable energy deployment in the world's poorest countries. To date, USD 264 million has been approved for 23 projects and programmes. An additional USD 1.9 billion in co-financing is expected from other sources.	http://www.climateinvestmentfunds.org/fund/scaling-renewable-energy-program
SNV Netherlands Development Organisation – Biogas Practice	A multi-actor sector development approach that supports the preparation and implementation of national biogas programmes throughout the world. In co-operation with its partners, by end-2015 SNV had installed over 700,000 bio-digesters in Asia, Africa and Latin America, impacting 3.5 million people.	http://www.snv.org/sector/energy/topic/biogas
Sustainable Energy for All Initiative (SEforALL)	A global initiative of former UN Secretary-General Ban Ki-moon with three objectives for 2030: achieving universal access to electricity and clean cooking solutions; doubling the share of the world's energy supplied by renewable sources; and doubling the rate of improvement in energy efficiency.	http://www.se4all.org
Sustainable Energy Fund for Africa (SEFA)	A fund administered by the African Development Bank and anchored by a Danish government commitment of USD 57 million to support small and medium-scale clean energy and energy efficiency projects in Africa through grants for technical assistance and capacity building, investment capital and guidance.	http://www.afdb.org/en/topics-and-sectors/initiatives-partnerships/sustainable-energy-fund-for-africa/

Table R13. Networks Furthering Energy Access: Selected Examples

NAME	BRIEF DESCRIPTION	WEB ADDRESS
African Bioenergy Development Platform	A platform launched by UNCTAD to help interested African countries develop their bioenergy potentials for advancing human and economic development through interactive, multi-stakeholder analytical exercises.	http://unctad.org/en/Pages/MeetingDetails.aspx?meetingid=347
African Center for Renewable Energy and Sustainable Technologies (ACREST)	A centre established in 2005 for information, demonstration, awareness, production and research on renewable energy and sustainable technologies in Africa. Its mission is to promote renewable energy technologies and sustainable technologies to improve people's living conditions and to fight poverty.	http://www.acrest.org
African Renewable Energy Alliance (AREA)	A global multi-stakeholder platform to exchange information and to consult about policies, technologies and financial mechanisms for the accelerated uptake of renewable energy in Africa.	http://www.area-net.org/
AKON Lighting Africa	An initiative launched in February 2014 that seeks to provide a concrete response at the grassroots level to Africa's energy crisis and to lay the foundations for future development. It aims to develop an innovative solar-powered solution that will provide African villages with access to a clean and affordable source of electricity.	http://akonlightingafrica.com/
Alliance for Rural Electrification (ARE)	An international business association that represents the decentralised energy sector and works towards the integration of renewables into rural electrification markets in developing and emerging countries. It has more than 90 members along the whole value chain of off-grid technologies.	http://www.ruralelec.org/
Alliance of CSOs for Clean Energy Access (ACCESS)	A coalition consisting of a range of civil society organisations (CSOs), both international and national. ACCESS aims to strengthen the visibility and presence of CSOs working to deliver universal energy access, particularly within SEforALL, Sustainable Development Goal 7 implementation and other global energy initiatives. ACCESS is co-ordinated by WWF, CAFOD, Practical Action, Greenpeace, IIED, ENERGIA, WRI, TERI and HIVOS.	https://access-coalition.org/
Climate Technology Centre and Network (CTCN)	The operational arm of the UNFCCC Technology Mechanism, hosted by UN Environment and UNIDO. CTCN promotes the accelerated transfer of environmentally sound technologies for low-carbon and climate-resilient development at the request of developing countries. It provides technology solutions, capacity building and advice on policy, legal and regulatory frameworks tailored to the needs of individual countries.	https://www.ctc-n.org/
Climate Technology Initiative Private Financing Advisory Network (CTI PFAN)	A multilateral, public-private partnership initiated by the Climate Technology Initiative (CTI) in co-operation with the UNFCCC Expert Group on Technology Transfer. PFAN operates to bridge the gap between investments and clean energy businesses. It is designed to be an "open source" network to fit seamlessly with existing global and regional initiatives and to be inclusive of all stakeholders with an interest in clean energy financing.	http://www.cti-pfan.net/
Consultative Group to Assist the Poor (CGAP)	A global partnership of 34 leading organisations, housed at the World Bank, that seeks to advance financial inclusion. It develops innovative solutions through practical research and active engagement with financial service providers, policy makers and funders to enable approaches at scale.	http://www.cgap.org/
ENERGIA International	An international network of more than 22 organisations working in Africa and Asia that are focused on gender issues, women's empowerment and sustainable energy.	http://www.energia.org/
Energy Access Practitioner Network	A global network of over 2,500 members representing small, medium-sized and large clean energy enterprises; civil society; government and academia and operating in over 170 countries. The Practitioner Network was established in 2011 to catalyse the delivery of modern energy services, particularly decentralised solutions for rural electrification.	http://www.energyaccess.org

Table R13. Networks Furthering Energy Access: Selected Examples (continued)

NAME	BRIEF DESCRIPTION	WEB ADDRESS
Energy & Environment Partnership (EEP)	A challenge fund that promotes renewable energy, energy efficiency and clean technology investments in Southern and East Africa. EEP supports projects that aim to provide sustainable energy services to the poor and to combat climate change. The EEP Programme is jointly funded by the Ministry of Foreign Affairs of Finland, the Austrian Development Agency and the UK Department for International Development.	http://eepafrica.org/
Energy for All Partnership (E4ALL)	A regional platform for co-operation, knowledge, technical exchange and key project development. It brings together key stakeholders from the private sector, financial institutions, governments, bilateral, multilateral and non-governmental development partners. The Partnership, led by the ADB, aims to provide access to safe, clean and affordable modern energy to 200 million households in the Oceania region by 2020.	https://www.adb.org/sectors/energy/programs/energy-for-all-initiative
Global Renewable Energy Islands Network (GREIN)	A network created to help islands accelerate their renewable energy uptake. It serves as a platform for pooling knowledge, sharing best practices and seeking innovative solutions for the accelerated update of clean and cost-effective renewable energy technologies in island states and territories.	https://sustainabledevelopment.un.org/partnership/?p=8011
HEDON Household Energy Network	A network aimed at empowering practitioners to unlock barriers to household energy access by addressing knowledge gaps, facilitating partnerships and fostering information sharing.	http://www.hedon.info/tiki-index.php
International Network for Sustainable Energy (INFORSE)	A network of 140 NGOs operating in 60 countries that was established as part of the Rio Convention. It is dedicated to promoting sustainable energy and social development and is funded by a mix of national governments, multilateral institutions and CSOs. INFORSE focuses on four areas: raising awareness about sustainable energy use; promoting institutional reform among national governments; building local and national capacity on energy-related issues; and supporting R&D.	http://www.inforse.org/
La Via Campesina (LVC)	Informally known as the "international peasants' movement", LVC is a group of about 150 organisational members that co-ordinate migrant workers, farmers, rural women and indigenous communities on rural development issues. The sustainable agriculture, water and women and human rights programmes deal with various aspects of rural energy use, especially the connections between food security and biofuels.	http://viacampesina.org/
RedBioLAC	A multinational network of institutions involved in research and dissemination of anaerobic bio-digestion and the treatment and management of organic waste in Latin America and the Caribbean.	http://www.wisions.net/pages/redbiolac
Small-Scale Sustainable Infrastructure Development Fund (S^{3}IDF)	A fund that promotes a Social Merchant Bank approach to help local entrepreneurs create micro-enterprises that provide infrastructure services to the poor. As of early 2015, it had a portfolio of almost 200 small investments and associated enterprises in India, and an additional 100 projects in the pipeline.	http://s3idf.org/
Wind Empowerment	A global association for the development of locally built small-scale wind turbines for sustainable rural electrification.	http://windempowerment.org/

Table R14. Global Trends in Renewable Energy Investment, 2006-2016

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
	Billion USD										
NEW INVESTMENT BY STAGE											
Technology Research											
Government R&D	2.2	2.7	2.8	5.4	4.9	4.8	4.7	5.2	4.5	4.4	5.5
Corporate R&D	2.9	3.2	3.6	3.8	3.9	4.5	4.2	4.0	3.9	4.2	2.5
Development / Commercialisation											
Venture capital	1.2	2.1	3.3	1.6	2.7	2.7	2.5	0.9	1.1	1.6	1.1
Manufacturing											
Private equity expansion capital	3.1	3.5	6.9	3.1	5.5	2.4	1.7	1.4	1.8	1.9	2.2
Public markets	9.3	21.4	10.8	12.7	10.8	9.9	4.0	10.3	15.9	13.3	6.3
Projects											
Asset finance	85.5	114.9	135.6	120.5	155.1	183.5	169.4	159.3	194.4	237.4	187.1
(re-invested equity)	0.8	2.6	3.6	1.9	1.5	1.8	2.6	1.0	3.3	6.1	2.9
Small-scale distributed capacity	9.4	14.0	22.1	33.0	62.2	75.2	71.6	54.4	60.0	55.5	39.8
Total New Investment	**112.7**	**159.3**	**181.4**	**178.3**	**243.6**	**281.2**	**255.5**	**234.4**	**278.2**	**312.2**	**241.6**
Merger & Acquisition Transactions	35.8	58.6	59.5	64.3	58.8	73.0	66.6	66.1	86.6	94.1	110.3
Total Transactions	**148.5**	**217.9**	**240.9**	**242.5**	**302.4**	**354.2**	**322.1**	**300.5**	**364.8**	**406.3**	**351.9**
NEW INVESTMENT BY TECHNOLOGY											
Solar power	21.9	38.9	61.3	64.0	103.6	154.9	140.6	119.1	143.9	171.7	113.7
Wind power	39.7	61.1	74.8	79.7	101.6	84.2	84.4	89.0	108.5	124.2	112.5
Bio-power[i]	12.8	23.0	17.5	15.0	16.6	19.9	14.9	12.4	10.8	6.7	6.8
Hydropower <50 MW	7.5	6.4	7.6	6.2	8.1	7.5	6.4	5.6	6.4	3.5	3.5
Biofuels	28.6	27.4	18.4	10.2	10.5	10.6	7.2	5.2	5.3	3.5	2.2
Geothermal power	1.4	1.7	1.7	2.8	2.9	3.9	1.6	2.9	2.9	2.3	2.7
Ocean energy	0.8	0.8	0.2	0.3	0.2	0.2	0.3	0.2	0.3	0.2	0.2
Total New Investment	**112.7**	**159.3**	**181.4**	**178.3**	**243.6**	**281.2**	**255.5**	**234.4**	**278.2**	**312.2**	**241.6**

[i] Includes solid biomass and waste-to-power technologies, but not waste-to-gas.

Table R15. Share of Primary and Final Energy from Renewable Sources, Targets and 2014/2015 Shares

Note: Text in **bold** indicates new/revised in 2016, brackets '[]' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

COUNTRY	PRIMARY ENERGY		FINAL ENERGY	
	Share	Target	Share	Target
EU-28			16%	→ 20% by 2020 → 27% by 2030
Albania		→ 18% by 2020	35%	→ 38% by 2020
Algeria				→ 37% by 2030 [40% by 2030]
Armenia	16%	→ 21% by 2020 → 26% by 2025		
Austria[1]			33%	→ 45% by 2020
Azerbaijan	0.5%			
Bangladesh				→ 10% by 2020
Barbados	3%			
Belarus			5.7%	→ 28% by 2015 → 32% by 2020
Belgium		→ 9.7% by 2020	8%	→ 13% by 2020
Wallonia				→ *20% by 2020*
Bosnia and Herzegovina		→ 20% by 2016		→ 40% by 2020
Botswana				→ 1% by 2016
Brazil			39.4%	→ 45% by 2030
Bulgaria			16%	→ 16% by 2020
Burundi				→ 2.1% by 2020
China[2]	**10%**	**→ 15% by 2020** **→ 20% by 2030**		
Côte d'Ivoire		→ 5% by 2015 → 15% by 2020 → 20% by 2030		
Croatia			29%	→ 20% by 2020
Cyprus			9.4%	→ 13% by 2020
Czech Republic[1]			13%	→ 13.5% by 2020
Denmark			30%	→ 35% by 2020 → 100% by 2050
Djibouti		→ 17% by 2035		
Egypt		→ 14% by 2020		
Estonia			25%	→ 25% by 2020
Fiji				→ 23% by 2030
Finland			39.3%	→ 25% by 2015 → 38% by 2020 → 40% by 2025
France			15%	→ 23% by 2020 → 32% by 2030
Gabon				→ 80% by 2020
Germany[1]			14%	→ 18% by 2020 → 30% by 2030 → 45% by 2040 → 60% by 2050
Ghana				→ Increase 10% by 2030 (base year 2010)
Greece[1]			15%	→ 20% by 2020
Grenada		→ 20% by 2020		

Table R15. Share of Primary and Final Energy from Renewable Sources, Targets and 2014/2015 Shares (continued)

Note: Text in **bold** indicates new/revised in 2016, brackets '[]' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

COUNTRY	PRIMARY ENERGY		FINAL ENERGY	
	Share	Target	Share	Target
Guatemala	31%			→ 80% by 2026
Guinea				→ 30% by 2030
Guyana	15%			→ 20% by 2025
Hungary[1]			15%	→ 14.65% by 2020
Iceland			70%	→ 64% by 2020
Indonesia		→ 25% by 2025		
Ireland			9.2%	→ 16% by 2020
Israel				→ 13% by 2025 → 17% by 2030
Italy			18%	→ 17% by 2020
Jamaica	8%		7.8%	→ 20% by 2030
Japan	5.8%	→ 14% by 2030		
Jordan				→ 11% by 2025
Korea, Republic of		→ 4.3% by 2015 → 6.1% by 2020 → 11% by 2030		
Kosovo[3]				→ 25% by 2020
Lao PDR				→ 30% by 2025
Latvia			38%	→ 40% by 2020
Lebanon				→ 15% by 2030
Liberia				→ 10% by 2030
Libya		→ 10% by 2020		
Lithuania		→ 20% by 2025	26%	→ 23% by 2020
Luxembourg			5%	→ 11% by 2020
Macedonia, FYR of			20%	→ 28% by 2020
Madagascar				→ 54% by 2020
Malawi	5.5%	→ 7% by 2020		
Mali		→ 15% by 2020		
Malta			5%	→ 10% by 2020
Mauritania		→ 15% by 2015 → 20% by 2020		
Moldova		→ 20% by 2020		→ 17% by 2020
Mongolia		→ 20-25% by 2020		
Montenegro			43%	→ 33% by 2020
Nauru				→ 50% by 2015
Nepal		→ 10% by 2030		
Netherlands[1]			6%	→ 16% by 2020
Niger		→ 10% by 2020		
Norway			69%	→ 67.5% by 2020
Palau		→ 20% by 2020		
Palestine, State of				→ 25% by 2020
Panama	18%	→ 18.3% by 2023		

Table R15. Share of Primary and Final Energy from Renewable Sources, Targets and 2014/2015 Shares (continued)

Note: Text in **bold** indicates new/revised in 2016, brackets '[]' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

COUNTRY	PRIMARY ENERGY		FINAL ENERGY	
	Share	Target	Share	Target
Poland		→ 12% by 2020	12%	→ 15.5% by 2020
Portugal			28%	→ 31% by 2020 → 40% by 2030
Romania			25%	→ 24% by 2020
Samoa		→ 20% by 2030		
Serbia				→ 27% by 2020
Slovak Republic			13%	→ 14% by 2020
Slovenia			22%	→ 25% by 2020
Spain[1]	14%		16%	→ 20.8% by 2020
St. Lucia	0.2%	→ 20% by 2020		
Sweden[1]			54%	→ 50% by 2020
Switzerland		→ 24% by 2020		
Syria		→ 4.3% by 2030		
Thailand				→ 25% by 2021 → 30% by 2036
Togo				→ 4% (no date)
Ukraine	2.7%	→ 18% by 2030		→ 11% by 2020
United Arab Emirates			<1%	→ 24% by 2021
United Kingdom			8.2%	→ 15% by 2020
Uzbekistan				→ 16% by 2030 → 19% by 2050
Vanuatu				→ 65% by 2020
Vietnam		→ 5% by 2020 → 8% by 2025 → 11% by 2050		

[1] Final energy targets by 2020 for all EU-28 countries are set under EU Directive 2009/28/EC. The governments of Austria, the Czech Republic, Germany, Greece, Hungary, Spain and Sweden have set higher targets, which are shown here. The government of the Netherlands has reduced its more ambitious target to the level set in the EU Directive.

[2] The Chinese target is for share of "non-fossil" energy. All targets include nuclear power.

[3] Kosovo is not a member of the United Nations.

Note: Actual percentages are rounded to the nearest whole decimal for numbers over 10% except where associated targets are expressed differently. Historical targets have been added as they are identified by REN21. Only bolded targets are new/revised in 2016. A number of nations have already exceeded their renewable energy targets. In many of these cases, targets serve as a floor setting the minimum share of renewable energy for the country. Some countries shown have other types of targets *(**→ see Tables R10, R16, R17, R18 and R19**)*.

Source: See endnote 15 for this section.

Table R16. Renewable Energy Targets for Technology-Specific Share of Primary and Final Energy

COUNTRY	TECHNOLOGY	TARGET
Guinea-Bissau	Solar PV	2% of primary energy by 2015
Indonesia	Hydropower, solar PV, wind power	1.4% share in primary energy (combined) by 2025
	Biofuels	10.2% biofuel share of primary energy by 2025
Samoa	Final energy	Increase the renewable share of final energy supply 20% by 2030 (base year 2007)
Spain	Bioenergy from solid biomass, biogas and organic MSW[1]	0.1% of final energy by 2020
	Geothermal energy, ocean power and heat pumps[2]	5.8% of final energy by 2020
	Hydropower	2.9% of final energy by 2020
	Solar PV	3% of final energy by 2020
	Wind power	6.3% of final energy by 2020

[1] It is not always possible to determine whether data for municipal solid waste (MSW) include non-organic waste (plastics, metal, etc.) or only the organic biomass share.

[2] The energy output of heat pumps is at least partially renewable on a final energy basis, which is why they are included in this table. For more information, see Sidebar 4, GSR 2014.

Note: Some countries shown have other types of targets ***(→ see Tables R10, R15, R17, R18 and R19)***.

Source: See endnote 16 for this section.

Table R17. Share of Electricity Generation from Renewable Sources, Targets and 2015 Shares

Note: Text in **bold** indicates new/revised in 2016, brackets '[]' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

Country	Share	Target
EU-28	28.8%	
Afghanistan[1]		→ **100% by 2050**
Algeria		→ 27% by 2030
Antigua and Barbuda		→ 10% by 2020 → 15% by 2030
Argentina		→ 8% by 2018 → 20% by 2025
Armenia	34%	→ 40% by 2025
Aruba		→ **100% by 2020**
Australia	10%	→ 23% by 2020
South Australia		→ *50% by 2020*
Tasmania		→ *100% by 2020*
Victoria		→ *20% by 2020* → ***40% by 2025***
Austria	70.3%	→ 70.6% by 2020
Azerbaijan	16%	→ 20% by 2020
Bahamas, The		→ 15% by 2020 → 30% by 2030
Bahrain		→ 5% by 2030
Bangladesh[1]		→ 10% by 2020 → **100% by 2050**
Barbados[1]		→ 29% by 2029 → 65% by 2030 → **100% by 2050**
Belgium	15.4%	→ 20.9% by 2020
Belize		→ 85% by 2017
Bhutan[1]		→ **100% by 2050**
Bolivia		→ 79% by 2030
Brazil[2]		→ 23% by 2030
Brunei Darussalam		→ 10% by 2035
Bulgaria	19.1%	→ 20.6% by 2020
Burkina Faso[1]		→ **100% by 2050**
Cabo Verde		→ **100% by 2020** → [100% by 2035] → [50% by 2020]
Cambodia[1]		→ 25% by 2035 → **100% by 2050**
Canada[3]	7.3%	No national target
Alberta		→ ***30% by 2030***
British Columbia		→ *93% (no date given)*
New Brunswick		→ *40% by 2020*
Nova Scotia		→ *40% by 2020*
Saskatchewan		→ *50% by 2030*
Chile	8.5%	→ 20% by 2025
China		No national target
Taipei	***4%***	→ ***20% by 2025***
Colombia[1]		→ **100% by 2050**
Comoros[1]		→ 43% by 2030 → **100% by 2050**
Congo, Republic of		→ 85% by 2025
Costa Rica		→ 100% by 2030
Côte d'Ivoire		→ 42% by 2020
Croatia	45%	→ 39% by 2020
Cuba		→ 24% by 2030
Cyprus	8.4%	→ 16% by 2020
Czech Republic	14%	→ 14.3% by 2020
Democratic Republic of the Congo[1]		→ **100% by 2050**
Denmark[4]	51%	→ 50% by 2020 → 100% by 2050
Djibouti		→ 35% by 2035
Dominica		→ 100% (no date)
Dominican Republic[1]		→ 25% by 2025 → **100% by 2050**
Ecuador		→ **90% by 2017** [85% by 2017]
Egypt		→ **20% by 2022** [20% by 2020]
Eritrea		→ 70% by 2030
Estonia	15.1%	→ 17.6% by 2020
Ethiopia[1]		→ **100% by 2050**
Fiji		→ 100% by 2030
Finland	33%	→ 33% by 2020
France	19%	→ 27% by 2020 → 40% by 2030
Gabon		→ 70% by 2020 → 80% by 2025
Gambia[1]		→ 35% by 2020 → **100% by 2050**
Germany	31%	→ 40–45% by 2025 → 55–60% by 2035 → 80% by 2050
Ghana[1]		→ 10% by 2020 → **100% by 2050**
Greece	22%	→ 40% by 2020
Grenada[1]		→ **100% by 2050**
Guatemala[1]		→ 80% by 2030 → **100% by 2050**
Guyana		→ 90% (no date)
Haiti[1]		→ 47% by 2030 → **100% by 2050**
Honduras[1]		→ 60% by 2022 → 80% by 2038 → **100% by 2050**

Table R17. Share of Electricity Generation from Renewable Sources, Targets and 2015 Shares (continued)

Note: Text in **bold** indicates new/revised in 2016, brackets '[]' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

Country	Share	Target
Hungary	7.3%	→ 10.9% by 2020
India[5]		→ 40% by 2030
Andaman and Nicobar		→ *3% (0.4% solar)*
Andhra Pradesh		→ *7% (0.2% solar)*
Arunchal Pradesh		→ *7% (0.2% solar)*
Assam		→ *7% (0.25% solar)*
Bihar		→ *5% (0.75% solar)* → *3% solar by 2022*
Chandigarh		→ *3% (0.4% solar)*
Chattisgarh		→ *6.75% (0.75% solar)* → *7.25% by 2016*
Dadra and Nagar Haveli		→ *3% (0.4% solar)*
Daman and Diu		→ *3% (0.4% solar)*
Delhi		→ *6.2% (0.25% solar)* → *9% by 2017*
Goa		→ *3.3% (0.6% solar)* → *6% by 2022*
Gujarat		→ *9% (1.5% solar)* → *10% by 2017*
Haryana		→ *3.25% (0.25% solar)* → *5.5% by 2022*
Himachal Pradesh		→ *10.25% (0.25% solar)* → *19% by 2022*
Jammu and Kashmir		→ *6% (0.75% solar)* → *9% by 2017*
Jharkhand		→ *4% (1% solar)* → *4% by 2016*
Karnataka		→ *10.25% (0.25% solar)*
Kerala		→ *4.5% (0.25% solar)* → *6.6% by 2022*
Lakshadweep		→ *3% (0.4% solar)*
Madhya Pradesh		→ *7% (1% solar)*
Maharashtra		→ *9% (0.5% solar)*
Manipur		→ *5% (0.25% solar)*
Meghalaya		→ *1% (0.4% solar)*
Mizoram		→ *7% (0.25% solar)*
Nagaland		→ *8% (0.25% solar)*
Orissa		→ *6.5% (0.25% solar)*
Pondicherry		→ *3% (0.4% solar)*
Punjab		→ *4% (0.19% solar)*
Rajasthan		→ *9% (1.5% solar)*
Tamil Nadu		→ *11% (2% solar)*
Tripura		→ *2.5% (1.05% solar)*
Uttar Pradesh		→ *6% (1% solar)*
Uttarakhand		→ *7.075% (0.075% solar)*
West Bengal		→ *4.5% (0.15% solar)*
Indonesia		→ 26% by 2025
Iraq		→ 10% by 2030

Country	Share	Target
Ireland	25.2%	→ 42.5% by 2020
Israel	3%	→ 10% by 2020 → 17% by 2030
Italy	34%	→ 26% by 2020
Jamaica		→ 20% by 2030
Japan	7.9%	→ 22-24% by 2030
Kazakhstan		→ 3% by 2020 → 50% by 2030
Kenya[1]		→ **100% by 2050**
Kiribati[1]		→ 3% by 2020 → **100% by 2050**
Korea, Republic of	**3.7%**	→ **5% by 2018 (4.5% by 2018)** → **6% by 2019 (5% by 2019)** → **7% by 2020 (6% by 2020)**
Kuwait		→ 10% (no date)
Latvia	52%	→ 60% by 2020
Lebanon[1]		→ 12% by 2020 → **100% by 2050**
Liberia		→ 30% by 2021
Libya		→ 7% by 2020 → 10% by 2025
Lithuania	16%	→ 21% by 2020
Luxembourg	6.2%	→ 11.8% by 2020
Macedonia, FYR of	22%	→ 24.7% by 2020
Madagascar[1]		→ 79% (no date) → **100% by 2050**
Malawi[1]		→ **100% by 2050**
Malaysia		→ 9% by 2020 → 11% by 2030 → 15% by 2050
Maldives[1]		→ 16% by 2017 → **100% by 2050**
Mali[6]		→ 25% by 2033
Malta	4.2%	→ 3.8% by 2020
Marshall Islands[1]		→ 20% by 2020 → **100% by 2050**
Mauritius		→ 35% by 2025
Mexico	8.9%	→ 35% by 2024 → 50% by 2050
Moldova		→ 10% by 2020
Montenegro		→ 51.4% by 2020
Mongolia[1]		→ 20% by 2020 → 30% by 2030 → **100% by 2050**

Table R17. Share of Electricity Generation from Renewable Sources, Targets and 2015 Shares (continued)

Note: Text in **bold** indicates new/revised in 2016, brackets '[]' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

Country	Share	Target
Morocco[1]		→ **52% by 2030** **[52% by 2039]** → **100% by 2050**
Myanmar		→ 15–18% by 2020
Namibia		→ 70% by 2030
Nepal[1]		→ **100% by 2050**
Netherlands	11%	→ 37% by 2020
New Zealand	29%	→ 90% by 2025
Cook Islands		→ *100% by 2020*
Niue		→ *100% by 2020*
Tokelau		→ *100% (no date)*
Nicaragua		→ 90% by 2027
Niger[1]		→ **100% by 2050**
Nigeria[7]		→ 10% by 2020
Palau[1]		→ **100% by 2050**
Palestine, State of [1]		→ 10% by 2020 → 100% by 2050
Papua New Guinea		→ 100% by 2030
Paraguay		→ 60% increase from 2014 to 2030
Peru		→ 60% by 2025
Philippines[1]		→ 40% by 2020 → **100% by 2050**
Poland	13.4%	→ 19.3% by 2020
Portugal	53%	→ 60% by 2020
Qatar		→ 2% by 2020 → 20% by 2030
Romania	43%	→ 43% by 2020
Russian Federation[8]		→ 4.5% by 2020
Rwanda[1]		→ **100% by 2050**
Samoa		→ 100% by 2030
São Tomé and Príncipe		→ 47% (no date)
Senegal[1]		→ 20% by 2017 → **100% by 2050**
Serbia		→ 37% by 2020
Seychelles		→ 5% by 2020 → 15% by 2030
Sierra Leone		→ 33% by 2020 → 36% by 2030
Singapore		→ 8% (no date)
Slovak Republic	23%	→ 24% by 2020
Slovenia	33%	→ 39.3% by 2020
Solomon Islands		→ 100% by 2030
South Africa		→ 9% by 2030
South Sudan[1]		→ **100% by 2050**
Spain	36.9%	→ 38.1% by 2020

Country	Share	Target
Sri Lanka[1]		→ 10% by 2016 → 20% by 2020 → 100% by 2050
St. Lucia[1]		→ 35% by 2020 → **100% by 2050**
St. Vincent and the Grenadines		→ 60% by 2020
Sudan[1]		→ 20% by 2030 → **100% by 2050**
Sweden	65.8%	→ 62.9% by 2020
Tajikistan		→ 10% (no date)
Tanzania[1]		→ **100% by 2050**
Thailand[9]		→ 20% by 2036
Timor-Leste[1]		→ 50% by 2020 → **100% by 2050**
Togo		→ 15% by 2020
Tonga		→ 50% by 2020
Tunisia[1]		→ 11% by 2016 → 30% by 2030 → **100% by 2050**
Turkey	33%	→ 30% by 2023
Tuvalu		→ 100% by 2020
Uganda		→ 61% by 2017
Ukraine		→ 11% by 2020 → 20% by 2030
United Arab Emirates		No national target
Abu Dhabi		→ *7% by 2020*
Dubai		→ *7% by 2020* → *15% by 2030*
United Kingdom	22%	No national target
Scotland		→ *100% by 2020*
United States[10]	8.4%	No national target
Arizona		→ *15% by 2025*
California		→ *33% by 2020* → *50% by 2030*
Colorado		→ *30% by 2020[11]*
Connecticut		→ *27% by 2020*
Delaware		→ *25% by 2026*
Hawaii		→ *25% by 2020* → *40% by 2030* → *100% by 2045*
Illinois		→ ***25% by 2026*** ***[25% by 2015-2016]***
Maine		→ *40% by 2017*
Maryland		→ ***25% by 2020*** ***[20% by 2020]***
Massachusetts		→ *15% by 2020 and an additional 1% each year thereafter*

Table R17. Share of Electricity Generation from Renewable Sources, Targets and 2015 Shares (continued)

Note: Text in **bold** indicates new/revised in 2016, brackets '[]' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

Country	Share	Target
Michigan		***→ 15% by 2021*** ***→ [10% by 2015]***
Minnesota		***→ 31.5% by 2020 (Xcel) [25% by 2025 (other utilities)]*** *→ 26.5% by 2025 (IOUs)[11]*
Missouri		*→ 15% by 2021[11]*
Nevada		*→ 25% by 2025*
New Hampshire		*→ 24.8% by 2025*
New Jersey		*→ 20.38% by 2020 and 4.1% solar by 2027*
New Mexico		*→ 20% by 2020 (IOUs)[11]* *→ 10% by 2020 (co-ops)[12]*
New York		*→ 50% by 2030*
North Carolina		*→ 10% by 2018 (co-ops)[12]* *→ 12.5% by 2021[11]*
Ohio		***→ 12.5% by 2026 [25% by 2024]***
Oregon		***→ 50% by 2040 [25% by 2025 (utilities with 3% or more of state's load); 10% by 2025 (utilities with 1.5-3% of state's load); 5% by 2025 (utilities with less than 1.5% of state's load)]***
Pennsylvania		*→ 18% by 2021*
Rhode Island		***→ 38.5% by 2035 [16% by 2019]***
Vermont		*→ 55% by 2017, increasing by 4% every 3 years until reaching 75% by 2032*
Washington		*→ 15% by 2020*
District of Columbia		***→ 50% by 2032*** *[20% by 2020]*
Northern Mariana Islands		*→ 20% by 2016 [80% by 2015]*
Puerto Rico		*→ 20% by 2035*
US Virgin Islands		***→ 30% by 2025 [30% by 2030]***
Uruguay		→ 95% by 2017
Vanuatu		→ 100% by 2030
Vietnam[1]		***→ 7% by 2020*** ***→ 10% by 2030*** [5% by 2020] ***→ 100% by 2050***
Yemen[1]		→ 15% by 2025 ***→ 100% by 2050***

[1] 100% by 2050 target established by the Climate Vulnerable Forum.

[2] Brazil's target excludes all hydropower.

[3] Canada's share excludes all hydropower.

[4] In March 2012, Denmark set a target of 50% electricity consumption supplied by wind power by 2020.

[5] India does not classify hydropower installations larger than 25 MW as renewable energy sources, so hydro >25 MW is excluded from national shares and targets. De facto sub-national targets have been set through existing RPS policies.

[6] Mali's target excludes large-scale hydropower.

[7] Nigeria's target excludes hydropower plants >30 MW.

[8] The Russian Federation's targets exclude hydropower plants >25 MW.

[9] Thailand does not classify hydropower installations larger than 6 MW as renewable energy sources, so hydro >6 MW is excluded from national shares and targets.

[10] The United States does not have a renewable electricity target at the national level. De facto state-level targets have been set through existing RPS policies.

[11] RPS mandate for Investor-owned utilities (IOUs), which are utilities operating under private control rather than government or co-operative operation.

[12] RPS mandate for co-operative utilities.

Note: Unless otherwise noted, all targets and corresponding shares represent all renewables including hydropower. A number of state/provincial and local jurisdictions have additional targets not listed here. Historical targets have been added as they are identified by REN21. Only bolded targets are new/revised in 2016. A number of nations have already exceeded their renewable energy targets. In many of these cases, targets serve as a floor setting the minimum share of renewable electricity for the country. Some countries shown have other types of targets *(→ see Tables R10 and R12–R22)*. See Policy Landscape chapter for more information about sub-national targets. Existing shares are indicative and may need adjusting if more accurate national statistics are published. Sources for reported data often do not specify the accounting method used; therefore, shares of electricity are likely to include a mixture of different accounting methods and thus are not directly comparable or consistent across countries. Where shares sourced from EUROSTAT differed from those provided to REN21 by country contributors, the former was given preference.

Source: See endnote 17 for this section.

Table R18. Renewable Energy Targets for Technology-Specific Share of Electricity Generation

Note: Text in **bold** indicates new/revised in 2016 and brackets '[]' indicate previous targets where new targets were enacted.

COUNTRY	TECHNOLOGY	TARGET
Benin	Generation (off-grid and rural)	50% by 2025
Colombia	Generation (grid-connected)[1]	3.5% by 2015; 6.5% by 2020
	Generation (off-grid)	20% by 2015; 30% by 2020
Denmark	Wind power	50% by 2020
Djibouti	Solar PV (off-grid and rural)	30% by 2017
Dominican Republic	Distributed power (rooftop solar)	20% by 2016
Egypt	Wind power	12% and 7.2 GW by 2020
Eritrea	Wind power	50% (no date)
Guinea	Solar power	6% of generation by 2025
	Wind power	2% of generation by 2025
Haiti	Bio-power	5.6% by 2030
	Hydropower	24.5% by 2030
	Solar power	7.55% by 2030
	Wind power	9.4% by 2030
Japan	Bio-power	3.7-4.6% by 2030
	Geothermal power	1-1.1% by 2030
	Hydropower	8.8-9.2% by 2030
	Solar PV	7% by 2030
	Wind power	1.7% by 2030
Latvia	Bio-power from solid biomass	8% by 2016
Lesotho	Generation (not specified)	35% of off-grid and rural electrification by 2020
Micronesia, Federated States of	Generation (not specified)	10% in urban centres and 50% in rural areas by 2020
Myanmar	Generation (not specified)	30% of rural electrification by 2030
Trinidad and Tobago	Generation (not specified)	5% of peak demand (or 60 MW) by 2020

[1] Colombia's target is to be met by "non-conventional sources of energy", which includes nuclear energy and renewables, small- and large-scale self-supply and distributed power generation, and non-diesel power generation in non-interconnected zones.

Note: Unless otherwise noted, all targets and corresponding shares represent all renewables including hydropower. A number of state/provincial and local jurisdictions have additional targets not listed here. Some countries shown have other types of targets ***(→ see Tables R12-R22)***. See Policy Landscape chapter and Table R23 for more information about sub-national and municipal-level targets, and see Table R10 for electricity access-specific targets. Existing shares are indicative and may need adjusting if more accurate national statistical data are published.

Source: See endnote 18 for this section.

Table R19. Targets for Renewable Power Installed Capacity and/or Generation

Note: Text in **bold** indicates new/revised in 2016, brackets '[]' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

COUNTRY	TECHNOLOGY	TARGET
Algeria	Capacity (not specified)	22 GW by 2030
	Bio-power from waste-to-energy	1 GW by 2030
	Geothermal power	15 MW by 2030
	Solar PV	13.5 GW by 2030
	CSP	2 GW by 2030
	Wind power	5 GW by 2030
Antigua and Barbuda	Capacity (not specified)	5 MW by 2030
Argentina	Capacity (not specified)	3 GW by 2016
	Geothermal power	30 MW by 2016
Armenia	Hydropower (small-scale)	377 MW by 2020; 397 MW by 2025
	Geothermal power	50 MW by 2020; 100 MW by 2025
	Solar PV	40 MW by 2020; 80 MW by 2025
	Wind power	50 MW by 2020; 100 MW by 2025
Austria	Bio-power from solid biomass and biogas	200 MW added 2010-2020
	Hydropower	1 GW added 2010-2020
	Solar PV	1.2 GW added 2010-2020
	Wind power	2 GW added 2010-2020
Azerbaijan	Capacity (not specified)	1 GW by 2020
Bangladesh	Bio-power from solid biomass	100,000 plants of 2.6 m^3 capacity capable of producing 40 MW of electricity
	Bio-power from biogas	7 MW by 2017
	Biogas digesters	150,000 plants by 2016
	Solar PV (off-grid and rural)	6 million solar home systems by 2016 (240 MW total); 50 mini-grids of 150 kW each; 1,550 solar irrigation pumps by 2017
	Wind power	400 MW by 2030
Belgium		No national target
Flanders	*Solar PV*	*Increase production 30% by 2020*
Wallonia	*Generation (not specified)*	*8 TWh per year by 2020*
Bhutan	Capacity (not specified)	20 MW by 2025
	Bio-power from solid biomass	5 MW by 2025
	Solar PV	5 MW by 2025
	Wind power	5 MW by 2025
Bolivia	Capacity (not specified)	160 MW added 2015–2025
Bosnia and Herzegovina	Hydropower	120 MW by 2030
	Solar PV	4 MW by 2030
	Wind power	175 MW by 2030
Brazil	**Bio-power**	**18 GW by 2024**
	Hydropower (small-scale)	**8 GW by 2024**
	Hydropower (large-scale)	**117 GW by 2024**
	Wind power	**24 GW by 2024**
	Solar	**7 GW by 2024**
Bulgaria	Hydropower	Three 174 MW plants commissioned by 2017–2018
Burundi	Bio-power from solid biomass	4 MW (no date)
	Hydropower	212 MW (no date)
	Solar PV	40 MW (no date)
	Wind power	10 MW (no date)

Table R19. Targets for Renewable Power Installed Capacity and/or Generation (continued)

Note: Text in **bold** indicates new/revised in 2016, brackets '[]' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

COUNTRY	TECHNOLOGY	TARGET
Canada		No national target
Ontario	*Capacity (not specified)*	*20 GW by 2025 supplied by a mix of renewable technologies, including:*
	Hydropower	*9.3 GW by 2025*
	Solar PV	*40 MW by 2025*
	Wind power	*5 GW by 2025*
Prince Edward Island	*Wind power*	*30 MW increase by 2030 (base year 2011)*
China	**Capacity (not specified)**	**680 GW non-fossil fuel generation capacity by 2020**
	Hydropower	**340 GW by 2020**
	Solar power	**110 GW by 2020** [150 GW by 2020] **of which 5 GW is CSP**
	Wind power	**210 GW by 2020** [250 GW by 2020] **of which 5 GW is offshore**
Taipei	*Capacity (not specified)*	*8,303 MW by 2020; 12,513 MW by 2025; 17,250 MW by 2030*
	Bio-power	*768 MW by 2020; 813 MW by 2025; 950 MW by 2030*
	Geothermal power	*10 MW by 2020; 150 MW by 2025; 200 MW by 2030*
	Solar PV	*1,115 MW by 2015; 3,615 MW by 2020; 6.2 GW by 2025; 8.7 GW by 2030*
	Wind power (onshore)	*1.2 GW by 2020; 1.2 GW by 2025; 1.2 GW by 2025*
	Wind power (offshore)	*520 MW by 2020; 2 GW by 2025; 4 GW by 2030*
Cuba	**Capacity (not specified)**	**2.1 GW of biomass, wind, solar and hydropower capacity by 2030**
Egypt	Hydropower	2.8 GW by 2020
	Solar PV	**300 MW small-scale (<500 kW) solar PV systems installed 2015-2017;** **2 GW medium and large-size solar PV (max. 50 MW) installed 2015-2017** [220 MW by 2020; 700 MW by 2027]
	CSP	1.1 GW by 2020; 2.8 GW by 2030
	Wind power	**2 GW installed 2015-2017,** 7.2 GW by 2020
Ethiopia	Bio-power from bagasse	103.5 MW (no date)
	Geothermal power	450 MW by 2018; 1 GW by 2030
	Hydropower	22 GW by 2030
	Wind power	**7 GW by 2030** [770 MW by 2014]
Finland	Bio-power	13.2 GW by 2020
	Hydropower	14.6 GW by 2020
	Wind power	884 MW by 2020
France	**Hydropower**	**25.8-26.05 GW by 2030**
	Ocean power	380 MW by 2020
	Solar	**10.2 GW by 2018**; **18.2-20.2 GW by 2023**; [8 GW by 2020]
	Wind power	**21.8-26 GW by 2023**
	Wind power (onshore)	19 GW by 2020
	Wind power (offshore)	6 GW by 2020
Germany	Bio-power	100 MW added per year
	Solar PV	2.5 GW added per year
	Wind power (onshore)	2.5 GW added per year
	Wind power (offshore)	6.5 GW added by 2020

Table R19. Targets for Renewable Power Installed Capacity and/or Generation (continued)

Note: Text in **bold** indicates new/revised in 2016, brackets '[]' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

COUNTRY	TECHNOLOGY	TARGET
Greece	Solar PV	2.2 GW by 2030
Grenada	Geothermal power	15 MW (no date)
	Solar power	10 MW (no date)
	Wind power	2 MW (no date)
India	Capacity (not specified)	175 GW by 2022
	Bio-power	10 GW by 2022
	Hydropower (small-scale)[1]	5 GW by 2022
	Solar PV	20 million solar lighting systems added 2010-2022
	Solar PV and CSP	100 GW by 2022
	Wind power	60 GW by 2022
Andhra Pradesh	*Solar PV*	*5,000 MW added between 2015 and 2020*
Jharkhand	*Solar PV*	*2,650 MW installed by 2019-2020*
Indonesia	Geothermal power	12.6 GW by 2025
	Hydropower	2 GW by 2025, including 0.43 GW micro-hydropower
	Pumped storage[2]	3 GW by 2025
	Solar power	**5 GW by 2020** [156.8 MW of solar PV by 2025]
	Wind power	100 MW by 2025
Iran	Solar power and wind power	5 GW by 2020
Iraq	Solar PV	240 MW by 2016
	CSP	80 MW by 2016
	Wind power	80 MW by 2016
Italy	Bio-power	19,780 GWh per year generation from 2.8 GW capacity by 2020
	Geothermal power	6,759 GWh per year of generation from 920 MW capacity by 2020
	Hydropower	42,000 GWh per year generation from 17.8 GW capacity by 2020
	Solar PV	23 GW by 2017
	Wind power (onshore)	18,000 GWh per year generation and 12 GW capacity by 2020
	Wind power (offshore)	2,000 GWh per year generation and 680 MW capacity by 2020
Japan	Ocean power (wave and tidal)	1.5 GW by 2030
Jordan	**Capacity (not specified)**	**1.8 GW by 2020**
	Solar power	**1 GW by 2020** [600 MW by 2020]
	Wind power	1.2 GW by 2020
Kazakhstan	Bio-power	15.05 MW at 3 bioelectric stations by 2020
	Hydropower	539 MW at 41 hydroelectric power stations by 2020
	Solar power	713.5 MW at 28 solar electric plants by 2020
	Wind power	1,787 MW at 34 wind power stations by 2020
Kenya	Geothermal power	1.9 GW by 2016; 5 GW by 2030
	Hydropower	794 MW by 2016
	Solar PV	423 MW by 2016
	Wind power	635 MW by 2016
Korea, Republic of	Generation (not specified)	13,016 GWh per year (2.9% of total generation) by 2015; 21,977 GWh per year (4.7%) by 2020; 39,517 GWh per year (7.7%) by 2030 supplied by a mix of renewable technologies, including:
	Bio-power from solid biomass	2,628 GWh per year by 2030
	Bio-power from biogas	161 GWh per year by 2030
	Bio-power from landfill gas	1,340 GWh per year by 2030

Table R19. Targets for Renewable Power Installed Capacity and/or Generation (continued)

Note: Text in **bold** indicates new/revised in 2016, brackets '[]' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

COUNTRY	TECHNOLOGY	TARGET
Korea, Republic of (continued)	Geothermal power	2,046 GWh per year by 2030
	Hydropower (large-scale)	3,860 GWh per year by 2030
	Hydropower (small-scale)	1,926 GWh per year by 2030
	Ocean power	6,159 GWh per year by 2030
	Solar PV	2,046 GWh per year by 2030
	CSP	1,971 GWh per year by 2030
	Wind power	900 MW by 2016; 1.5 GW by 2019; 16,619 GWh per year by 2030
	Wind power (offshore)	2.5 GW by 2019
Kuwait	Solar PV	3.5 GW by 2030
	CSP	1.1 GW by 2030
	Wind power	3.1 GW by 2030
Lebanon	Wind power	400-500 MW by 2020
Lesotho	Capacity (not specified)	260 MW by 2030
Libya	Solar PV	344 MW by 2020; 844 MW by 2025
	CSP	125 MW by 2020; 375 MW by 2025
	Wind power	600 MW by 2020; 1 GW by 2025
Macedonia, FYR of	Bio-power from solid biomass	50 GWh by 2020
	Bio-power from biogas	20 GWh by 2020
	Hydropower (small-scale)	216 GWh by 2020
	Solar PV	14 GWh by 2020
	Wind power	300 GWh by 2020
Malaysia	Generation (not specified)	2.1 GW (excluding large-scale hydropower), 11.2 TWh per year, or 10% of national supply (no date given); 11% by 2020; 14% by 2030; 36% by 2050
	Solar power	1 GW of capacity added by 2020
Mexico	Capacity	20 GW by 2030, of which:
	Wind power	10 GW by 2030
Morocco	Hydropower	2 GW by 2020
	Solar PV and CSP	2 GW by 2020
	Wind power	2 GW by 2020
Mozambique	Bio-digesters for biogas	1,000 systems installed (no date)
	Hydropower, solar PV, wind power	2 GW each (no date)
	Solar PV	82,000 solar home systems installed (no date)
	Wind turbines for water pumping	3,000 stations installed (no date)
	"Renewable energy-based productive systems"	5,000 installed (no date)
Myanmar	Hydropower	9.4 GW by 2030
Nigeria	Bio-power	400 MW by 2025
	Hydropower (small-scale)[3]	2 GW by 2025
	Solar PV (large-scale, >1 MW)	500 MW by 2025
	CSP	5 MW by 2025
	Wind power	40 MW by 2025
Norway	Generation (not specified)	30 TWh per year by 2016
	Generation (not specified)	26.4 TWh common electricity certificate market with Sweden by 2020

Table R19. Targets for Renewable Power Installed Capacity and/or Generation (continued)

Note: Text in **bold** indicates new/revised in 2016, brackets '[]' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

COUNTRY	TECHNOLOGY	TARGET
Palestine, State of	Bio-power	21 MW by 2020
	Solar PV	45 MW by 2020
	CSP	20 MW by 2020
	Wind power	44 MW by 2020
Philippines	Capacity (not specified)	Triple the 2010 capacity by 2030
	Bio-power	277 MW added 2010-2030
	Geothermal power	1.5 GW added 2010-2030
	Hydropower	5,398 MW added 2010-2030
	Ocean power	75 MW added 2010-2030
	Solar PV	284 MW added 2010-2030
	Wind power	2.3 GW added 2010-2030
Poland	Wind power (offshore)	1 GW by 2020
Portugal	Capacity (not specified)	15.8 GW by 2020
	Bio-power from solid biomass	769 MW by 2020
	Bio-power from biogas	59 MW by 2020
	Geothermal power	29 MW by 2020
	Hydropower (small-scale)	400 MW by 2020
	Ocean power (wave)	6 MW by 2020
	Solar PV	670 MW by 2020
	Concentrating solar photovoltaics (CPV)	50 MW by 2020
	Wind power	5.3 GW onshore by 2020; 27 MW offshore by 2020
Russian Federation	Capacity (not specified)[4]	5.87 GW installed capacity commissioned by 2020
Rwanda	Bio-power from biogas	300 MW by 2017
	Geothermal power	310 MW by 2017
	Hydropower	340 MW by 2017
	Capacity (not specified; off-grid)	5 MW by 2017
Saudi Arabia	**Capacity (not specified)**	**9.5 GW by 2023;** 54 GW by 2040
	Solar PV and CSP	41 GW by 2040 (25 GW CSP, 16 GW PV)
	Geothermal, bio-power (waste-to-energy)[5], wind power	13 GW combined by 2040
Serbia	Solar PV	150 MW by 2017
	Wind power	1.4 GW (no date)
Sierra Leone	Capacity (not specified)	1 GW (no date)
Singapore	Solar PV	350 MW by 2020
Solomon Islands	Geothermal power	20-40 MW (no date)
	Hydropower	3.77 MW (no date)
	Solar power	3.2 MW (no date)
South Africa	Capacity (not specified)	17.8 GW by 2030; 42% of new generation capacity installed 2010-2030
Spain	Bio-power from solid biomass	1.4 GW by 2020
	Bio-power from organic MSW[5]	200 MW by 2020
	Bio-power from biogas	400 MW by 2020
	Geothermal power	50 MW by 2020
	Hydropower	13.9 GW by 2020

Table R19. Targets for Renewable Power Installed Capacity and/or Generation (continued)

Note: Text in **bold** indicates new/revised in 2016, brackets '[]' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

COUNTRY	TECHNOLOGY	TARGET
Spain (continued)	Pumped storage[2]	8.8 GW by 2020
	Ocean power	100 MW by 2020
	Solar PV	7.3 GW by 2020
	CSP	4.8 GW by 2020
	Wind power (onshore)	35 GW by 2020
	Wind power (offshore)	750 MW by 2020
Sudan	Bio-power from solid biomass	54 MW by 2031
	Bio-power from biogas	68 MW by 2031
	Hydropower	63 MW by 2031
	Solar PV	667 MW by 2031
	CSP	50 MW by 2031
	Wind power	680 MW by 2031
Sweden	Generation (not specified)	25 TWh more renewable electricity annually by 2020 (base year 2002)
	Generation (not specified)	26.4 TWh common electricity certificate market with Norway by 2020
Switzerland	Generation (not specified)	12 TWh per year by 2035; 24.2 TWh per year by 2050
	Hydropower	43 TWh per year by 2035
Syria	Bio-power	140 MW by 2020; 260 MW by 2025; 400 MW by 2030
	Solar PV	380 MW by 2020; 1.1 GW by 2025; 1.8 GW by 2030
	CSP	50 MW by 2025
	Wind power	1 GW by 2020; 1.5 GW by 2025; 2 GW by 2030
Tajikistan	Hydropower (small-scale)	100 MW by 2020
Thailand	Bio-power from solid biomass	4.8 GW by 2021
	Bio-power from biogas	600 MW by 2021
	Bio-power from organic MSW[5]	400 MW by 2021
	Geothermal power	1 MW by 2021
	Hydropower	6.1 GW by 2021
	Ocean power (wave and tidal)	2 MW by 2021
	Solar PV	**1.7 GW by 2016; 3 GW by 2021; 6 GW by 2036**
	Wind power	1.8 GW by 2021
Trinidad and Tobago	Wind power	100 MW (no date given)
Tunisia	Capacity (not specified)	1 GW (16% of capacity) by 2016; 4.6 GW (40% of capacity) by 2030
	Bio-power from solid biomass	40 MW by 2016; 300 MW by 2030
	Solar power	10 GW by 2030
	Wind power	16 GW by 2030
Turkey	Bio-power from solid biomass	1 GW by 2023
	Geothermal power	1 GW by 2023
	Hydropower	34 GW by 2023
	Solar PV	5 GW by 2023
	Wind power	20 GW by 2023
Uganda	Bio-power from organic MSW[5]	30 MW by 2017
	Geothermal power	45 MW by 2017
	Hydropower (large-scale)	1.2 GW by 2017
	Hydropower (mini- and micro-scale)	85 MW by 2017
	Solar PV (solar home systems)	700 kW by 2017

Table R19. Targets for Renewable Power Installed Capacity and/or Generation (continued)

Note: Text in **bold** indicates new/revised in 2016, brackets '[]' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

COUNTRY	TECHNOLOGY	TARGET
United Kingdom	Wind power (offshore)	39 GW by 2030
United States		No national target
Iowa	*Capacity (not specified)*	*105 MW of generating capacity for IOUs*[6]
Massachusetts	***Wind (offshore)***	***1.6 GW by 2027***
Texas	*Capacity (not specified)*	*5,880 MW*
Venezuela	Capacity (not specified)	613 MW new capacity installed 2013-2019, including:
	Wind power	500 MW new capacity installed 2013-2019
Vietnam	Hydropower	21.6 GW by 2020; 24.6 GW by 2025; 27.8 GW by 2030
	Wind power	800 MW by 2020; 2 GW by 2025; 6 GW by 2030
	Solar power	850 MW by 2020; 4 GW by 2025; 12 GW by 2030
Yemen	Bio-power	6 MW by 2025
	Geothermal power	200 MW by 2025
	Solar PV	4 MW by 2025
	CSP	100 MW by 2025
	Wind power	400 MW by 2025

[1] India does not classify hydropower installations larger than 25 MW as renewable energy sources. Therefore, national targets and data for India do not include hydropower facilities >25 MW.

[2] Pumped storage plants are not energy sources but a means of energy storage. As such, they involve conversion losses and are powered by renewable or non-renewable electricity. Pumped storage is included here because it can play an important role as balancing power, in particular for variable renewable resources.

[3] Nigeria's target excludes hydropower plants >30 MW.

[4] The Russian Federation's targets exclude hydropower plants >25 MW.

[5] It is not always possible to determine whether municipal solid waste (MSW) data include non-organic waste (plastics, metal, etc.) or only the organic biomass share.

[6] Investor-owned utilities (IOUs) are those operating under private control rather than government or co-operative operation.

Note: All capacity targets are for cumulative capacity unless otherwise noted. Targets are rounded to the nearest tenth decimal. Renewable energy targets are not standardised across countries; therefore, the table presents a variety of targets for the purpose of general comparison. Countries on this list also may have primary/final energy, electricity, heating/cooling or transport targets ***(→ see Tables R10, R12–R22)***.

Source: See endnote 19 for this section.

Table R20. Cumulative Number[1] of Countries/States/Provinces Enacting Feed-in Policies, and 2016 Revisions

Note: Text in **bold** indicates new/revised in 2016.

YEAR	CUMULATIVE #[1]	COUNTRIES/STATES/PROVINCES ADDED THAT YEAR
1978	1	United States[2]
1988	2	Portugal
1990	3	**Germany**
1991	4	Switzerland
1992	5	Italy
1993	7	**Denmark**; India
1994	10	Luxembourg; Spain; **Greece**
1997	11	Sri Lanka
1998	12	Sweden
1999	14	Norway; **Slovenia**
2000	14	[None identified]
2001	17	Armenia; **France**; Latvia
2002	23	Algeria; Austria; Brazil; Czech Republic; **Indonesia**; Lithuania
2003	29	Cyprus; Estonia; Hungary; Slovak Republic; Republic of Korea; Maharashtra (India)
2004	34	Israel; Nicaragua; Prince Edward Island (Canada); Andhra Pradesh and Madhya Pradesh (India)
2005	41	**China**; Ecuador; Ireland; Turkey; Karnataka, Uttar Pradesh and Uttarakhand (India)
2006	46	Argentina; Pakistan; Thailand; **Ontario (Canada)**; Kerala (India)
2007	55	Albania; Bulgaria; Croatia; Dominican Republic; Finland; FYR of Macedonia; Moldova; Mongolia; South Australia (Australia)
2008	70	Iran; **Kenya**; Liechtenstein; **Philippines**; San Marino; Tanzania; **Queensland (Australia)**; Chhattisgarh, Gujarat, Haryana, Punjab, Rajasthan, **Tamil Nadu** and West Bengal (India); California (United States)
2009	81	**Japan**; Serbia; South Africa; **Ukraine**; Australian Capital Territory, New South Wales and Victoria **(Australia)**; Taipei (China); Hawaii, Oregon and Vermont (United States)
2010	87	Belarus; Bosnia and Herzegovina; Malaysia; Malta; Mauritius; **United Kingdom**
2011	94	Ghana; Montenegro; Netherlands; Syria; Vietnam; Nova Scotia (Canada); Rhode Island (United States)
2012	99	Jordan; Nigeria; State of Palestine; Rwanda; Uganda
2013	101	Kazakhstan; **Pakistan**
2014	104	**Egypt**; Vanuatu; Virgin Islands (United States)
2015	104	[None identified]
2016	104	**Czech Republic (reinstated)**
Total Existing[3]	**110**	

[1] "Cumulative number" refers to number of jurisdictions that had enacted feed-in policies as of the given year.

[2] The US PURPA policy (1978) is an early version of the FIT, which has since evolved.

[3] "Total existing" excludes eight countries that are known to have subsequently discontinued policies (Brazil, Republic of Korea, Mauritius, Norway, South Africa, Spain, Sweden and the United States) and adds nine countries (Andorra, Honduras, Maldives, Panama, Peru, Poland, Russian Federation, Senegal and Tajikistan) and five Indian states (Bihar, Himachal Pradesh, Jammu and Kashmir, Jharkhand and Orissa) that are believed to have FITs but with an unknown year of enactment.

Source: See endnote 20 for this section.

Table R20. Cumulative Number[1] of Countries/States/Provinces Enacting Feed-in Policies, and 2016 Revisions (continued)

Note: Text in **bold** indicates new/revised in 2016, and text in *italics* indicates policies adopted at the state/provincial level.

2016 FIT POLICY ADJUSTMENTS	
Australia – Queensland	*Increased size of solar power systems eligible for FIT from 5 kW to 30 kW*
Canada – Ontario	*Opened fifth round of FIT to new applications*
China	Solar PV FIT rate reduced 13-19% (regionally dependent); FIT for distributed solar PV and offshore wind unchanged; onshore wind FIT set to decrease by 15% from 2018
Czech Republic	FIT reinstated
Denmark	Introduced FIT for small-scale wind power installations
Egypt	Solar PV (500 kW to 20 MW) reduced from USD 0.136 per kWh to USD 0.078 per kWh; solar PV (20 MW to 50 MW) reduced from USD 0.1434 per kWh to USD 0.084 per kWh; wind power reduced from USD 0.0957–0.1148 per kWh to USD 0.04 per kWh
France	FIT restricted to installations of less than 500 kW
Germany	FIT restricted to installations of less than 750 kW, 150 kW limit for bio-power installations
Greece	FIT expanded to allow small-scale projects and installations on non-interconnected islands to receive support
India – Tamil Nadu	*Solar PV FIT reduced 27%*
Indonesia	Solar FIT increased 70%
Japan	Solar FIT reduced 11%
Kenya	Proposed tenders to replace FIT
Pakistan	Solar FIT reduced 36%
Philippines	Solar power FIT reduced 10% for second wave of FIT
Slovenia	FIT restricted to installations of less than 500 kW
Ukraine	Rates reduced from EUR 0.16 per kWh to EUR 0.15 per kWh for commercial solar power installations greater than 10 MW
United Kingdom	All FIT rates reduced 65%

[1] "Cumulative number" refers to number of jurisdictions that had enacted feed-in policies as of the given year.

Source: See endnote 20 for this section.

Table R21. Cumulative Number[1] of Countries/States/Provinces Enacting RPS/Quota Policies, and 2016 Revisions

Note: Text in **bold** indicates new/revised in 2016.

YEAR	CUMULATIVE #[1]	COUNTRIES/STATES/PROVINCES ADDED THAT YEAR
1983	1	Iowa (United States)
1994	2	**Minnesota (United States)**
1996	3	Arizona (United States)
1997	6	Maine, Massachusetts, Nevada (United States)
1998	9	Connecticut, Pennsylvania, Wisconsin (United States)
1999	12	Italy; New Jersey, Texas (United States)
2000	13	New Mexico (United States)
2001	15	Australia; Flanders (Belgium)
2002	18	United Kingdom; Wallonia (Belgium); California (United States)
2003	22	Japan; Portugal; Sweden; Maharashtra (India)
2004	35	Poland; Nova Scotia, Ontario and Prince Edward Island (Canada); Andhra Pradesh, Karnataka, Madhya Pradesh, Orissa (India); Colorado, Hawaii, **Maryland, New York, Rhode Island (United States)**
2005	39	Gujarat (India); Delaware, **District of Columbia,** Montana (United States)
2006	40	Washington State (United States)
2007	46	China; **Illinois,** New Hampshire, North Carolina, **Northern Mariana Islands, Oregon** (United States)
2008	53	Chile; India; Philippines; Romania; **Michigan,** Missouri, **Ohio** (United States)
2009	54	Kansas (United States)
2010	57	Republic of Korea; British Columbia (Canada); Puerto Rico (United States)
2011	59	Albania; Israel
2012	60	Norway
2013	60	[None identified]
2014	60	[None identified]
2015	**62**	**Vermont,** US Virgin Islands (United States)
2016	**62**	[None identified]
Total Existing[2]	**100**	

[1] "Cumulative number" refers to the number of jurisdictions that had enacted RPS/quota policies as of the given year. Jurisdictions are listed under the year of first policy enactment. Many policies shown have been revised or renewed in subsequent years, and some policies shown may have been repealed or lapsed.

[2] "Total existing" adds 40 jurisdictions believed to have RPS/Quota policies but whose year of enactment is not known (Belarus, Ghana, Indonesia, Kyrgyzstan, Lithuania, Malaysia, Palau, Peru, Senegal, South Africa, Sri Lanka, United Arab Emirates, the Indian states of Arunchal Pradesh, Assam, Bihar, Chhattisgarh, Goa, Haryana, Himachal Pradesh, Jammu and Kashmir, Jharkhand, Kerala, Manipur, Meghalaya, Mizoram, Nagaland, Punjab, Rajasthan, Tamil Nadu, Tripura, Uttarakhand, Uttar Pradesh and West Bengal and the Indian Union Territories of Andaman and Nicobar Islands, Chandigarh, Dadra and Nagar Haveli, Daman and Diu, Delhi, Lakshadweep and Puducherry) and excludes Italy, which phased out its RPS in 2012, and the US state of Kansas which downgraded its RPS to a voluntary goal in 2015. In the United States, there are nine additional states and territories with policy goals that are not legally binding RPS policies (Guam, Indiana, Kansas, North Dakota, Oklahoma, South Carolina, South Dakota, Utah and Virginia). West Virginia's non-binding goal was repealed in 2015. Three additional Canadian provinces also have non-binding policy goals (Alberta, Manitoba and Québec).

Source: See endnote 21 for this section.

Table R22. Renewable Energy Auctions Held in 2016 by Country/State/Province

COUNTRY	TECHNOLOGY	DESCRIPTION
Argentina	Bio-power	100 MW offered in 2016
	Bio-power (liquid biofuel)	150 MW offered in 2016
	Bio-power (urban solid waste)[1]	120 MW offered in 2016
	Bio-power (biogas)	20 MW offered in 2016
	Geothermal power	30 MW offered in 2016
	Small-scale hydropower	60 MW offered in 2016
	Solar power	20 MW offered in 2016
	Wind power	500 MW offered in 2016
Chile	Non-technology-specific	12,430 GWh offered in 2016
China	Non-technology-specific	5.5 GW of renewable energy capacity in 2016
El Salvador	Solar PV	100 MW
	Wind power	50 MW
France	Solar PV	3 GW of solar through six 500 MW application rounds to be held until 2019
Germany	Solar PV	400 MW cumulative capacity offered in 2016
Greece	Solar PV	40 MW of small-scale projects
India	Solar PV	1 GW
Indonesia	Geothermal power	680 MW
Iraq	Solar PV	50 MW
Israel	Solar PV	At least 1 GW, as well as 500 MW in the Negev desert and 40 MW in Ashalim
Jordan	Solar power	200 MW offered in 2016
	Wind power	100 MW offered in 2016
Malawi	Solar PV	4 solar PV plants with a cumulative capacity of 70 MW
Mexico	Solar and wind power	8,909 GWh awarded in 2016
Morocco	Non-technology-specific	1 GW of large-scale renewable energy projects
Netherlands	Solar PV	179 MW awarded in spring Simulation of Sustainable Energy Production (SDE+) scheme, 2.5 GW bids in fall SDE+ scheme
	Wind power (offshore)	700 MW of capacity awarded in July 2016; 680 MW of capacity awarded in December 2016
Palestine, State of	Solar PV	100 MW offered in 2016
Poland	Solar PV	100 MW of small-scale projects
Saudi Arabia	Solar PV	100 MW offered in 2016
Suriname	Solar PV	500 kW solar PV plant with battery storage awarded in 2016
Turkey	Solar PV	1 GW offered in 2016
Zambia	Solar PV	100 MW offered in 2016

COUNTRY	STATE/PROVINCE	TECHNOLOGY	DESCRIPTION
Australia	New South Wales	Renewable energy	173 GWh per year
Canada	Alberta	Renewable energy	400 MW
India	Tamil Nadu	Solar PV	500 MW
United Arab Emirates	Dubai	Solar PV	800 MW
	Abu Dhabi	Solar PV	350 MW

[1] It is not always possible to determine whether municipal solid waste (MSW) data include non-organic waste (plastics, metal, etc.) or only the organic biomass share.

Note: Table R22 provides an overview of identified renewable energy tenders in 2016 and likely does not constitute a comprehensive picture of all capacity offered through tenders during the year.

Source: See endnote 22 for this section.

Table R23. Heating and Cooling from Renewable Sources, Targets and 2015 Shares

COUNTRY	SHARE (2015)	TARGET
Austria	32%	32.6% by 2020
Belgium	7.6%	11.9% by 2020
Bhutan		Solar thermal: 3 MW equivalent by 2025
Bulgaria	28.6%	24% renewables in total heating and cooling by 2020
China		Solar thermal: 800 m^2 by 2020
Croatia	38.6%	19.6% by 2020
Cyprus	22.5%	23.5% by 2020
Czech Republic	19.8%	14.1% by 2020
Denmark	39.6%	39.8% by 2020
Estonia	49.6%	38% by 2020
Finland	52.8%	47% by 2020
France	19.8%	38% by 2030
Germany	12.9%	14% by 2020
Greece	25.9%	20% by 2020
Hungary	21.3%	18.9% by 2020
India		Solar water heating: 5.6 GW_{th} (8 million m^2) of new capacity to be added 2012-2017
Ireland	6.4%	15% by 2020
Italy	19.2%	17.1% by 2020 Bioenergy: 5,670 ktoe for heating and cooling by 2020 Geothermal: 300 ktoe for heating and cooling by 2020 Solar water and space heating: 1,586 ktoe by 2020
Jordan		Solar water heating: systems for 30% of households by 2020
Kenya		Solar water heating: 60% of annual demand for buildings that use over 100 litres of hot water per day (no date)
Kosovo[1]		45.65% by 2020
Latvia	51.8%	53.4% by 2020
Lebanon		15% renewables in gross final consumption in power and heating by 2030
Libya		Solar water heating: 80 MW_{th} by 2015; 250 MW_{th} by 2020
Lithuania	46.1%	39% by 2020
Luxembourg	6.9%	8.5% renewables in gross final consumption in heating and cooling by 2020
Macedonia, FYR of		11% by 2020
Malawi		Solar water heating: produce 2,000 solar water heaters (no date); increase total installed to 20,000 by 2030
Malta	14.1%	6.2% by 2020
Mexico		Solar water heating: Install 18.2 million m^2 of collectors by 2027
Moldova		27% by 2020
Montenegro	68.6%	38.2% by 2020
Morocco		Solar water heating: 1.2 GW_{th} (1.7 million m^2) by 2020
Mozambique		Solar water and space heating: 100,000 systems installed in rural areas (no date)
Netherlands	5.5%	8.7% by 2020
Poland	14.3%	17% by 2020
Portugal	33.4%	30.6% by 2020
Romania	25.9%	22% by 2020
Serbia		30% by 2020
Sierra Leone		Solar water heating: 2% penetration in hotels, guest houses and restaurants by 2020; 5% by 2030 Solar water heating: 1% penetration in the residential sector by 2030
Slovak Republic	10.8%	14.6% by 2020
Slovenia	34.1%	30.8% by 2020
Spain	16.8%	18.9% by 2020 Bioenergy: 4,653 ktoe by 2020 Geothermal: 9.5 ktoe by 2020 Heat pumps: 50.8 ktoe by 2020 Solar water and space heating: 644 ktoe by 2020
Sweden	69.6%	62.1% by 2020
Thailand		Bioenergy: 8,200 ktoe by 2022 Biogas: 1,000 ktoe by 2022 Organic MSW[2]: 35 ktoe by 2022 Solar water heating: 300,000 systems in operation and 100 ktoe by 2022
Uganda		Solar water heating: 21 MW_{th} (30,000 m^2) by 2017
Ukraine		12.4% by 2020
United Kingdom	5.5%	12% by 2020

[1] Kosovo is not a member of the United Nations.

[2] It is not always possible to determine whether municipal solid waste (MSW) data include non-organic waste (plastics, metal, etc.) or only the organic biomass share.

Note: Targets refer to share of renewable heating and cooling in total energy supply unless otherwise noted. Historical targets have been added as they are identified by REN21. Only bolded targets are new/revised in 2016. A number of nations have already exceeded their renewable energy targets. In many of these cases, targets serve as a floor setting the minimum share of renewable heat for the country. Table R23 includes targets established under EU National Renewable Energy Action Plans. Because heating and cooling targets are shares and are not standardised across countries, the table presents a variety of targets for the purpose of general comparison.

Source: See endnote 23 for this section.

Table R24. Transportation Energy from Renewable Sources, Targets and 2015 Shares

Note: Text in **bold** indicates new/revised in 2016, brackets '[]' indicate previous targets where new targets were enacted, and text in *italics* indicates policies adopted at the state/provincial level.

COUNTRY	SHARE	TARGET
EU-28		10% of EU-wide transport final energy demand by 2020
Albania	0%	→ 10% by 2020
Austria	11%	→ 11.4% by 2020
Belgium	3.8%	→ 10% by 2020
Wallonia		→ *10.14% by 2020*
Bulgaria	6.5%	→ 11% by 2020
Croatia	3.5%	→ 10% by 2020
Cyprus	2.5%	→ 4.9% by 2020
Czech Republic	6.5%	→ 10.8% by 2020
Denmark	6.7%	→ 10% by 2020
Estonia	0.4%	→ 10% by 2020
Finland	**22%**	→ **30% biofuel blending and 40% renewable transport fuel use by 2030** [20% by 2020]
France	8.5%	→ 15% by 2020
Germany	6.8%	→ 20% by 2020
Greece	1.4%	→ 10.1% by 2020
Hungary	6.2%	→ 10% by 2020
Iceland	5.7%	→ 10% by 2020
Ireland	6.5%	→ 10% by 2020
Italy	6.4%	→ 10.1% (2,899 ktoe) by 2020
Latvia	3.9%	→ 10% by 2020
Liberia		→ 5% palm oil blends in transport fuel by 2030
Lithuania	4.6%	→ 10% by 2020
Luxembourg	6.5%	→ 10% by 2020
Malta	4.7%	→ 10.7% by 2020
Macedonia, FYR of		→ 2% by 2020
Moldova		→ 20% by 2020
Montenegro		→ 10.2% by 2020
Netherlands	5.3%	→ 10% by 2020
Norway	**8.9%**	→ **20% by 2020** [10% by 2020]
Poland	6.4%	→ 20% by 2020
Portugal	7.4%	→ 10% by 2020
Qatar		→ 10% by 2020
Romania	5.5%	→ 10% by 2020
Serbia		→ 10% by 2020
Slovak Republic	8.5%	→ 10% by 2020
Slovenia	2.2%	→ 10.5% by 2020
Spain	1.7%	→ 11.3% from biodiesel by 2020 → 2,313 ktoe ethanol/bio-ETBE[1] by 2020 → 4.7 GWh per year electricity in transport by 2020 (501 ktoe from renewable sources by 2020)
Sri Lanka		→ 20% from biofuels by 2020
Sweden	24%	→ Vehicle fleet independent from fossil fuels by 2030
Thailand		→ 9 million litres per day ethanol consumption by 2022 → 6 million litres per day biodiesel consumption by 2022 → 25 million litres per day advanced biofuels production by 2022
Uganda		→ 2,200 million litres per year biofuels consumption by 2017
Ukraine		→ 10% by 2020
United Kingdom	4.4%	→ 10.3% by 2020
Vietnam		→ 5% of transport petroleum energy demand by 2025

[1] ETBE is a form of biofuel produced from ethanol and isobutylene.

Note: Targets refer to share of renewable transport in total energy supply unless otherwise noted. Historical targets have been added as they are identified by REN21. Only bolded targets are new/revised in 2016. A number of nations have already exceeded their renewable energy targets. In many of these cases, targets serve as a floor setting the minimum share of renewable energy for the country. Panama has an additional target for 30% of new vehicle purchases for public fleets to be flex-fuel (no date).

Source: See endnote 24 for this section.

Table R25. National and State/Provincial Biofuel Blend Mandates, 2016

Note: Text in **bold** indicates new/revised in 2016, brackets '[]' indicate previous mandates where new mandates were enacted, and text in *italics* indicates mandates adopted at the state/provincial level.

COUNTRY	MANDATE
Angola	E10
Argentina	**E10** [E5] and B10
Australia	[no national mandate]
New South Wales	*E6 and B2*
Queensland	*E3 by July 2017; E4 by July 2018 and B0.5*
Belgium	E4 and B4
Brazil	E27.5 and **B8**
Canada	E5 and B2
Alberta	*E5 and B2*
British Columbia	*E5 and B4*
Manitoba	*E8.5 and B2*
Ontario	*E5, B2 and B3 by 2016; B4 by 2017*
Saskatchewan	*E7.5 and B2*
China[1]	E10 in nine provinces, B1 in Taipei
Colombia	E8 and B10
Costa Rica	E7 and B20
Ecuador	B5 and E10, E5 in 2016
Ethiopia	E10
Guatemala	E5
India	**E22.5 and B15** [E10]
Indonesia	E3, **B20** [B5]
Italy	0.6% advanced biofuels blend by 2018; 1% by 2022
Jamaica	E10
Korea, Republic of	B2.5; B3 by 2018
Malawi	E10
Malaysia	**E10 and B10**
Mexico	**E5.8**
Mozambique	E15 in 2016-20; E20 from 2021
Norway	B3.5
Panama	**E10** [E7]
Paraguay	E25 and B1

COUNTRY	MANDATE
Peru	E7.8 and B2
Philippines	E10 and B2
South Africa	E2 and B5 (targets came into force in 2015)
Sudan	E5
Thailand	E5 and B7
Turkey	E2
Ukraine	E5; E7 by 2017
United States	Renewable Fuel Standard (RFS) 2016 standards: 68.6 billion litres total renewable fuels, including 871 million litres cellulosic biofuel, 7.2 billion litres biodiesel, 13.7 billion litres advanced biofuel; **2017 standards: 73 billion litres renewable fuels, including 1.2 billion litres cellulosic biofuel, 7.8 billion litres biomass-based diesel, 16.2 billion litres advanced biofuel; 7.9 billion litres biomass-based diesel fuel in 2018**[2]
Louisiana	*E2 and B2*
Massachusetts	*B5*
Minnesota	*E20 and B10*
Hawaii, Missouri and Montana	*E10*
New Mexico	*B5*
Oregon	*E10 and B5*
Pennsylvania	*B2 one year after 200 million gallons, and B20 one year after 1.5 billion litres (400 million gallons)*[2]
Washington	*E2 and B2, increasing to B5 180 days after in-state feedstock, and oil-seed crushing capacity can meet 3% requirement*
Uruguay	E5 and B5
Vietnam	**E5**
Zimbabwe	**E15** [E5]

[1] Chinese provincial mandates include Anhui, Heilongjian, Henan, Jilin and Liaoning.

[2] Original target(s) set in gallons and converted to litres for consistency.

Note: 'E' refers to bioethanol and 'B' refers to biodiesel. Chile has targets of E5 and B5 but has no current blending mandate. The Dominican Republic has targets of B2 and E15 for 2015 but has no current blending mandate. Fiji approved voluntary B5 and E10 blending in 2011 with a mandate expected. The Kenyan city of Kisumu has an E10 mandate. Table R25 lists only biofuel blend mandates; transport and biofuel targets can be found in Table R24.

Source: See endnote 25 for this section.

Table R26. City and Local Renewable Energy Targets: Selected Examples

Note: Text in **bold** indicates new/revised in 2016, and brackets '[]' indicate previous targets where new targets were enacted.

TARGETS FOR 100% OF TOTAL ENERGY OR ELECTRICITY FROM RENEWABLES

	TARGET DATE FOR 100% TOTAL ENERGY	TARGET DATE FOR 100% ELECTRICITY
Australian Capital Territory, Australia		**2020**
Boulder, Colorado, United States	**2030**	
Burlington, Vermont, United States		Achieved in 2014
Byron Shire County, Australia	2025	
Coffs Harbour, Australia		2030
Copenhagen, Denmark	2050	
Frankfurt, Germany	2050	
Fukushima Prefecture, Japan	2040	
Greensburg, Kansas, United States		Achieved in 2015
Hamburg, Germany	2050	
Jeju Self Governing Province, Republic of Korea		2030
Lancaster, California, United States		2020
Malmö, Sweden		2030
Munich, Germany		2025
Osnabrueck, Germany		2030
Oxford County, Australia	2050	
Palo Alto, California, United States		[no date given]
Rochester, Minnesota, United States		2031
Salt Lake City, Utah, United States		**2032**
San Diego, California, United States		2035
San Francisco, California, United States		2020
San Jose, California, United States		2022
Seattle, Washington, United States		[no date given]
Skellefteå, Sweden		2020
Sønderborg, Denmark	2029	
St. Petersburg, Florida, United States	**[no date given]**	
Sydney, Australia	2030	
Ulm, Germany		2025
Uralla, Australia	[no date given]	
Vancouver, Canada	2050	
Växjö, Sweden	2030	

TARGETS FOR RENEWABLE SHARE OF TOTAL ENERGY, ALL CONSUMERS

Austin, Texas, United States	→ 65% by 2025
Calgary, Alberta, Canada	→ 30% by 2036
Cape Town, South Africa	
Howrah, India	→ 10% by 2018
Nagano Prefecture, Japan	→ 70% by 2050
Oaxaca, Mexico	→ 5% by 2017
Paris, France	→ 25% by 2020
Skellefteå, Sweden	→ Net exporter of biomass, hydro or wind energy by 2020

TARGETS FOR RENEWABLE SHARE OF ELECTRICITY, ALL CONSUMERS

Amsterdam, Netherlands	→ 25% by 2025; 50% by 2040
Austin, Texas, United States	→ 35% by 2020
Canberra, Australian Capital Territory, Australia	→ 90% by 2020
Cape Town, South Africa	→ **20% by 2020** [15% by 2020]
Nagano Prefecture, Japan	→ 10% by 2020; 20% by 2030; 30% by 2050
Nelson Mandela Bay Metropolitan Municipality, South Africa	→ **10% by 2020**
Taipei City, Taipei, China	→ 12% by 2020
Tokyo, Japan	→ **30% by 2030** [24% by 2024]
Wellington, New Zealand	→ 78-90% by 2020

Table R26. City and Local Renewable Energy Targets: Selected Examples (continued)

Note: Text in **bold** indicates new/revised in 2016, and brackets '[]' indicate previous targets where new targets were enacted.

TARGET FOR RENEWABLE ELECTRIC CAPACITY OR GENERATION	
Adelaide, Australia	→ 2 MW of solar PV on residential and commercial buildings by 2020
Esklistuna, Sweden	→ 48 GWh from wind power, 9.5 GWh from solar PV by 2020
Gothenburg, Sweden	→ 500 GWh by 2030
Los Angeles, California, United States	→ 1.3 GW of solar PV by 2020
New York, New York, United States	→ **1 GW solar power and 100 MWh energy storage by 2020** [350 MW of solar PV by 2024]
San Francisco, California, United States	→ 100% of peak demand (950 MW) by 2020

TARGETS FOR GOVERNMENT SELF-GENERATION/ OWN-USE PURCHASES OF RENEWABLE ENERGY	
Belo Horizonte, Brazil	→ 30% of electricity from solar PV by 2030
Calgary, Alberta, Canada	→ **100% of government operations by 2025**
Cockburn, Australia	→ 20% of final energy in city buildings by 2020
Ghent, Belgium	→ 50% of final energy by 2020
Hepburn Shire, Australia	→ 100% of final energy in public buildings; 8% of electricity for public lighting
Kristianstad, Sweden	→ 100% of final energy by 2020
Malmö, Sweden	→ 100% of final energy by 2020
Portland, Oregon, United States	→ 100% of final energy by 2030
Sydney, Australia	→ 100% of electricity in buildings; 20% for street lamps

HEAT-RELATED MANDATES AND TARGETS	
Amsterdam, Netherlands	District heating for at least 200,000 houses by 2040 (using biogas, woody biomass and waste heat)
Chandigarh, India	Mandatory use of solar water heating in industry, hotels, hospitals, prisons, canteens, housing complexes, and government and residential buildings (as of 2013)
Helsingborg, Sweden	100% renewable energy district heating (community-scale) by 2035
Loures, Portugal	Solar thermal systems mandated as of 2013 in all sports facilities and schools that have good sun exposure
Munich, Germany	80% reduction of heat demand by 2058 (base 2009) through passive solar design (includes heat, process heat and water heating)
Nantes, France	Extend the district heating system to source heat from biomass boilers for half of city inhabitants by 2017
New York, New York, United States	**Biofuel blend in heating oil equivalent to 2% by 2016, 5% by 2017, 10% by 2025, and 20% by 2034**
Oslo, Norway	**Phase out fossil fuels and transition to electric heating in homes and offices by 2020**[1]
Osnabrück, Germany	100% renewable heat by 2050
Täby, Sweden	100% renewable heat in local government operations by 2020
Vienna, Austria	50% of total heat demand with solar thermal energy by 2050

[1] Norway's share of renewable electricity production to electricity consumption was 106% in 2015.

Note: Table R26 provides a sample of local renewable energy commitments worldwide. It does not aim to present a comprehensive picture of all municipal renewable energy goals.

Source: See endnote 26 for this section.

METHODOLOGICAL NOTES

This 2017 report is the 12th edition of the *Renewables Global Status Report* (GSR), which has been produced annually since 2005 (with the exception of 2008). Readers are directed to the previous GSR editions for historical details.

Most 2016 data[i] for national and global capacity, output, growth and investment portrayed in this report are preliminary. Where necessary, information and data that are conflicting, partial or older are reconciled by using reasoned expert judgment. Endnotes provide additional details, including references, supporting information and assumptions where relevant.

Each edition draws from thousands of published and unpublished references, including: official government sources; reports from international organisations and industry associations; input from the GSR community via hundreds of questionnaires submitted by country, regional and technology contributors as well as feedback from several rounds of formal and informal reviews; additional personal communications with scores of international experts; and a variety of electronic newsletters, news media and other sources.

Much of the data found in the GSR is built from the ground up by the authors with the aid of these resources. This often involves extrapolation of older data, based on recent changes in key countries within a sector or based on recent growth rates and global trends. Other data, often very specific and narrow in scope, come more-or-less prepared from third parties. The GSR attempts to synthesise these data points into a collective whole for the focus year.

The GSR endeavours to provide the best data available in each successive edition; as such, data should not be compared with previous versions of this report to ascertain year-by-year changes.

Note on Accounting and Reporting

A number of issues arise when counting renewable energy capacities and energy output. Some of these are discussed below:

1. Capacity versus Energy Data

The GSR aims to give accurate estimates of capacity additions and totals, as well as of electricity, heat and transport fuel production in the past year. These measures are subject to some uncertainty, which varies by technology. The chapter on Market and Industry Trends includes estimates for energy produced where possible, but it focuses mainly on power or heat capacity data. This is because capacity data generally can be estimated with a greater degree of confidence than generation data. Official heat and electricity generation data often are not available within the production time frame of the GSR.

2. Constructed Capacity versus Connected Capacity and Operational Capacity

Over the past few years, the solar PV and wind power markets have seen increasing amounts of capacity that was connected to the electricity grid but not yet deemed officially operational, or constructed capacity that was not connected to the grid by year's end. This phenomenon has been particularly evident for wind power installations in China (2009-2016). Starting with the 2012 edition, the GSR has aimed to count only capacity additions that were grid-connected or that otherwise went into service (e.g., capacity intended for off-grid use) during the previous calendar (focus) year. However, there may be exceptions related to data availability and other factors (as with China, for example). Known deviations to this approach are outlined in the text or endnotes for the technology sections.

3. Renewable Energy Shares of Total Final Energy Consumption (TFEC)

Renewable energy shares of TFEC are estimated by drawing on various data sources. TFEC in the target year is estimated by applying the one-year growth rate in primary energy demand (from the latest available version of BP's *Statistical Review of World Energy*) to the TFEC in the previous year (from the IEA's *World Energy Statistics and Balances*). Renewable energy consumption in the target year is based on various sources and is not necessarily internally consistent with estimates of the same in the IEA's statistics for the preceding year (which constitute the basis for estimating TFEC in the target year). Apportioning of renewable heat and electricity output for estimating total renewable energy consumption is not based on the share of renewables in gross production. Instead, the allocation of final consumption of electricity to renewables assumes electricity transmission losses and industry's own use of electricity to amount to 7% of gross generation.

See relevant endnotes for more-detailed information regarding sources and methodologies.

i For information on renewable energy data and related challenges, see Sidebar 4 in GSR 2015 and Sidebar 1 in GSR 2014.

4. Other General Notes on Capacity Data

Data on capacity retirements and replacements (re-powering) are incomplete for many technologies, although data on several technologies do attempt to account for these directly. It is not uncommon for reported new capacity installations to exceed the implied net increase in cumulative capacity; in some instances, this is explained by revisions to data on installed capacity, while in others it is due to capacity retirements and replacements.

5. Bio-power Data

Given existing complexities and constraints *(→ see Figure 6 in GSR 2015, and Sidebar 2 in GSR 2012)*, the GSR strives to provide the best and latest available data regarding biomass energy developments. The reporting of biomass-fired combined heat and power (CHP) systems varies among countries; this adds to the challenges experienced when assessing total heat and electricity capacities and total bioenergy outputs. Wherever possible, the bio-power data presented include capacity and generation from both electricity-only and CHP systems using solid biomass, landfill gas, biogas and liquid biofuels.

6. Hydropower Data and Treatment of Pumped Storage

Starting with the 2012 edition, the GSR has made an effort to report hydropower generating capacity without including pure pumped storage capacity (the capacity used solely for shifting water between reservoirs for storage purposes). The distinction is made because pumped storage is not an energy source but rather a means of energy storage. It involves conversion losses and potentially is fed by all forms of electricity, renewable and nonrenewable.

Some conventional hydropower facilities do have pumping capability that is not separate from, or additional to, their normal generating capability. These facilities are referred to as "mixed" plants and are included, to the extent possible, with conventional hydropower data. It is the aim of the GSR to distinguish and separate only the pure (or incremental) pumped storage component.

Where the GSR presents data for renewable power capacity not including hydropower, the distinction is made because hydropower remains the largest single component by far of renewable power capacity, and thus can mask developments in other renewable energy technologies if included. Investments and jobs data separate out large-scale hydropower statistics where original sources use different methodologies for tracking or estimating values. Footnotes and endnotes provide additional details.

7. Solar PV Capacity Data

The capacity of a solar PV panel is rated according to direct current (DC) output, which is most cases must be converted by inverters to alternating current (AC) to be compatible with end-use electricity supply. No single equation is possible for calculating solar PV data in AC because conversion depends on many factors, including the inverters used, shading, dust build-up, line losses and temperature effects on conversion efficiency. Residential systems typically have a ratio of 1:1, whereas utility-scale projects have ratios of as high as 1.4:1, with commercial installations in between.

This report attempts to report all solar PV capacity data on the basis of DC output (where data are provided in AC, this is specified) for consistency across countries. Some countries (e.g., Canada, Chile, Japan since 2012, and Spain) report official capacity data on the basis of output in alternating current (AC); these capacity data were converted to direct current (DC) output by data providers (see relevant endnotes) for the sake of consistency. Global capacity totals in this report include solar PV data in DC; as with all statistics in this report, they should be considered as indicative of global capacity and trends rather than as exact statistics[i].

8. Solar Thermal Heat Data

Starting with GSR 2014, the GSR includes all solar thermal collectors that use water as the heat transfer medium (or heat carrier) in global capacity data and ranking of top countries. Previous GSRs focused primarily on glazed water collectors (both flat plate and evacuated tube); the GSR now also includes unglazed water collectors, which are used predominantly for swimming pool heating. Data for solar air collectors (solar thermal collectors that use air as the heat carrier) and concentrating collectors mainly used for industrial applications (worldwide) or cooking (India) are far more uncertain, and these collector types play a minor role in the market overall. Solar thermal air collectors are included where specified.

9. Other

Editorial content of this report closed by 15 May 2017 for technology data, and by 1 May 2017 or earlier for other content. The Policy Landscape chapter covers policy developments through the end of 2016.

Growth rates in the GSR are calculated as compound annual growth rates (CAGR) rather than as an average of annual growth rates.

All exchange rates in this report are as of 31 December 2016 and are calculated using the OANDA currency converter (http://www.oanda.com/currency/converter/).

Corporate domicile, where noted, is determined by the location of headquarters.

i Based in part on information drawn from International Energy Agency Photovoltaic Systems Programme (IEA PVPS), *Trends in Photovoltaic Applications, 2016: Survey Report of Selected IEA Countries Between 1992 and 2015* (Paris: 2016), p. 7; from Gaëtan Masson, Becquerel Institute and IEA PVPS, personal communication with REN21, May 2017; and from Dave Renné, International Solar Energy Society, personal communication with REN21, March 2017.

GLOSSARY

Absorption chillers. Chillers that use heat energy from any source (solar, biomass, waste heat, etc.) to drive air conditioning or refrigeration systems. The heat source replaces the electric power consumption of a mechanical compressor. Absorption chillers differ from conventional (vapour compression) cooling systems in two ways: 1) the absorption process is thermochemical in nature rather than mechanical, and 2) the substance that is circulated as a refrigerant is water rather than chlorofluorocarbons (CFCs) or hydrochlorofluorocarbons (HCFCs), also called Freon. The chillers generally are supplied with district heat, waste heat or heat from co-generation, and they can operate with heat from geothermal, solar or biomass resources.

Adsorption chillers. Chillers that use heat energy from any source to drive air conditioning or refrigeration systems. They differ from absorption chillers in that the adsorption process is based on the interaction between gases and solids. A solid material in the chiller's adsorption chamber releases refrigerant vapour when heated; subsequently, the vapour is cooled and liquefied, providing a cooling effect at the evaporator by absorbing external heat and turning back into a vapour, which is then re-adsorbed into the solid.

Bagasse. The fibrous matter that remains after extraction of sugar from sugar cane.

Auction. (See Tendering.)

Behind-the-meter system. Any generation capacity, storage or demand management device on the customer side of the interface with the distribution grid.

Biodiesel. A fuel produced from oilseed crops such as soy, rapeseed (canola) and palm oil, and from other oil sources such as waste cooking oil and animal fats. Biodiesel is used in diesel engines installed in cars, trucks, buses and other vehicles, as well as in stationary heat and power applications. Also see Hydrotreated vegetable oil.

Bioenergy. Energy derived from any form of biomass (solid, liquid or gaseous) for heat, power and transport. (See Biofuel.)

Biofuel. A fuel derived from biomass that may include liquid fuel ethanol and biodiesel, as well as biogas. Biofuels can be combusted in vehicle engines as transport fuels and in stationary engines for heat and electricity generation. They also can be used for domestic heating and cooking (for example, as ethanol gels). Advanced biofuels are made from feedstocks derived from the lignocellulosic fractions of biomass sources or from algae. They are made using non-traditional biochemical and thermochemical conversion processes.

Biogas/Biomethane. Biogas is a gaseous mixture consisting mainly of methane and carbon dioxide produced by the anaerobic digestion of organic matter (broken down by microorganisms in the absence of oxygen). Organic material and/or waste is converted into biogas in a digester. Suitable feedstocks include agricultural residues, animal wastes, food industry wastes, sewage sludge, purpose-grown green crops and the organic components of municipal solid wastes. Raw biogas can be combusted to produce heat and/or power; it also can be transformed into biomethane through a process known as scrubbing that removes impurities including carbon dioxide, siloxanes and hydrogen sulphides, followed by compression. Biomethane can be injected directly into natural gas networks and used as a substitute for natural gas in internal combustion engines without fear of corrosion.

Biomass. Any material of biological origin, excluding fossil fuels or peat, that contains a chemical store of energy (originally received from the sun) and that is available for conversion to a wide range of convenient energy carriers.

Biomass energy, modern. Energy derived from combustion of solid, liquid and gaseous biomass fuels in high-efficiency conversion systems, which range from small domestic appliances to large-scale industrial conversion plants. Modern applications include heat and electricity generation, combined heat and power (CHP) and transport.

Biomass, traditional. Solid biomass including fuel wood, charcoal, agricultural and forest residues, and animal dung, that typically is used in rural areas of developing countries with traditional technologies such as open fires for cooking, kilns, and ovens for cooking and residential heating as well as small-scale agricultural and industrial processing. Often the use of traditional biomass leads to high pollution levels, forest degradation and deforestation.

Biomass pellets. Solid biomass fuel produced by compressing pulverised dry biomass, such as waste wood and agricultural residues. Pellets typically are cylindrical in shape with a diameter of around 10 millimetres and a length of 30-50 millimetres. Pellets are easy to handle, store, and transport and are used as fuel for heating and cooking applications, as well as for electricity generation and CHP. (Also see Torrefied wood.)

Building codes and standards. Rules specifying the minimum standards for buildings and other structures for increasing energy efficiency. These can refer to new and/or renovated and refurbished buildings.

Capacity. The rated capacity of a heat or power generating plant, which refers to the potential instantaneous heat or electricity output, or the aggregate potential output of a collection of such units (such as a wind farm or set of solar panels). Installed capacity describes equipment that has been constructed, although it may or may not be operational (e.g., delivering electricity to the grid, providing useful heat or producing biofuels).

Capacity factor. The ratio of the actual output of a unit of electricity or heat generation over a period of time (typically one year) to the theoretical output that would be produced if the unit were operating without interruption at its rated capacity during the same period of time.

Capital subsidy. A subsidy that covers a share of the upfront capital cost of an asset (such as a solar water heater). These include, for example, consumer grants, rebates or one-time payments by a utility, government agency or government-owned bank.

Combined heat and power (CHP) (also called co-generation). CHP facilities produce both heat and power from the combustion of fossil and/or biomass fuels, as well as from geothermal and solar thermal resources. The term also is applied to plants that recover "waste heat" from thermal power generation processes.

Community energy. An approach to renewable energy development that involves a community initiating, developing, operating, owning, investing and/or benefiting from a project. Communities vary in size and shape (e.g., schools, neighbourhoods, partnering city governments, etc.); similarly, projects vary in technology, size, structure, governance, funding and motivation.

Competitive bidding. (See Tendering.)

Concentrating photovoltaics (CPV). Technology that uses mirrors or lenses to focus and concentrate sunlight onto a relatively small area of photovoltaic cells that generate electricity (see Solar photovoltaics). Low-, medium- and high-concentration CPV systems (depending on the design of reflectors or lenses used) operate most efficiently in concentrated, direct sunlight.

Concentrating solar thermal power (CSP) (also called concentrating solar power or solar thermal electricity, STE). Technology that uses mirrors to focus sunlight into an intense solar beam that heats a working fluid in a solar receiver, which then drives a turbine or heat engine/generator to produce electricity. The mirrors can be arranged in a variety of ways, but they all deliver the solar beam to the receiver. There are four types of commercial CSP systems: parabolic troughs, linear Fresnel, power towers and dish/engines. The first two technologies are line-focus systems, capable of concentrating the sun's energy to produce temperatures of 400°C, while the latter two are point-focus systems that can produce temperatures of 800°C or higher.

Conversion efficiency. The ratio between the useful energy output from an energy conversion device and the energy input into it. For example, the conversion efficiency of a PV module is the ratio between the electricity generated and the total solar energy received by the PV module. If 100 kWh of solar radiation is received and 10 kWh electricity is generated, the conversion efficiency is 10%.

Crowdfunding. The practice of funding a project or venture by raising money – often relatively small individual amounts – from a relatively large number of people ("crowd"), generally using the Internet and social media. The money raised through crowdfunding does not necessarily buy the lender a share in the venture, and there is no guarantee that money will be repaid if the venture is successful. However, some types of crowdfunding reward backers with an equity stake, structured payments and/or other products.

Curtailment. A reduction in the output of a generator, typically on an involuntary basis, from what it could produce otherwise given the resources available. Curtailment of electricity generation has long been a normal occurrence in the electric power industry and can occur for a variety of reasons, including a lack of transmission access or transmission congestion.

Degression. A mechanism built into policy design establishing automatic rate revisions, which can occur after specific thresholds are crossed (e.g., after a certain amount of capacity is contracted, or a certain amount of time passes).

Demand-side energy management. Primarily, the pursuit of cost-effective energy efficiency measures on the customer side for least-cost overall energy system optimisation. Also includes demand-side load shifting and conservation measures.

Distributed generation. Generation of electricity from dispersed, generally small-scale systems that are close to the point of consumption.

Distributed renewable energy. Energy systems are considered to be distributed if 1) the systems of production are relatively small and dispersed (such as small-scale solar PV on rooftops), rather than relatively large and centralised; or 2) generation and distribution occur independently from a centralised network. Specifically for the purpose of the chapter on Distributed Renewable Energy for Energy Access, "distributed renewable energy" meets both conditions. It includes energy services for electrification, cooking, heating and cooling that are generated and distributed independent of any centralised system, in urban and rural areas of the developing world.

Distribution grid. The portion of the electrical supply distribution network that takes power off the transmission network via substations and feeds electricity at varying voltages to customers.

Electric vehicle (EV) (also called electric drive vehicle). A vehicle that uses one or more electric motors for propulsion. A battery electric vehicle is a type of EV that uses chemical energy stored in rechargeable battery packs. A plug-in hybrid EV can be recharged by an external source of electric power. Fuel cell vehicles are EVs that use pure hydrogen (or gaseous hydrocarbons before reformation) as the energy storage medium.

Energiewende. German term that means "transformation of the energy system". It refers to the move away from nuclear and fossil fuels towards an energy system based primarily on energy efficiency improvements and renewable energy.

Energy. The ability to do work, which comes in a number of forms including thermal, radiant, kinetic, chemical, potential and electrical. Primary energy is the energy embodied in (energy potential of) natural resources, such as coal, natural gas and renewable sources. Final energy is the energy delivered for end-use (such as electricity at an electrical outlet). Conversion losses occur whenever primary energy needs to be transformed for final energy use, such as combustion of fossil fuels for electricity generation.

Energy audit. Analysis of energy flows in a building, process or system, conducted with the goal of reducing energy inputs into the system without negatively affecting outputs.

Energy efficiency. The measure that accounts for delivering more services for the same energy input, or the same amount of services for less energy input. Conceptually, this is the reduction of losses from the conversion of primary source fuels through final energy use, as well as other active or passive measures to reduce energy demand without diminishing the quality of energy services delivered.

Energy efficiency mandate/obligation. A measure that requires designated parties (consumers, suppliers, generators) to meet a minimum, and often gradually increasing, target for energy efficiency. Mandates can include, for example, energy efficiency portfolio standards (EEPS) and/or building codes or obligations.

Energy efficiency target. An official commitment, plan or goal set by a government (at the local, state, national or regional level) to achieve a certain amount of energy efficiency by a future date. Targets may be backed by specific compliance mechanisms or policy support measures. Some targets are legislated, while others are set by regulatory agencies, ministries or public officials.

Energy intensity. Primary energy consumption per unit of economic output. Energy intensity typically is used as a proxy for energy efficiency in macro-level analyses due to the lack of an internationally agreed-upon high-level indicator for measuring energy efficiency.

Energy service company (ESCO). A company that provides a range of energy solutions including selling the energy services from a (renewable) energy system on a long-term basis while retaining ownership of the system, collecting regular payments from customers and providing necessary maintenance service. An ESCO can be an electric utility, co-operative, non-governmental organisation or private company, and typically installs energy systems on or near customer sites. An ESCO also can advise on improving the energy efficiency of systems (such as a building or an industry) as well as on methods for energy conservation and energy management.

Ethanol (fuel). A liquid fuel made from biomass (typically maize, sugar cane or small cereals/grains) that can replace petrol in modest percentages for use in ordinary spark-ignition engines (stationary or in vehicles), or that can be used at higher blend levels (usually up to 85% ethanol, or 100% in Brazil) in slightly modified engines, such as those provided in "flex-fuel" vehicles. Ethanol also is used in chemical and beverage industries.

Feed-in policy (feed-in tariff or feed-in premium). A policy that typically guarantees renewable generators specified payments per unit (e.g., USD per kWh) over a fixed period. Feed-in tariff (FIT) policies also may establish regulations by which generators can interconnect and sell power to the grid. Numerous options exist for defining the level of incentive, such as whether the payment is structured as a guaranteed minimum price (e.g., a FIT), or whether the payment floats on top of the wholesale electricity price (e.g., a feed-in premium).

Final energy. The part of primary energy, after deduction of losses from conversion, transmission and distribution, that reaches the consumer and is available to provide heating, hot water, lighting and other services. Final energy forms include electricity, district heating, mechanical energy, liquid hydrocarbons such as kerosene or fuel oil, and various gaseous fuels such as natural gas, biogas and hydrogen.

Final energy consumption. Energy that is supplied to the consumer for all final energy services such as cooling and lighting, building or industrial heating or mechanical work including transport.

Fiscal incentive. An incentive that provides individuals, households or companies with a reduction in their contribution to the public treasury via income or other taxes.

Flywheel energy storage. Energy storage that works by applying available energy to accelerate a high-mass rotor (flywheel) to a very high speed and thereby storing energy in the system as rotational energy.

Generation. The process of converting energy into electricity and/or useful heat from a primary energy source such as wind, solar radiation, natural gas, biomass, etc.

Geothermal energy. Heat energy emitted from within the earth's crust, usually in the form of hot water and steam. It can be used to generate electricity in a thermal power plant or to provide heat directly at various temperatures.

Green bond. A bond issued by a bank or company, the proceeds of which will go entirely into renewable energy and other environmentally friendly projects. The issuer will normally label it as a green bond. There is no internationally recognised standard for what constitutes a green bond.

Green energy purchasing. Voluntary purchase of renewable energy – usually electricity, but also heat and transport fuels – by residential, commercial, government or industrial consumers, either directly from an energy trader or utility company, from a third-party renewable energy generator or indirectly via trading of renewable energy certificates (such as renewable energy credits, green tags and guarantees of origin). It can create additional demand for renewable capacity and/or generation, often going beyond that resulting from government support policies or obligations.

Heat pump. A device that transfers heat from a heat source to a heat sink using a refrigeration cycle that is driven by external electric or thermal energy. It can use the ground (geothermal/ground-source), the surrounding air (aerothermal/air-source) or a body of water (hydrothermal/water-source) as a heat source in heating mode, and as a heat sink in cooling mode. A heat pump's final energy output can be several multiples of the energy input, depending on its inherent efficiency and operating condition. The output of a heat pump is at least partially renewable on a final energy basis. However, the renewable component can be much lower on a primary energy basis, depending on the composition and derivation of the input energy; in the case of electricity, this includes the efficiency of the power generation process. The output of a heat pump can be fully renewable energy if the input energy is also fully renewable.

Hydropower. Electricity derived from the potential energy of water captured when moving from higher to lower elevations. Categories of hydropower projects include run-of-river, reservoir-based capacity and low-head in-stream technology (the least developed). Hydropower covers a continuum in project scale from large (usually defined as more than 10 MW of installed capacity, but the definition varies by country) to small, mini, micro and pico.

Hydrotreated vegetable oil (HVO). A "drop-in" biofuel produced by using hydrogen to remove oxygen from waste cooking oils, fats and vegetable oils. The result is a hydrocarbon fuel that blends more easily with diesel and jet fuel than does biodiesel produced from triglycerides as fatty acid methyl esters (FAME).

Ice storage. Thermal energy storage using ice that utilises the large amount of heat given off by the fusion of water.

Inverter (and micro-inverter), solar. Inverters convert the direct current (DC) generated by solar PV modules into alternating current (AC), which can be fed into the electric grid or used by a local, off-grid network. Conventional string and central solar inverters are connected to multiple modules to create an array that effectively is a single large panel. By contrast, micro-inverters convert generation from individual solar PV modules; the output of several micro-inverters is combined and often fed into the electric grid. A primary advantage of micro-inverters is that they isolate and tune the output of individual panels, reducing the effects that shading or failure of any one (or more) module(s) has on the output of an entire array. They eliminate some design issues inherent to larger systems and allow for new modules to be added as needed.

Investment. Purchase of an item of value with an expectation of favourable future returns. In this report, new investment in renewable energy refers to investment in: technology research and development, commercialisation, construction of manufacturing facilities and project development (including the construction of wind farms and the purchase and installation of solar PV systems). Total investment refers to new investment plus merger and acquisition (M&A) activity (the refinancing and sale of companies and projects).

Investment tax credit. A fiscal incentive that allows investments in renewable energy to be fully or partially credited against the tax obligations or income of a project developer, industry, building owner, etc.

Joule. A joule (J) is a unit of work or energy equal to the energy expended to produce one watt of power for one second. The potential chemical energy stored in one barrel of oil and released when combusted is approximately 6 gigajoules (GJ); a tonne of oven-dry wood contains around 20 GJ of energy.

Labelling. A system in which the energy efficiency of the product/appliance is rated/listed on a label to inform customers of product energy performance so that they can select among various models. Labelling systems can be voluntary or mandatory.

Levelised cost of energy/electricity (LCOE). The unique cost price of energy outputs (e.g., USD/kWh or USD/GJ) of a project that makes the present value of the revenues equal to the present value of the costs over the lifetime of the project.

Long-term strategic plan. Strategy to achieve energy savings over a specified period of time (i.e., several years), including specific goals and actions to improve energy efficiency, typically spanning all major sectors.

Mandate/Obligation. A measure that requires designated parties (consumers, suppliers, generators) to meet a minimum, and often gradually increasing, target for renewable energy, such as a percentage of total supply, a stated amount of capacity, or the required use of a specified renewable technology. Costs generally are borne by consumers. Mandates can include renewable portfolio standards (RPS); building codes or obligations that require the installation of renewable heat or power technologies (often in combination with energy efficiency investments); renewable heat purchase requirements; and requirements for blending specified shares of biofuels (biodiesel or ethanol) into transport fuel.

Market concession model. A model in which a private company or non-governmental organisation is selected through a competitive process and given the exclusive obligation to provide energy services to customers in its service territory, upon customer request. The concession approach allows concessionaires to select the most appropriate and cost-effective technology for a given situation.

Merit order. A way of ranking available sources of energy (particularly electricity generation) in ascending order based on short-run marginal costs of production, such that those with the lowest marginal costs are the first ones brought online to meet demand, and those with the highest are brought on last. The merit-order effect is a shift of market prices along the merit-order or supply curve due to market entry of power stations with lower variable costs (marginal costs). This displaces power stations with the highest production costs from the market (assuming demand is unchanged) and admits lower-priced electricity into the market.

Micro-grids. These are similar to mini-grids, but there is no universal definition differentiating the two (see Mini-grids). For distributed renewable energy in developing countries, micro-grids typically refer to independent grid networks operating on a scale of 1-10 kW. In the United States, for example, micro-grids also refer to larger networks (up to several MW) that can operate independently of, or in conjunction with, an area's main power grid. It can be intended as back-up power or to bolster main grid power during periods of heavy demand. It often is used to reduce costs, to enhance reliability and/or as a means of incorporating renewable energy.

Mini-grids. Grids that provide small-scale generation (10 kW to 10 MW) and distribution of grid-quality electricity to a relatively small and concentrated group of customers, most commonly in remote areas. They often are managed locally and can operate with or without interconnection to the wider external transmission grid.

Molten salt. An energy storage medium used predominantly to retain the thermal energy collected by a solar tower or solar trough of a concentrating solar power plant, so that this energy can be used at a later time to generate electricity.

Monitoring. Energy use is monitored to establish a basis for energy management and to provide information on deviations from established patterns.

Net metering/Net billing. A regulated arrangement in which utility customers with on-site electricity generators can receive credits for excess generation, which can be applied to offset consumption in other billing periods. Under net metering, customers typically receive credit at the level of the retail electricity price. Under net billing, customers typically receive credit for excess power at a rate that is lower than the retail electricity price. Different jurisdictions may apply these terms in different ways, however.

Ocean energy. Energy captured from ocean waves, tides, currents, salinity gradients and ocean temperature differences. Wave energy converters capture the energy of surface waves to generate electricity; tidal stream generators use kinetic energy of moving water to power turbines; and tidal barrages are essentially dams that cross tidal estuaries and capture energy as tides ebb and flow.

Off-take agreement. An agreement between a producer of energy and a buyer of energy to purchase/sell portions of the producer's future production. An off-take agreement normally is negotiated prior to the construction of a renewable energy project or installation of renewable energy equipment in order to secure a market for the future output (e.g., electricity, heat). Examples of this type of agreement include power purchase agreements (PPAs) and FITs.

Off-taker. The purchaser of the energy from a renewable energy project or installation (e.g., a utility company) following an off-take agreement. See Off-take agreement.

Peaker generation plant. Power plants that generally run predominantly during peak demand periods for electricity. Such plants exhibit the optimum balance - for peaking duty - of relatively high variable cost (fuel and maintenance cost per unit of generation) relative to fixed cost per unit of energy produced (low capital cost per unit of generating capacity).

Power. The rate at which energy is converted into work, expressed in watts (joules/second).

Power purchase agreement (PPA). A contract between two parties, one which generates electricity (the seller) and one which is looking to purchase electricity (the buyer).

Power to gas. The conversion of electricity, either from renewable or conventional sources, to chemical energy.

Primary energy. The theoretically available energy content of a naturally occurring energy source (such as coal, oil, natural gas, uranium ore, geothermal and biomass energy, etc.) before it undergoes conversion to useful final energy delivered to the end-user. Conversion of primary energy into other forms of useful final energy (such as electricity and fuels) entails losses. Some primary energy is consumed at the end-user level as final energy without any prior conversion.

Primary energy consumption. The direct use of energy at the source, or supplying users with unprocessed fuel.

Product and sectoral standards. Rules specifying the minimum standards for certain products (e.g., appliances) or sectors (industry, transport, etc.) for increasing energy efficiency.

Production tax credit. A tax incentive that provides the investor or owner of a qualifying property or facility with a tax credit based on the amount of renewable energy (electricity, heat or biofuel) generated by that facility.

Prosumer. The idea that citizens are not just consumers but also have potential to be energy producers, particularly of renewable energy, playing an active role in the generation of energy, energy storage and demand-side management.

Public financing. A type of financial support mechanism whereby governments provide assistance, often in the form of grants or loans, to support the development or deployment of renewable energy technologies.

Pumped storage hydropower. Plants that pump water from a lower reservoir to a higher storage basin using surplus electricity, and that reverse the flow to generate electricity when needed. They are not energy sources but means of energy storage and can have overall system efficiencies of around 80-90%.

Regulatory policy. A rule to guide or control the conduct of those to whom it applies. In the renewable energy context, examples include mandates or quotas such as renewable portfolio standards, FITs and technology/fuel specific obligations.

Renewable energy certificate (REC). A certificate awarded to certify the generation of one unit of renewable energy (typically 1 MWh of electricity but also less commonly of heat). In systems based on RECs, certificates can be accumulated to meet renewable energy obligations and also provide a tool for trading among consumers and/or producers. They also are a means of enabling purchases of voluntary green energy.

Renewable energy target. An official commitment, plan or goal set by a government (at the local, state, national or regional level) to achieve a certain amount of renewable energy by a future date. Targets may be backed by specific compliance mechanisms or policy support measures. Some targets are legislated while others are set by regulatory agencies, ministries or public officials.

Renewable portfolio standard (RPS). An obligation placed by a government on a utility company, group of companies or consumers to provide or use a predetermined minimum targeted renewable share of installed capacity, or of electricity or heat generated or sold. A penalty may or may not exist for non-compliance. These policies also are known as "renewable electricity standards", "renewable obligations" and "mandated market shares", depending on the jurisdiction.

Reverse auction. (See Tendering.)

Sector coupling. The expanded use of varying energy sources across end-use sectors, such as the electrification of both transport and thermal applications in buildings and industry.

Smart energy system. An energy system that aims to optimise the overall efficiency and balance of a range of interconnected energy technologies and processes, both electrical and non-electrical (including heat, gas and fuels). This is achieved through dynamic demand- and supply-side management; enhanced monitoring of electrical, thermal and fuel-based system assets; control and optimisation of consumer equipment, appliances and services; better integration of distributed energy (on both the macro and micro scales); as well as cost minimisation for both suppliers and consumers.

Smart grid. Electrical grid that uses information and communications technology to co-ordinate the needs and capabilities of the generators, grid operators, end-users and electricity market stakeholders in a system, with the aim of operating all parts as efficiently as possible, minimising costs and environmental impacts and maximising system reliability, resilience and stability.

Smart grid technology. Advanced information and control technology that is required for improved systems integration and resource optimisation on the grid.

Solar collector. A device used for converting solar energy to thermal energy (heat), typically used for domestic water heating but also used for space heating, industrial process heat or to drive thermal cooling machines. Evacuated tube and flat plate collectors that operate with water or a water/glycol mixture as the heat-transfer medium are the most common solar thermal collectors used worldwide. These are referred to as glazed water collectors because irradiation from the sun first hits a glazing (for thermal insulation) before the energy is converted to heat and transported away by the heat transfer medium. Unglazed water collectors, often referred to as swimming pool absorbers, are simple collectors made of plastics and used for lower-temperature applications. Unglazed and glazed air collectors use air rather than water as the heat-transfer medium to heat indoor spaces or to pre-heat drying air or combustion air for agriculture and industry purposes.

Solar cooker. A cooking device for household and institutional applications, which converts sunlight to heat energy that is retained for cooking. There are five types of solar cookers: box cookers, panel cookers, parabolic cookers, evacuated tube cookers and trough cookers.

Solar home system (SHS). A stand-alone system composed of a relatively low-power photovoltaic module, a battery and sometimes a charge controller, that can power small electric devices and provide modest amounts of electricity to homes for lighting and radios, usually in rural or remote regions that are not connected to the electricity grid.

Solar photovoltaics (PV). A technology used for converting light into electricity. Solar PV cells are constructed from semiconducting materials that use sunlight to separate electrons from atoms to create an electric current. Modules are formed by interconnecting individual cells. Monocrystalline modules typically are slightly more efficient but relatively more expensive than multi-crystalline silicon modules, although these differences have narrowed with advances in manufacturing and technology. Thin film solar PV materials can be applied as flexible films laid over existing surfaces or integrated with building components such as roof tiles. Building-integrated PV (BIPV) generates electricity and replaces conventional materials in parts of a building envelope, such as the roof or facade.

Solar photovoltaic-thermal (PV-T). A solar PV-thermal hybrid system that includes solar thermal collectors mounted beneath PV modules to convert solar radiation into electrical and thermal energy. The solar thermal collector removes waste heat from the PV module, enabling it to operate more efficiently.

Solar pico system (SPS). A very small solar PV system – such as a solar lamp or an information and communication technology (ICT) appliance – with a power output of 1-10 watts that typically has a voltage of up to 12 volts.

Solar-plus-storage. A hybrid technology of solar PV with battery storage. Other types of renewable energy-plus-storage plants also exist.

Solar water heater (SWH). An entire system consisting of a solar collector, storage tank, water pipes and other components. There are two types of solar water heaters: pumped solar water heaters use mechanical pumps to circulate a heat transfer fluid through the collector loop (active systems), whereas thermosyphon solar water heaters make use of buoyancy forces caused by natural convection (passive systems).

Storage battery. A type of battery that can be given a new charge by passing an electric current through it. A lithium-ion battery uses a liquid lithium-based material for one of its electrodes. A lead-acid battery uses plates made of pure lead or lead oxide for the electrodes and sulphuric acid for the electrolyte and which remain common for off-grid installations. A flow battery uses two chemical components dissolved in liquids contained within the system and most commonly separated by a membrane. Flow batteries can be recharged almost instantly by replacing the electrolyte liquid, while simultaneously recovering the spent material for re-energisation.

Subsidy. A government measure that artificially reduces the price that consumers pay for energy or that reduces the production cost.

Tendering (also called auction / reverse auction or tender). A procurement mechanism by which renewable energy supply or capacity is competitively solicited from sellers, who offer bids at the lowest price that they would be willing to accept. Bids may be evaluated on both price and non-price factors.

Thermal energy storage. Technology that allows the transfer and storage of thermal energy. (See Ice storage and Molten salt.)

Torrefied wood. Solid fuel, often in the form of pellets, produced by heating wood to 200-300°C in restricted air conditions. It has useful characteristics for a solid fuel including relatively high energy density, good grindability into pulverised fuel and water repellency.

Transmission grid. The portion of the electrical supply distribution network that carries bulk electricity from power plants to substations where voltage is stepped down for further distribution. High-voltage transmission lines can carry electricity between regional grids in order to balance supply and demand.

Variable renewable energy (VRE). A renewable energy source that fluctuates within a relatively short time frame, such as wind and solar power, which vary within daily, hourly and even sub-hourly time frames. By contrast, resources and technologies that are variable on an annual or seasonal basis due to environmental changes, such as hydropower (due to changes in rainfall) and thermal power plants (due to changes in temperature of ambient air and cooling water), do not fall into this category.

Vehicle fuel standards. Rules specifying the minimum fuel economy of automobiles.

Voltage and frequency control. The process of maintaining grid voltage and frequency stable within a narrow band through management of system resources.

Watt. A unit of power that measures the rate of energy conversion or transfer. A kilowatt is equal to one thousand watts; a megawatt to one million watts; and so on. A megawatt-electrical (MW) is used to refer to electric power, whereas a megawatt-thermal (MW_{th}) refers to thermal/heat energy produced. Power is the rate at which energy is consumed or generated. A kilowatt-hour is the amount of energy equivalent to steady power of 1 kW operating for one hour.

Yield company (yieldco). Renewable energy yieldcos are publicly traded financial vehicles created when power companies spin off their renewable power assets into separate, high-yielding entities. They are formed to reduce risk and volatility, and to increase capital and dividends. Shares are backed by completed renewable energy projects with long-term PPAs in place to deliver dividends to investors. They attract new types of investors who prefer low-risk and dividend-like yields, and those who wish to invest specifically in renewable energy projects. The capital raised is used to pay off debt or to finance new projects at lower rates than those available through tax equity finance.

LIST OF ABBREVIATIONS

AC	Alternating current
AfDB	African Development Bank
APEC	Asia-Pacific Economic Cooperation
AREI	Africa Renewable Energy Initiative
BIPV	Building-integrated solar photovoltaics
BNEF	Bloomberg New Energy Finance
BRICS	Brazil, Russian Federation, India, China and South Africa
BRT	Bus Rapid Transit
CDM	Clean Development Mechanism
CHP	Combined heat and power
CO_2	Carbon dioxide
COP21	Conference of the Parties, 21st meeting
COP22	Conference of the Parties, 22nd meeting
CPV	Concentrating solar photovoltaics
CSP	Concentrating solar thermal power
CVF	Climate Vulnerable Forum
DC	Direct current
DESCO	Distributed energy service company
DFI	Development finance institution
DNI	Direct normal insolation
DRE	Distributed renewable energy for energy access
DSM	Demand-side management
EBRD	European Bank for Reconstruction and Development
EC	European Commission
ECOWAS	Economic Community of West African States
EEG	German Renewable Energy Law – "Erneuerbare-Energien-Gesetz"
EIB	European Investment Bank
EJ	Exajoule
EMEC	European Marine Energy Centre
EnDev	Energising Development
EPA	US Environmental Protection Agency
EPC	Engineering, procurement and construction
ESCO	Energy service company
ETS	Emissions Trading System
EU	European Union (specifically the EU-28)
EV	Electric vehicle
FERC	US Federal Energy Regulatory Commission
FIP	Feed-in premium
FIT	Feed-in tariff
G20	Group of Twenty
GACC	Global Alliance for Clean Cookstoves
GCF	Green Climate Fund
GDP	Gross domestic product
GEF	Global Environment Facility
GFR	Global Futures Report
GSR	Renewables Global Status Report
GW/GWh	Gigawatt/gigawatt-hour
GW_{th}	Gigawatt-thermal
HVAC	Heating, ventilation and air conditioning
HVO	Hydrotreated vegetable oil
IEA	International Energy Agency
IEA PVPS	IEA Photovoltaic Power Systems Programme
IEA SHC	Solar Heating and Cooling Programme of the International Energy Agency
IFC	International Finance Corporation
INDC	Intended Nationally Determined Contribution
INR	Indian rupee
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent power producer
IRENA	International Renewable Energy Agency
ITC	Investment tax credit
kW/kWh	Kilowatt/kilowatt-hour
LCOE	Levelised cost of electricity/energy
LED	Light-emitting diode
LLC	Limited liability company
LNG	Liquefied natural gas
m^2	Square metre
m^3	Cubic metre
M&A	Mergers and acquisitions
MENA	Middle East and North Africa
MEPS	Minimum Energy Performance Standards
MSW	Municipal solid waste
MW/MWh	Megawatt/megawatt-hour
MW_{th}	Megawatt-thermal
NDC	Nationally Determined Contribution
NEEAP	National Energy Efficiency Action Plan
NGO	Non-governmental organisation
nZEB	Nearly zero energy building
NZEB	Net zero energy building
OECD	Organisation for Economic Co-operation and Development
O&M	Operation and maintenance
OMC	Omnigrid Micropower Company
OPEC	Organization of the Petroleum Exporting Countries
OPIC	US Overseas Private Investment Corporation
PAYG	Pay-As-You-Go
PHEV	Plug-in hybrid electric vehicle
PJ	Petajoule
PPA	Power purchase agreement
PTC	Production tax credit
PUC	Public utility commission
PV	Photovoltaic
PV-T	Photovoltaic-thermal
Q1	First quarter
R&D	Research and development
RFS	US Renewable Fuel Standard
RHI	UK Renewable Heat Incentive
RPS	Renewable portfolio standard(s)
SDG	Sustainable Development Goal
SEforALL	United Nations Sustainable Energy for All initiative
SHIP	Solar heat for industrial processes
SHS	Solar home system(s)
SIDS	Small-island developing states
SME	Small and medium-sized enterprise
SWH	Solar water heater/heating
T&D	Transmission and distribution
TES	Thermal energy storage
TFC	Total final consumption
TFEC	Total final energy consumption
toe	Tonne of oil equivalent
TPES	Total primary energy supply
TW/TWh	Terawatt/Terawatt-hour
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organization
USAID	US Agency for International Development
USD	United States dollar
VAT	Value-added tax
VRE	Variable renewable energy
W/Wh	Watt/watt-hour
yieldcos	yield companies
ZEV	Zero-emission vehicle

ENERGY UNITS AND CONVERSION FACTORS

METRIC PREFIXES

kilo	(k)	=	10^3
mega	(M)	=	10^6
giga	(G)	=	10^9
tera	(T)	=	10^{12}
peta	(P)	=	10^{15}
exa	(E)	=	10^{18}

VOLUME

1 m^3	=	1,000 litres (l)
1 US gallon	=	3.78 l
1 Imperial gallon	=	4.55 l

Example: 1 TJ = 1,000 GJ = 1,000,000 MJ = 1,000,000,000 kJ = 1,000,000,000,000 J = 1012 J
1 J = 0.001 MJ = 0.000001 GJ = 0.000000001 TJ

ENERGY UNIT CONVERSION

Multiply by:	GJ	Toe	MBtu	MWh
GJ	1	0.024	0.948	0.278
Toe	41.868	1	39.683	11.630
MBtu	1.055	0.025	1	0.293
MWh	3.600	0.086	3.412	1

Toe = tonnes oil equivalent

1 Mtoe = 41.9 PJ

Example: 1 MWh x 3.600 = 3.6 GJ

HEAT OF COMBUSTION (HIGH HEAT VALUES)

1 l ethanol	=	84,530 Btu / US gallon	=	21.2 MJ / l
1 l biodiesel	=	127,960 Btu / US gallon	=	32.1 MJ / l

Example: 1) These values can vary with fuel and temperature.
2) Around 1.5 litres of ethanol is required to equate to 1 litre of gasoline.
3) Heat values from U.S. Department of Energy Alternative Fuels Data Center.

SOLAR THERMAL HEAT SYSTEMS

1 million m^2 = 0.7 GW_{th}

Used where solar thermal heat data have been converted from square metres (m^2) into gigawatts thermal (GW_{th}), by accepted convention.

COPYRIGHT & IMPRINT

Renewable Energy Policy Network for the 21st Century

REN21 Secretariat
c/o UNEP
1 Rue Miollis, Building VII
75015 Paris
France

PHOTO CREDITS

page 18: © National Power Company of Iceland; Landsvirkjun, Iceland, Aflstöðvar
page 20: Shutterstock, © miroslav110
page 22: Biofuel factory, Shutterstock, © Stockr
page 23: Shutterstock, © Stockr
page 24: © M-Kopa Solar
page 28: © Caspar Sessler, 2013; Fraunhofer IWES's LiDAR buoy floating in the German Bight. The measurement mast Fino 1 and the Alpha Ventus wind farm are visible in the background.
page 29: Shutterstock, © Diyana Dimitrova
page 31: Rio do fogo, Rio Grande do Norte, Brazil ©Wind Power Works
page 33: Campo solar de colectores cilindroparabólicos en Solana (Arizona, USA) 2, © ABENGOA
page 35: Acesso_#05_AUGVI#02_à_Frente_e_atrás_linha_de_aeros_AUGVI#03_a_08_Decrescente
page 35: Wind turbine transport, iStock, © axel-ellerhorst
page 36: Shutterstock, © msgrafixx
page 37: Solar boilers based on unique Fresnel collector technology, Shutterstock, © Eunika Sopotnicka
page 38: de Purmer biomass district heating plant boilers photo via CleanTechnica
page 38: © Viessmann Werke
page 39: © DayOwl, Toronto,Canada
page 40: fotolia, © JH-Photo
page 40: Filling up natural gas, Wikimedia Commons, © Andreas Geick
page 40: Shutterstock, © moreimages
page 41: Shutterstock, © Veniamin Kraskov; Nice, France
page 44: Biomass power plant, Shutterstock, © nostal6ie
page 45: Oak Biomass, Shutterstock, © tchara
page 51: Shutterstock, © Moreno Soppelsa
page 52: Geothermal power station, Shutterstock, © N.Minton
page 53: © Marcus Schlaf; Freiham, Germany
page 53: Shutterstock, © Noor Patria Budhiekusuma
page 54: Shutterstock, © N.Minton
page 55: © National Power Company of Iceland; Landsvirkjun; Iceland; Aflstöðvar
page 56: © Turboden, www.thinkgeoenergy.com
page 57: Shutterstock, © Gary Saxe
page 58: Shutterstock, © Johnson76
page 58: Shutterstock, © Lukasz Siekierski; Zydowo, Poland
page 59: Shutterstock, © CCat82; Romania
page 61: EDF Paimpol–Bréhat, © openhydro.com
page 62: © Pieter de Haas, pdhaas@haske.net
page 63: Shutterstock, © Lukasz Siekierski; Shanghai, China
page 65: Shutterstock, © ArtisticPhoto
page 66: Shutterstock, © gyn9037
page 67: Shutterstock, © humphery; Jiujiang, East China
page 68: © Woody Welch 2015
page 69: © Solarcity, http://breakingenergy.com/2014/06/18/solarcity-buys-solar-maker-plans-massive-factory/
page 70: © Hanwha Q CELLS
page 71: Wikimedia Commons, © [[User:]]
page 72: KHI SOLAR ONE, www.planet.com; South Africa
page 75: www.solare-prozesswärme.info; Sahab, Jordania
page 76: © faisphoto
page 78: © Morten Kjerulff
page 78: Shutterstock, © John_T
page 80: afula chromagen.jpg
page 82: Shutterstock, © Ppictures; Oahu, Hawaii, USA
page 83: © Joachim Ladefoged
page 84: Shutterstock, © Aerovista Luchtfotografie; Volkerak, The Netherlands
page 85: © Michael Durham
page 86: Shutterstock, © biggunsband
page 87: Shutterstock, © Joao Wendel
page 88: Shutterstock, © Mimadeo
page 89: Shutterstock, © DJ Mattaar
page 89: © Nordex production line

PHOTO CREDITS

page 90: Shutterstock, © Stockr
page 96: Shutterstock, © Byelikova Oksana; Antenna in the Savannah, Maasai Mara National Park, Kenya
page 99: Shutterstock, © Michael Wick; Row of electricity pylons in the Namib desert, Namibia, Africa
page 99: Shutterstock, © Africa Rising; Energy efficient African small business barber with inverter and car batteries in trolley
page 99: Shutterstock, © TTphoto; Kenya
page 101: © SIMPA; https://cleantechnica.com/2015/06/09/simpa-networks-gets-renewable-energy-opic-impact-award/
page 101: Leparua, Kenya, Photo: Annie Bungeroth/CAFOD, May 2014
page 103: Shutterstock, © Clara_C; Traditional fire-cooking, Varanasi, India
page 103: Shutterstock, © Patryk Kosmider
page 103: Shutterstock, © IkeHayden
page 104: Biogas plant, https://synodbio-science.wordpress.com/tag/biogas-plant-in-bangalore/
page 104: Digester dome under construction, Wikimedia Commons, © SuSanA Secretariat; Navin Well-Field Area, Herat
page 105: © mobisol
page 106: Painting newly manufactured cook stoves, © Global Alliance for Clean Cookstoves
page 107: © M-Kopa Solar; Kenya
page 108: © M-Kopa Solar; Kenya
page 109: Mera Gao Power, India © National Geographic, Terra Watt Prize
page 110: High-voltage direct current converter tower, © Siemens AG; Nuremberg, Germany
page 111: © Klaus Leidorf, D-84172 Buch am Erlbach, www.leidorf.de
page 113: Shutterstock, © humphery; Jiujiang, East China
page 113: Shutterstock, © nuu_jeed; Khaokho, Thailand
page 118: BP Helios Plaza Trading Floor, © 2013 BP plc; Houston, Texas, United States
page 122: Shutterstock, © Aerovista Luchtfotografie; Eemshaven, The Netherlands
page 126: Solar Hot Water System, © Tatiana Chekryzhova
page 128: Shutterstock, © Feel good studio
page 129: Shutterstock, © Marcin-linfernum; Warsaw University, Poland
page 134: Portland General Electric's Salem Smart Power Center includes a large-scale energy storage system
page 136: © 2011 foto@luftbild-blossey.de
page 136: © 360PIXEL.DE
page 137: Staumauer Muttsee, © Fotowerder
page 137: Energy Storage, © Andy Clary
page 137: Electric vehicle charging station for home, Shutterstock, © Chesky
page 138: Staumauer Muttsee, © Fotowerder
page 138: Hydroelectric pumped storage river, Shutterstock, © Roman Rybaleov
page 141: Battery storage, © p2photography; California, Escondido
page 143: © Enno Friedrich; www.ef-artfoto.de
page 143: © Viessmann Werke
page 144: © Viessmann Werke
page 145: Shutterstock, © Philip Lange; Hannover, Germany
page 146: BYD E6 electric tax, © Stephen Edelstein, www.greencarreport.com; Shenzhen, China
page 146: Shutterstock, © Nadezda Murmakova, Czech Republic
page 148: Bidgely, California USA
page 157: Shutterstock, © Sarine Arslanian; Kampala, Uganda
page 158: SolarCarport, BMW Group Designworks, © BMW i; Malibu, United States
page 159: Shutterstock, © Frank Fennema
page 160: iStock, © Juan Enrique del Barrio Arri
page 222: Shutterstock, © Satit Soithongcharoen
page 223: Shutterstock, © MPSPhotography

GLOBAL OVERVIEW

1 Data for 2010-2014 from International Energy Agency (IEA), *World Energy Outlook 2016* (Paris: 2016), http://www.worldenergyoutlook.org/publications/weo-2016/.

2 Ibid.

3 Estimate for 2016 from Corinne Le Quere et al., "Global Carbon Project 2016", *Earth System Science Data*, vol. 8 (2016), pp. 605-49, http://www.earth-syst-sci-data.net/8/605/2016/essd-8-605-2016.pdf; estimate for the past decade from Ottmar Edenhofer et al., "Summary for Policy Makers", in Intergovernmental Panel on Climate Change, *Climate Change 2014: Mitigation of Climate Change* (New York and Cambridge, UK: Cambridge University Press, 2015), p. 7, https://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_summary-for-policymakers.pdf.

4 Scott Waldman, "Global carbon emissions have now been flat for 3 years", *E&E News*, 14 November 2016, http://www.eenews.net/climatewire/2016/11/14/stories/1060045682; IEA, "IEA finds CO2 emissions flat for third straight year even as global economy grew in 2016", 17 March 2017, http://www.iea.org/newsroom/news/2017/march/iea-finds-co2-emissions-flat-for-third-straight-year-even-as-global-economy-grew.html.

5 Enerdata, "Global Energy Statistical Yearbook 2016 – Coal and Lignite Production", https://yearbook.enerdata.net/coal-and-lignite-production.html, viewed 21 March 2017; Babs McHugh, "Japanese government planning to build 45 new coal fired power stations to diversify", *ABC News*, updated 31 January 2017, http://www.abc.net.au/news/2017-01-31/japan-coal-power-plants/8224302.

6 The Netherlands' commitment to reducing emissions 55% by 2030 may require closure of some of the country's remaining five coal-fired power stations, from Arthur Neslen, "Dutch parliament votes to close down country's coal industry", *The Guardian* (UK), 23 September 2016, https://www.theguardian.com/environment/2016/sep/23/dutch-parliament-votes-to-close-down-countrys-coal-industry; Canada has committed to eliminating coal use in the power sector by 2030, from "Canada set to phase out coal-fired power by 2030", *The Independent* (UK), 21 November 2016, http://www.independent.co.uk/news/world/americas/canada-renewable-energy-catherine-mckenna-coal-fired-power-2030-a7430471.html; Finland aims to phase out coal by 2030, from Alexandra Sims, "Finland plans to completely phase out coal by 2030", *The Independent* (UK), 25 November 2016, http://www.independent.co.uk/news/world/europe/finland-plans-completely-phase-out-coal-2030-a7438731.html; France has pledged to shut down all coal-fired power plants by 2023, from Charlotte England, "France to shut down all coal-fired power plants by 2023", *The Independent* (UK), 19 November 2016, http://www.independent.co.uk/news/world/europe/france-close-coal-plants-shut-down-2023-global-warming-climate-change-a7422966.html; Cassandra Profita, "Oregon utilities agree to phase out coal-fired power", Oregon Public Broadcasting, 6 January 2016, http://www.opb.org/news/article/utilities-agree-to-phase-out-coal-fired-power-in-oregon/; Marcelo Teixeira, "Brazil development bank scraps financing for coal-fired plants", *Reuters*, 3 October 2016, http://www.reuters.com/article/brazil-power-financing-idUSL2N1C913N.

7 McHugh, op. cit. note 5.

8 Oil prices and impact on renewable energy from IEA, *Medium-Term Renewable Energy Market Report 2016* (Paris: 2016), https://www.iea.org/newsroom/news/2016/october/medium-term-renewable-energy-market-report-2016.html; BP, "Natural gas prices", http://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/natural-gas/natural-gas-prices.html, viewed 3 May 2017.

9 Methodologies for quantifying total subsidies around the world vary, with the IEA (op. cit. note 1) estimating fossil fuel subsidies at USD 325 billion in 2015, whereas the International Monetary Fund (IMF), which seeks to include the cost of externalities in addition to direct payments, valued the combined subsidies for coal (USD 3.1 trillion), petroleum (USD 1.5 trillion), natural gas (USD 510 billion) and electricity rate subsidies for consumers (USD 148 billion) at an estimated USD 5.3 trillion in 2015; see David Coady et al., *How Large Are Global Energy Subsidies?* (Washington, DC: IMF, 2015), http://www.imf.org/~/media/Websites/IMF/Imported/external/pubs/ft/wp/2015/_wp15105pdf.ashx. By comparison, the IEA estimates renewable energy subsidies at USD 150 billion, from IEA, op. cit. note 1. Impacts on renewable energy from Richard Bridle and Lucy Kitson, *The Impact of Fossil-Fuel Subsidies on Renewable Electricity Generation* (Winnipeg, Canada: International Institute for Sustainable Development (IISD), December 2014), http://www.iisd.org/sites/default/files/publications/impact-fossil-fuel-subsidies-renewable-electricity-generation.pdf.

10 Ivetta Gerasimchuk, *Fossil-Fuel Subsidy Reform: Critical Mass for Critical Change* (Austin: University of Texas at Austin, 2015), www.stanleyfoundation.org/climatechange/Gerasimchuk-Fossil-FuelSubsidyReform.pdf.

11 IISD, Global Subsidies Initiative, "Tracking Progress: International Cooperation to Reform Fossil-Fuel Subsidies", http://www.iisd.org/gsi/tracking-progress-g-20-and-apec-commitments-reform, viewed 25 February 2017.

12 Data in text and **Figure 1** from estimated shares based on the following sources: total 2015 final energy consumption (estimated at 363.5 EJ) is based on 359.9 EJ for 2014 from International Energy Agency (IEA), *World Energy Statistics and Balances, 2016 edition* (Paris: OECD/IEA, 2016) and escalated by the 0.97% increase in global primary energy demand from 2014 to 2015, derived from BP, *Statistical Review of World Energy 2016* (London: 2016), http://www.bp.com/content/dam/bp/pdf/energy-economics/statistical-review-2016/bp-statistical-review-of-world-energy-2016-full-report.pdf. For bioenergy inputs, see Biomass Energy section and related endnotes in the Market and Industry Trends chapter. Solar PV generation of 285 TWh from IEA Photovoltaic Power System Programme (IEA PVPS), *Trends in Photovoltaic Applications 2016, Survey Report of Selected IEA Countries between 1992 and 2015* (Paris: 2016), Table 10, p. 65, http://www.iea-pvps.org/fileadmin/dam/public/report/national/Trends_2016_-_mr.pdf. Concentrated solar thermal power (CSP) estimated at 9.8 TWh, based on the reported output of Spain and the United States (8,385 GWh) and by applying their average capacity factor to remaining global CSP capacity of 667 MW. Spain's capacity based on data in CSP section of Market and Industry Trends chapter and related endnotes, and generation in 2015 from RED Eléctrica de España (REE), Statistical series of the Spanish electricity system, http://www.ree.es/en/statistical-data-of-spanish-electrical-system/national-indicators/national-indicators; US CSP capacity based on data from US Energy Information Administration (EIA), *Electric Power Monthly with Data for December 2016* (Washington, DC: February 2017), Table 6.2.B. Net Summer Capacity Using Primarily Renewable Energy Sources and by State, https://www.eia.gov/electricity/monthly/current_year/february2017.pdf; and US generation from EIA, op. cit. this note, Table 1.1.A. Net Generation from Renewable Sources: Total (All Sectors). Ocean energy of 1 TWh, from IEA, *Medium-Term Renewable Energy Market Report 2016*, (Paris: OECD/IEA, 2016), p. 174. Geothermal electricity generation of 78 TWh based on year-end capacity and global average capacity factor in 2014 from Ruggero Bertani, "Geothermal Power Generation in the World 2010-2014 Update Report," Proceedings of the World Geothermal Congress 2015 (Melbourne, Australia: 19–25 April 2015). Hydropower of 3,946 TWh from BP, *Statistical Review of World Energy 2016* (London: 2016). Solar thermal heating/cooling estimated at 1.28 EJ, from Monika Spörk-Dür, AEE-Institute for Sustainable Technologies (AEE INTEC), Gleisdorf, Austria, personal communications with Renewable Energy Network for the 21st Century (REN21), April 2017; Werner Weiss, Monika Spörk-Dür and Franz Mauthner, *Solar Heat Worldwide – Markets and Contribution to the Energy Supply 2015* (Gleisdorf, Austria: International Energy Agency (IEA) Solar Heating and Cooling Programme (SHC), forthcoming 2017), www.aee-intec.at/0uploads/dateien1252.pdf. Geothermal heat (excluding heat pumps) was estimated at 0.28 EJ, based on an extrapolation of 2014 values from John W. Lund and Tonya L. Boyd, "Direct Utilization of Geothermal Energy: 2015 Worldwide Review," in Proceedings of the World Geothermal Congress 2015 (Melbourne, Australia: 19–25 April 2015). Nuclear power final consumption based on generation of 2,577 TW, from BP, op. cit. this note (converted by source from primary energy on the basis of thermal equivalence, assuming 38% conversion efficiency), and global average electricity losses in 2014 from IEA, *World Energy Statistics and Balances, 2016 edition* (Paris: OECD/IEA, 2016). Methodology for Figure 1 differs from previous years in the application of estimated average system losses and estimates of the energy industry's own use of electricity from renewable sources. Previous versions of Figure 1 have discounted such losses but this version assumes an average combined reduction

of 7% when establishing renewable electricity consumption relative to gross generation estimates. This adjustment reduces the estimated contribution of renewable electricity in total final energy consumption.

13 **Figure 2** from all values derived from International Energy Agency (IEA), *World Energy Statistics and Balances*, 2016 edition (Paris: OECD/IEA, 2016). Consumption of traditional biomass based on the combined values for solid biomass and charcoal consumption in the residential sector of non-OECD countries. Consumption of renewable electricity is based on the share of renewables in global gross electricity generation. This results in the assumption that renewable electricity consumption is more than 16% lower than gross renewable electricity generation, due to system losses and the energy industry's own use. Industry own use includes the difference between gross and net generation at thermal power plants (the difference lies in the power consumption of various internal loads, such as fans, pumps and pollution controls at thermal plants), and other uses such as electricity use in coal mining and fossil fuel refining. This differs from the methodology applied in Figure 1, where system losses and energy industry's own use of renewable electricity is assumed to amount of 7% of gross renewable generation. Consumption of produced heat from renewable sources (from heat plants) is based on the renewable share of heat production in heat plants.

14 IEA, op. cit. note 8.

15 15 "China to slow green growth for first time after record boom", *Bloomberg*, 23 September 2016, http://www.bloomberg.com/news/articles/2016-09-22/china-to-rein-in-green-growth-for-first-time-after-record-boom.

16 25x'25, "U.S. continues to lead global Renewable Energy Attractiveness Index", Weekly REsource, 27 May 2016, http://www.25x25.org/index.php?option=com_content&task=view&id=1356&Itemid=246.

17 Zuzana Dubrotkova and Gevorg Sargsyan, World Bank, Washington, DC, personal communication with Renewable Energy Policy Network for the 21st Century (REN21), 8 December 2016.

18 Energy Institute, *Energy Barometer 2016* (London: 2016), https://www.energyinst.org/_uploads/documents/energy-barometer-2016.pdf; Lada Kochtcheeva, "Renewable Energy: Global Challenges", E-International Relations, 27 May 2016, http://www.e-ir.info/2016/05/27/renewable-energy-global-challenges/.

19 REN21 Policy Database.

20 United Nations Framework Convention on Climate Change (UNFCCC), "The Paris Agreement", http://unfccc.int/paris_agreement/items/9485.php, viewed 11 March 2017.

21 Heymi Bahar, IEA, Paris, personal communication with REN21, 28 November 2016.

22 Rainer Hinrichs-Rahlwes, European Renewable Energies Federation, Berlin, personal communication with REN21, 1 December 2016.

23 The Climate Vulnerable Forum comprises Afghanistan, Bangladesh, Barbados, Bhutan, Burkina Faso, Cambodia, Colombia, Comoros, Costa Rica, Democratic Republic of the Congo, Dominican Republic, Ethiopia, Fiji, The Gambia, Ghana, Grenada, Guatemala, Haiti, Honduras, Kenya, Kiribati, Lebanon, Madagascar, Malawi, Maldives, Marshall Islands, Mongolia, Morocco, Nepal, Niger, Palau, the State of Palestine, Papua New Guinea, Philippines, Rwanda, Saint Lucia, Samoa, Senegal, South Sudan, Sri Lanka, Sudan, Tanzania, Timor-Leste, Tunisia, Tuvalu, Vanuatu, Vietnam and Yemen. It is an international partnership of countries highly vulnerable to global climate change. Climate Vulnerable Forum, "The Climate Vulnerable Forum Vision", http://www.thecvf.org/marrakech-vision/, viewed 20 December 2016; Saleemul Huq, "Vulnerable countries take the lead in commitments", *Daily Star*, 30 November 2016, http://www.thedailystar.net/opinion/politics-climate-change/vulnerable-countries-take-the-lead-commitments-1322506.

24 World Trade Organization (WTO), "Progress made on Environmental Goods Agreement, setting stage for further talks", 4 December 2016, https://www.wto.org/english/news_e/news16_e/ega_04dec16_e.htm; "Key lawmaker, EU and industry all blame China for torpedoing EGA deal", *Daily News*, 7 December 2016, https://wtonewsstand.com/topic/environmental-goods-agreement.

25 **Figure 3** based on the following: World Bank, *State and Trends of Carbon Pricing* (Washington, DC: October 2016), p. 12, https://openknowledge.worldbank.org/bitstream/handle/10986/25160/9781464810015.pdf?sequence=3&isAllowed=y; European Commission, *The EU Emissions Trading System (EU ETS)* (Brussels: 2016), p. 1, https://ec.europa.eu/clima/sites/clima/files/factsheet_ets_en.pdf; International Carbon Action Partnership, *Emissions Trading Worldwide* (Berlin: 2016), pp. 22-23, https://icapcarbonaction.com/en/?option=com_attach&task=download&id=339; Government of Canada "Pan-Canadian Approach to Pricing Carbon Pollution", 3 October 2016, http://news.gc.ca/web/article-en.do?nid=1132169; Colombia from Juan Camilo Gómez Trillos, University of Oldenberg, personal communication with REN21, 3 May 2017.

26 IPCC, *Renewable Energy Sources and Climate Change Mitigation: Special Report of the Intergovernmental Panel on Climate Change* (Cambridge, UK: Cambridge University Press, 2012), https://www.ipcc.ch/pdf/special-reports/srren/SRREN_Full_Report.pdf. The current low carbon price under the European Emissions Trading Scheme has led many industry and government officials to suggest that the scheme has done little to incentivise the deployment of renewable technologies, from Robert Hodgson, "The price is right? Crunch time for EU carbon market reform", EurActiv, 13 February 2017, http://www.euractiv.com/section/energy/news/the-price-is-right-its-crunch-time-for-eu-carbon-market-reform/. At the same time, markets for some renewable heating and cooling technologies have grown following the implementation of well-designed carbon pricing mechanisms; for example, bioenergy heat grew substantially in Sweden after significantly high taxes were introduced, first on fossil fuels in the 1970s and then on carbon in the early 1990s, from Bengt Johansson et al., *The Use of Biomass for Energy in Sweden – Critical Factors and Lessons Learned* (Lund, Sweden: Lund University Department of Technology and Society, August 2002) http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/42/022/42022188.pdf.

27 International Renewable Energy Agency (IRENA), *Renewable Energy and Jobs – Annual Review 2017* (Abu Dhabi: 2017). **Sidebar 1** from idem.

28 See sources in Market and Industry Trends chapter.

29 Dubrotkova and Sargsyan, op. cit. note 17.

30 See Market and Industry Trends chapter, Reference Table R1 and related endnotes for details.

31 Ibid.

32 Based on renewable power capacity data provided in this report; on capacity additions for fossil fuels from Frankfurt School-UNEP Collaborating Centre for Climate & Sustainable Energy Finance and Bloomberg New Energy Finance (BNEF), *Global Trends in Renewable Energy Investment 2017* (Frankfurt: April 2017), pp. 32-33, http://fs-unep-centre.org/publications/global-trends-renewable-energy-investment-2016; and on nuclear power capacity data from International Atomic Energy Agency (IAEA), PRIS Database, "Nuclear Power Capacity Trends", http://www.iaea.org/pris/, updated 5 May 2017. Note that "some 87 GW" of coal-fired power capacity was added in 2016, but 33 GW was decommissioned, from Frankfurt School-UNEP Centre and BNEF, op. cit. this note, p. 33.

33 See Market and Industry Trends chapter, Reference Table R1 and related endnotes for details.

34 See, for example, past editions of this report and Frankfurt School-UNEP Centre and BNEF, op. cit. note 32, p. 33.

35 Share of net additions from an estimate of 61.9%, based on a total of approximately 161.1 GW of renewable capacity added (net), as noted in this report, and on assumed net additions of 99.3 GW nuclear and fossil fuel capacity, for a total of 260.43 GW of global net additions, of which renewables account for 61.9%. Nuclear and fossil fuel estimate based on the following: net capacity additions of 54 GW of coal and 37 GW of natural gas, from Frankfurt School-UNEP Centre and BNEF, op. cit. note 32, p. 33. Gross capacity additions of coal were "some 87 GW", from idem. Note that per BNEF, there also were net reductions in oil-fired generating capacity (totalling 9 GW) that are not included in these calculations, from Frankfurt School-UNEP Centre and BNEF, op. cit. note 32, p. 33. Net nuclear capacity increase of 8.33 GW based on year-end 2015 and year-end 2016 cumulative operational capacity, from IAEA, op. cit. note 32. See Reference Table R1, technology sections in Market and Industry Trends chapter and related endnotes for more detail on renewable power

generating capacity. Note that some hydropower capacity added may have been for refurbishment of existing plants; however, even omitting half of hydro capacity as net (replacement), the renewable energy share is approximately 60%.

36 Renewable share of total global electric generating capacity is based on an estimated renewable total approaching 2,017 GW at end-2016 (see Reference Table R1 and related endnote for details and sources) and on total global electric capacity in the range of 6,660.5 GW. Estimated total global capacity for end-2016 is based on 2015 total of 6,400 GW, from IEA, op. cit. note 1, p. 258; on nearly 260.5 GW of net power capacity additions in 2016, as outlined in endnote 35. Share of generation based on the following: Total global electricity generation in 2016 is estimated at 24,756 TWh, based on 24,098 TWh in 2015 from BP, *Statistical Review of World Energy 2016* (London: 2016), and an estimated 2.73% growth in global electricity generation for 2016. The growth rate is based on the weighted average actual change in total generation for the following countries (which together account for nearly two-thirds of global generation in 2015): United States (+0.03% net generation), EU-28 (+0.31%), Russian Federation (+2.1%), India (+6.49%), China (+5.6%) and Brazil (+1.33%). Sources for 2015 and 2016 total electricity generation by country are: US Energy Information Administration (EIA), *Electric Power Monthly with Data for December 2016* (Washington, DC: February 2017), Table 1.1; European Commission, Eurostat database, http://ec.europa.eu/eurostat; System Operator of the Unified Energy System of Russia, *Report on the Unified Energy System in 2016* (Moscow: 31 January 2017), http://www.so-ups.ru/fileadmin/files/company/reports/disclosure/2017/ups_rep2016.pdf; Government of India, Ministry of Power, Central Electricity Authority (CEA), "Monthly Generation Report," http://www.cea.nic.in/monthlyarchive.html; National Bureau of Statistics of China, "Statistical communiqué of the People's Republic of China on the 2016 national economic and social development", press release (Beijing: 28 February 2017), http://www.stats.gov.cn/english/PressRelease/201702/t20170228_1467503.html; National Electrical System Operator of Brazil (ONS), "Geração de Energia", http://www.ons.org.br/historico/geracao_energia.aspx. Hydropower generation in 2016 of 4,102 TWh from IHA, *2017 Key Trends in Hydropower*, op. cit. note 1. CSP estimated at 10.09 TWh, based on the reported output of Spain and the United States (totalling 8,460 GWh) and by applying their average capacity factor to remaining global CSP capacity of 777 MW. Spain's capacity based on data in CSP section of Market and Industry Trends chapter and related endnotes, and generation in 2016 from REE, "Statistical series of the Spanish electricity system", http://www.ree.es/en/statistical-data-of-spanish-electrical-system/national-indicators/national-indicators; US capacity from CSP section in Market and Industry Trends chapter and related endnotes, and from EIA, *Electric Power Monthly* (Washington, DC: February 2017), Table 6.2.B., http://www.eia.gov/electricity/monthly/pdf/epm.pdf; and US CSP generation from idem, Table 1.1.A. Sources for other renewable generation in 2016 are detailed by technology in the Market and Industry Trends chapter. **Figure 4** based on idem.

37 Rankings were determined by gathering data for over 70 countries based on the world's top countries for cumulative capacity of hydro, wind, solar PV, CSP, biomass, geothermal and ocean power. See Market and Industry Trends chapter and related endnotes for more detailed information. Country data from the following sources: **China:** Hydropower based on data from China National Energy Administration (CNEA), summary of national electric industry statistics for 2016, http://www.nea.gov.cn/2017-01/16/c_135986964.htm; capacity additions in 2016, including pumped storage, from China Electricity Council, annual report on national power system, 25 January 2017, http://www.cec.org.cn/yaowenkuaidi/2017-01-25/164285.html; capacity, including pumped storage, at year-end 2015 from CNEA, *13th Five-Year-Plan for Hydro Power Development* (Beijing: 29 November 2016), http://www.nea.gov.cn/135867663_14804701976251n.pdf. Wind power from Shi Pengfei, Chinese Wind Energy Association (CWEA), personal communication with REN21, 21 March 2017, and from Global Wind Energy Council (GWEC), *Global Wind Report – Annual Market Update 2016* (Brussels: April 2017), http://www.gwec.net/strong-outlook-for-wind-power/. Solar PV from Dazhong Xiao, "2016 photovoltaic power generation statistics", National Energy Board, 4 February 2017, http://www.nea.gov.cn/2017-02/04/c_136030860.htm (using Google Translate), and from IEA Photovoltaic Power Systems Programme (PVPS), *Snapshot of Global Photovoltaic Markets 2016* (Paris: April 2017), p. 15, http://iea-pvps.org/fileadmin/dam/public/report/statistics/IEA-PVPS_-_A_Snapshot_of_Global_PV_-_1992-2016__1_.pdf. Bio-power from IEA, op. cit. note 8, and from IRENA, *Renewable Capacity Statistics 2017* (Abu Dhabi: 2017), http://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Capacity_Statistics_2017.pdf. Geothermal power from CNEA, *13th Five-Year-Plan for Geothermal Power* (Beijing: 6 February 2017), http://www.nea.gov.cn/136035635_14863708180701n.pdf, provided by Frank Haugwitz, Asia Europe Clean Energy (Solar) Advisory Company, Ltd (AECEA), personal communication with REN21, February 2017. CSP from US National Renewable Energy Laboratory (NREL), "Concentrating solar power projects in China", http://www.nrel.gov/csp/solarpaces/by_country_detail.cfm/country=CN, updated 17 April 2017, and from CSP Today, "Projects Tracker", http://tracker.newenergyupdate.com/tracker/projects, viewed on numerous dates leading up to 27 March 2017; see CSP section in Market and Industry Trends chapter for more details. Ocean power from Ocean Energy Systems (OES), *Annual Report 2015* (Lisbon: April, 2016), https://www.ocean-energy-systems.org, and from IRENA, op. cit. this note. **United States:** Hydropower from US EIA, op. cit. note 36, Tables 6.2.B and 6.3; wind power from American Wind Energy Association (AWEA), AWEA U.S. *Wind Industry Annual Market Report Year Ending 2016* (Washington, DC: April 2017); solar PV from GTM Research, personal communication with REN21, 2 May 2017; biopower from US Federal Energy Regulatory Commission (FERC), Office of Energy Projects Energy Infrastructure, "Update for December 2016", https://www.ferc.gov/legal/staff-reports/2016/dec-energy-infrastructure.pdf; geothermal from US Geothermal Energy Agency (GEA), unpublished database, provided by Benjamin Matek, GEA, personal communication with REN21, 11 May 2016, and from EIA, op. cit. note 36, Table 6.2.B; CSP from NREL, "Concentrating solar power projects in the United States", https://www.nrel.gov/csp/solarpaces/by_country_detail.cfm/country=US, updated 14 April 2017, and from CSP Today, op. cit. this note, viewed on numerous dates leading up to 27 March 2017; ocean power from OES, op. cit. this note, and from IRENA, op. cit. this note. **Brazil:** Hydropower based on data from National Agency for Electrical Energy (ANEEL), "Resumo geral dos novos empreendimentos de geração", http://www.aneel.gov.br/documents/655816/15240845/Resumo_Geral_das_Usinas_abril_2017/289799f3-1f4c-8491-39f2-ba170ad8b37e, updated March 2017; wind power from Associação Brasileira de Energia Eólica (ABEEólica), "Dados Mensais", January 2017, http://www.abeeolica.org.br/wp-content/uploads/2017/01/Dados-Mensais-ABEEolica-01.2017-1.pdf, pp. 4, 6; solar PV from Ministério de Minas e Energia, Brasil, *Boletim Mensal de Monitoramento do Sistema Elétrico Brasileiro*, Dezembro 2016, provided by Arnaldo Vieira de Carvalho, Inter-American Development Bank, personal communication with REN21, 5 May 2017; bio-power from Empresa de Pesquisa Energética (EPE), *Brazilian Energy Balance 2016* (Rio de Janeiro: 2016), and from Ministério de Minas e Energia (MME), *Anuário Estatístico 2016* (Rio de Janeiro: EPE, 2016). **Germany:** Hydropower, wind power, solar PV, bio-power and geothermal power all from German Federal Ministry for Economic Affairs and Energy (BMWi), *Zeitreihen zur Entwicklung der erneuerbaren Energien in Deutschland, unter Verwendung von Daten der Arbeitsgruppe Erneuerbare Energien-Statistik (AGEEStat) (Stand: Februar 2017)*, p. 7, http://www.erneuerbare-energien.de/EE/Redaktion/DE/Downloads/zeitreihen-zur-entwicklung-der-erneuerbaren-energien-in-deutschland-1990-2016.pdf; CSP from NREL, "Concentrating solar power projects in Germany", http://www.nrel.gov/csp/solarpaces/by_country_detail.cfm/country=DE, updated 12 February 2013, and from CSP Today, op. cit. this note, viewed on numerous dates leading up to 27 March 2017. **Canada:** Hydropower based on data from Statistics Canada, Table 127-0009, "Installed generating capacity, by class of electricity producer", http://www5.statcan.gc.ca, from IHA, 2016 *Key Trends in Hydropower*, op. cit. note 1, IHA, personal communication, op. cit. note 1, and no evidence of capacity completed during 2016; wind power from Canadian Wind Energy Association (CanWEA), "Installed capacity", http://canwea.ca/wind-energy/installed-capacity/, viewed 17 February 2017; solar PV from IEA PVPS, op. cit. this note; bio-power from IEA, op. cit. note 8; CSP (pilot only) from NREL, "City of Medicine Hat ISCC Project", http://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=278, updated 3 August 2015, and from CSP Today, op. cit. this note, viewed on numerous dates leading up to 27 March 2017; ocean power from OES, op. cit. this note, and from IRENA, op. cit. this note.

38 China share and capacity data based on statistics and references provided elsewhere in this section, including endnote 37. See also Market and Industry Trends chapter and Reference Table R2.

39 Rankings for top countries for non-hydropower capacity based on data provided in endnote 37, and on the following: **Japan:** Hydropower based on data for 2015 from Institute for Sustainable Energy Policies (ISEP), *Renewables 2016 Japan Status Report* (Tokyo: 2016), http://www.isep.or.jp/en/jsr2016, and preliminary estimates for 2016 additions, provided by Hironao Matsubara, ISEP, personal communication with REN21, 13 April 2017; wind power from GWEC, op. cit. note 37; solar PV from IEA PVPS, op. cit. note 37, and from Gaëtan Masson, Becquerel Institute and IEA PVPS, personal communications with REN21, March-May 2016; bio-power from Japan Ministry of Economy Trade and Industry (METI), provided by Matsubara, op. cit. this note; geothermal power from ISEP, op. cit. this note. **India:** Hydropower based on data from Government of India, Ministry of Power, CEA, "All India installed capacity (in MW) of power stations", December 2016, http://www.cea.nic.in/reports/monthly/installedcapacity/2016/installed_capacity-12.pdf, from Government of India, CEA, "Executive summary of the power sector (monthly)", http://www.cea.nic.in/monthlyarchive.html, and from Government of India, Ministry of New and Renewable Energy (MNRE), "Physical progress (achievements)", http://www.mnre.gov.in/mission-and-vision-2/achievements/, viewed 19 January 2017; wind power from Government of India, Ministry of Power, CEA, "All India Installed Capacity, Monthly Report January 2017" (New Delhi: 2017), Table: "All India Installed Capacity (in MW) of Power Stations (As on 31.01.2017) (Utilities)", http://www.cea.nic.in/reports/monthly/installedcapacity/2017/installed_capacity-01.pdf, and from GWEC, op. cit. note 37; solar PV based on data from Government of India, MNRE, op. cit. this note, and from MNRE, ""Physical progress (achievements)", data as on 31 December 2015, viewed 1 February 2016; bio-power from MNRE, idem, and accounting for national CSP capacity at end-2016; CSP from NREL, "Concentrating solar power projects in India", http://www.nrel.gov/csp/solarpaces/by_country_detail.cfm/country=IN, updated 27 July 2015, from CSP Today, op. cit. note 37, viewed on numerous dates leading up to 27 March 2017, and from Heba Hashem, "India's PV-led solar growth casts eyes on performance of CSP projects", CSP Today, 9 November 2015, http://analysis.newenergyupdate.com/csp-today/markets/indias-pv-led-solar-growth-casts-eyes-performance-csp-projects. **Italy:** Hydropower from Gestore dei Servizi Energetici GSE S.p.A (GSE), *Rapporto Statistico, Energia da fonti rinnovabili in Italia, Anno 2015* (Rome: March 2017), http://www.gse.it/it/Statistiche/RapportiStatistici/Pagine/default.aspx; wind power from WindEurope, *Wind in Power 2016 European Statistics* (Brussels: 9 February 2017), https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Statistics-2016.pdf; solar PV from IEA PVPS, op. cit. note 37; bio-power from GSE, provided by Luca Benedetti, GSE, Rome, personal communication with REN21, 3 May 2017; geothermal power from GSE, *Rapporto Statistico, Energia da fonti rinnovabili in Italia, Anno 2015*, op. cit. this note; CSP (all pilots) from NREL, "Concentrating solar power projects in Italy", http://www.nrel.gov/csp/solarpaces/by_country_detail.cfm/country=IT, updated 16 February 2015, and from CSP Today, op. cit. note 37, viewed on numerous dates leading up to 27 March 2017; ocean power from IRENA, op. cit. note 37. **Spain:** Hydropower from Red Eléctrica de España (REE), "Potential instalada nacional (MW)", http://www.ree.es/en/statistical-data-of-spanish-electrical-system/national-indicators/national-indicators, viewed 18 April 2017; wind power from WindEurope, op. cit. this note, and from REE, op. cit. this note; solar PV from IEA PVPS, op. cit. note 37; bio-power from IEA, op. cit. note 8; ocean power from IRENA, op. cit. note 37. **United Kingdom:** Hydropower from UK Department for Business, Energy & Industrial Strategy, *National Statistics, Energy Trends Section 6: Renewables*, Table 6.1 "Renewable electricity capacity and generation", updated 30 March 2017, p. 69, https://www.gov.uk/government/statistics/energy-trends-section-6-renewables; wind power from WindEurope, op. cit. this note; solar PV from UK Department for Business, Energy & Industrial Strategy, "Solar Photovoltaics Deployment in the UK February 2017", updated 30 March 2017, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/585828/Solar_photovoltaics_deployment_March_2017.xlsx; bio-power from UK Department for Business, Energy & Industrial Strategy, *National Statistics, Energy Trends section 6: Renewables*, op. cit. this note; ocean power from IRENA, op. cit. note 37. **Figure 5** based on sources in this note and in endnote 37, and on global data available throughout this report, including Reference Tables R1 (and associated endnote) and R2, as well as on data for the following: **European Union** (EU-28): Hydropower from European Commission, Eurostat, Energy Database, http://ec.europa.eu/eurostat/web/energy/data/database, viewed May 2017; wind power from WindEurope, op. cit. this note; solar PV from Gaëtan Masson, IEA PVPS and Becquerel Institute, personal communication with REN21, 8 May 2017; bio-power from IEA, op. cit. note 8; geothermal from Eurostat, op. cit. this note; CSP from Luis Crespo, European Solar Thermal Electricity Association (ESTELA), Brussels, personal communication with REN21, 21 February 2016, REE, op. cit. this note, from NREL, "Concentrating solar power projects", http://www.nrel.gov/csp/solarpaces/, and from CSP Today, "Global Tracker", http://social.csptoday.com/tracker/projects, continuously updated and viewed on numerous occasions leading up to 27 March 2017; ocean power from IRENA, op. cit. note 37. **Russian Federation:** Hydropower from System Operator of the Unified Energy System of Russia, op. cit. note 36; wind power from WindEurope, op. cit. this note; solar PV from IRENA, op. cit. note 37; bio-power from IEA, op. cit. note 8; geothermal based on data from GEA, op. cit. this note; ocean power from IRENA, op. cit. note 37. **South Africa:** Hydropower from Hydro4Africa, "African Hydropower Database – South Africa", http://hydro4africa.net, viewed May 2017; wind power from GWEC, op. cit. note 37; solar PV from IEA PVPS, op. cit. note 37; bio-power from IEA, op. cit. note 8; CSP from CSP Today, op. cit. note 37, and from NREL, "Concentrating solar power projects by project name", http://www.nrel.gov/csp/solarpaces/by_project.cfm, viewed on numerous dates leading up to 27 March 2017.

40 Based on population data for 2015 from World Bank, "World Development Indicators – Population, Total", 2017, http://data.worldbank.org/indicator/SP.POP.TOTL, updated 23 March 2017, on data gathered from various sources for more than 70 countries, and on data and references provided elsewhere in this chapter, in Market and Industry Trends chapter and from the following: **Iceland:** Wind power from WindEurope, op. cit. note 39; solar PV from IRENA, op. cit. note 37; geothermal power from IEA Geothermal Implementing Agreement, *Annual Report 2015* (Paris: February 2017), http://iea-gia.org/wp-content/uploads/2017/02/2015-IEA-Geothermal-Annual-Report.pdf. **Denmark:** Wind power from WindEurope, op. cit. note 39; solar PV from IEA PVPS, op. cit. note 37; biopower based on IEA, op. cit. note 8, and on IRENA, op. cit. note 37. **Sweden:** Wind power from WindEurope, op. cit. note 39; solar PV from IEA PVPS, op. cit. note 37, p. 4; bio-power from IEA, op. cit. note 8; ocean power from OES, op. cit. note 37, and from IRENA, op. cit. note 37.

41 For wind power shares: Denmark from Energinet.dk, cited in David Weston, "Danish wind share falls in 2016", Windpower Monthly, 13 January 2017, http://www.windpowermonthly.com/article/1420900/danish-wind-sharefalls-2016; Ireland and Cyprus from WindEurope, op. cit. note 39, p. 21; Portugal from João Gomes, Associação Portuguesa de Energias Renováveis, personal communication with REN21, April 2017; Costa Rica from Instituto Costarricense de Electricidad, *Generación y Demanda Informe Annual Centro Nacional de Control de Energía, 2016* (San José: March 2017), p. 4, https://appcenter.grupoice.com/CenceWeb/CenceDescargaArchivos.jsf?init=true&categoria=3&codigoTipoArchivo=3008; see Wind Power section in Market and Industry Trends chapter for more details. Solar PV shares: Honduras from Empresa Nacional de Energía Eléctrica (ENEE), *Boletín Estadistíco Diciembre 2016* (Tegucigalpa: undated), p. 5, http://www.enee.hn/planificacion/2016/Boletines/BOLETIN%20%20DICIEMBRE%202016.pdf; Italy from Terna, *Rapporto mensile sul Sistema Elettrico* (Rome: December 2016), p. 13, http://download.terna.it/terna/0000/0893/13.PDF; Greece from Greek Operator for Electricity Market, Independent Power Transmission Operator, provided by Ioannis Tsipouridis, R.E.D. Pro Consultants S.A., Athens, personal communication with REN21, 21 April 2017; Germany from BMWi, op. cit. note 37, pp. 41-42.

42 Max Dupuy and Ranjit Bharvirkar "Renewables in China and India: how two Asian giants struggle with inflexible power system operations", Utility Dive, 26 April 2016, http://www.utilitydive.com/news/renewables-in-china-india-how-two-asian-giants-struggle-with-inflexible/418118/.

43 Arthur Neslen, "Wind power generates 140% of Denmark's electricity demand", *The Guardian* (UK), 10 July 2015,

https://www.theguardian.com/environment/2015/jul/10/denmark-wind-windfarm-power-exceed-electricity-demand; "Scotland's wind turbines cover all its electricity needs to one day", *The Guardian* (UK), 11 August 2016, https://www.theguardian.com/environment/2016/aug/11/scotland-completely-powered-by-wind-turbines-for-a-day.

44 Decreasing price as driver from Dubrotkova and Sargsyan, op. cit. note 17.

45 Lazard, "Levelized cost of energy analysis – Version 10.0", December 2016, https://www.lazard.com/media/438038/levelized-cost-of-energy-v100.pdf.

46 GWEC, *Global Wind Report 2016 – Annual Market Update* (Brussels: April 2017), http://www.gwec.net/strong-outlook-for-wind-power/, p. 21.

47 Dubrotkova and Sargsyan, op. cit. note 17.

48 See Policy Landscape chapter and associated references.

49 See sources in Market and Industry Trends chapter. See also Dupuy and Bharvirkar, op. cit. note 42, and Ryan Woo, "China's solar power capacity more than doubles in 2016", *Reuters*, 4 February 2017, http://www.reuters.com/article/us-china-solar-idUSKBN15J0G7.

50 Xiao, op. cit. note 37.

51 Curtailment values for 2015 from Dupuy and Bharvirkar, op. cit. note 42.

52 IEA, op. cit. note 8.

53 Kaavya Chandrasekaran, "Capacity for renewable energy in India hits 42,850 MW; surpasses capacity of hydro projects", *Economic Times*, 10 June 2016, http://economictimes.indiatimes.com/industry/energy/power/capacityfor-renewable-energy-in-india-hits-42850-mw-surpasses-capacity-of-hydel-projects/articleshow/52680042.cms; bio-power generation from Government of India, MNRE "Physical progress (achievements) for 2015 and 2016", http://www.mnre.gov.in/mission-and-vision-2/achievements, viewed 19 January 2017.

54 For more information and references, see Geothermal Power and Heat text and related endnotes in Market and Industry Trends chapter.

55 WindEurope, op. cit. note 39, p. 6.

56 Tenders are envisioned to be on a technology-neutral basis and open to bids from neighbouring countries, from Hinrichs-Rahlwes, op. cit. note 22.

57 EIA, *Electric Power Monthly*, February 2017, Tables 1.1 and 1.1A, https://www.eia.gov/electricity/monthly/current_year/february2017.pdf.

58 EIA, *Electric Power Monthly*, "Net Generation from Renewable Sources: 2007-January 2017", January 2017, https://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_1_01_a.

59 EIA, *Electric Power Monthly*, "Electric Generating Summer Capacity Changes (MW)", January 2017, https://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_6_01.

60 Tatiana Schlossberg, "America's first offshore wind farm spins to life", *New York Times*, 14 December 2016, https://www.nytimes.com/2016/12/14/science/wind-power-block-island.html.

61 Generation values are for 2015. *Canada National Energy Board, Canada's Renewable Power Landscape* (Ottawa: October 2016), p. 8, https://www.neb-one.gc.ca/nrg/sttstc/lctrct/rprt/2016cndrnwblpwr/index-eng.html; CanWEA, "Wind energy in Canada", http://canwea.ca/wind-energy/installed-capacity/, viewed 26 March 2017.

62 Honduras from ENEE, op. cit. note 41, p. 5; Uruguay Secretary of Energy, Ministry of Industry, Energy and Mining, *Balance Energético Preliminar 2016* (Montevideo: 2017), http://www.dne.gub.uy/web/energia/-/balance-energetico-nacion-1.

63 Diego Acevedo, Bluerise BV, Delft, the Netherlands, personal communication with REN21, 5 May 2017.

64 See sources in Market and Industry Trends chapter. See also Brian Gaylord, "Brazilian auction cancellation is understandable yet inadvisable", MAKE, https://www.linkedin.com/pulse/brazilian-auction-cancellation-understandable-yet-still-brian-gaylord, viewed 31 March 2017.

65 IRENA, *Renewable Energy in the Arab Region: Overview of Developments* (Abu Dhabi: 2016), p. 9, http://www.irena.org/DocumentDownloads/Publications/IRENA_Arab_Region_Overview_2016.pdf.

66 Leaders in Africa from IRENA, op. cit. note 37, p. 12; share of capacity from GreenCape, *Utility-scale Renewable Energy – 2017 Market Intelligence Report* (Cape Town: 2017), p. 12, http://www.greencape.co.za/assets/Uploads/GreenCape-Renewable-Energy-MIR-2017-electronic-FINAL-v1.pdf.

67 See sources in Solar PV and Wind Power sections in Market and Industry Trends chapter. CSP from CSP Today, "Projects Tracker", op. cit. note 37.

68 For more information and sources, see Solar PV and Geothermal Power and Heat sections in Market and Industry Trends chapter.

69 See, for example, Rusumo Project, "Groundbreaking ceremony of Rusumo Dam construction", 21 March 2017, http://rusumoproject.org/index.php/en/news-events/232-ground-breaking-ceremony, and Michael Harris, "AfDB announces financing for 147 MW Ruzizi 3 hydropower plant", HydroWorld, 22 March 2016, http://www.hydroworld.com/articles/2016/03/afdb-announces-financing-for-147-mw-ruzizi-3-hydropower-plant.html.

70 Clean Energy Council, *Progress and Status of the Renewable Energy Target* (Melbourne: June 2016), p. 6, https://www.cleanenergycouncil.org.au/dam/cec/policy-and-advocacy/reports/2016/renewable-energy-target-progress-report.pdf. See also sources in Solar PV section in Market and Industry Trends chapter.

71 See text and sources in Market and Industry Trends chapter, and IRENA, op. cit. note 65, p. 12.

72 See Solar PV text and sources in Market and Industry Trends chapter.

73 See sources in Solar PV, Wind and CSP sections in Market and Industry Trends chapter.

74 United States from Peter Kelly-Detwiler, "The morphing role of the electric utility: investors in the change to come", *Forbes*, 28 July 2016, https://www.forbes.com/sites/peterdetwiler/2016/07/28/the-morphing-role-of-the-electric-utility-investors-in-the-change-to-come/#43c2f3aa1985; Germany from Sam Pothecary, "RWE to acquire PV and storage specialist Belectric Solar & Battery", *PV Magazine*, 29 August 2016, https://www.pv-magazine.com/2016/08/29/rwe-to-acquire-pv-and-storage-specialist-belectric-solar-battery_100025933/; Liam Stoker, "Innogy completes purchase of Belectric Solar & Battery", PV-Tech, 4 January 2017, https://www.pv-tech.org/news/innogy-completes-purchase-of-belectric-solar-battery; China from Frank Haugwitz, AECEA, personal communication with REN21, 3 May 2017; Susan Kraemer, "$100 billion now building Indian clean energy", Renewable Energy World, 2 August 2016, http://www.renewableenergyworld.com/articles/2016/08/100-billion-now-building-indian-clean-energy.html; Sweden and Denmark from Susan Kraemer, "Scandanavian offshore wind nixed due to Russian threat", Renewable Energy World, 26 January 2017, http://www.renewableenergyworld.com/articles/2017/01/scandinavian-offshore-wind-nixed-due-to-russian-threat.html.

75 Fossil fuel companies from Mikael Holter, "Statoil buys half of $1.4 billion EON German wind project", Renewable Energy World, 25 April 2016, http://www.renewableenergyworld.com/articles/2016/04/statoil-buys-half-of-1-4-billion-eon-german-wind-project.html, from William Steel, "Wärtsilä diversifies into solar PV", Renewable Energy World, 3 May 2016, http://www.renewableenergyworld.com/articles/2016/05/wartsila-diversifies-into-solar-pv.html, and from "Oil giants ENI, Sonatrach to develop solar in Algeria", PV Insider, 27 September 2016, http://analysis.pv-insider.com/solar-dominate-us-renewables-2021-africa-pv-plant-costs-drop-61; nuclear power from Barry O'Halloran, "Gaelectric sells wind farms to China General Nuclear Power", *Irish Times*, 7 December 2016, http://www.irishtimes.com/business/energy-and-resources/gaelectric-sells-wind-farmsto-china-general-nuclear-power-1.2897059; Rosatom from FTI Consulting, *Global Wind Market Update – Demand & Supply 2016 Part Two – Demand Side Analysis* (London: 2016), p. 18.

76 RE 100, *Accelerating Change: How Corporate Users Are Transforming the Renewable Energy Market, RE 100 Annual Report 2017* (London: The Climate Group, 2017), p. 3, http://media.virbcdn.com/files/a9/55845b630b54f906-RE100AnnualReport2017.pdf.

77 David Ferris, "Big business likes wind power, study finds", *E&E News*, 19 October 2016, http://www.eenews.net/energywire/2016/10/19/stories/1060044490; Elaine Hsieh, "Corporate clean energy deals are a bigger priority than ever", GreenBiz, 27 February 2017, https://www.greenbiz.com/article/corporate-clean-energy-deals-are-bigger-priority-ever.

78 DLA Piper, *2016: The Year of PPAs and the Corporate Green Agenda*, 2016, p. 6, https://www.dlapiper.com/~/media/Files/Insights/Publications/2016/06/PPA_Paper_Energy_2016_updated.pdf. For example, Microsoft, building on previous agreements to purchase wind energy, announced its largest purchase to date in 2016 for 237 MW of wind energy from new wind farms in the US states of Kansas and Wyoming, from Microsoft, "Microsoft announces largest wind energy purchase to date", press release (Redmond, WA: 14 November 2016), https://news.microsoft.com/2016/11/14/microsoft-announces-largest-wind-energy-purchase-to-date/; Google progressed on its 2015 commitment to 100% renewable power by means of direct purchase from developers and from partnerships with utilities – the company is now committed to 2.6 GW of wind and solar power, from RE 100, "Google set to reach 100% renewable electricity", 6 December 2016, http://there100.org/news/14239851; other new agreements were signed by General Motors (for 6% of its electricity demand to be supplied by a wind farm in Texas by 2018) and Nestlé (for 125 GWh annually from a wind farm in Scotland beginning in 2017), from General Motors, "GM makes its largest green energy purchase to date", press release (Detroit, MI: 16 November 2016), http://media.gm.com/media/us/en/gm/news.detail.html/content/Pages/news/us/en/2016/nov/1116-green.html, and from Nestlé, "Brand new Scottish wind farm to power Nestlé UK and Ireland's operations", press release (Gatwick, UK: 22 June 2016), http://www.nestle.co.uk/media/pressreleases/Wind-Farm-in-Scotland-to-Power-Nestles-Operations.

79 Frankfurt School–UNEP Centre and BNEF, op. cit. note 32.

80 Jelte Harnmeijer, Scene Consulting, personal communication with REN21, 6 February 2017.

81 Oxford Community Energy Cooperative, "Oxford Community Energy Co-operative announces Gunn's Hill Wind Farm has reached commercial operation", http://www.oxford-cec.ca/, viewed 7 March 2017; Anna Leidreiter, World Future Council, Hamburg, personal communication with REN21, 2 March 2017.

82 Ibid.; Leidreiter, op. cit. note 81. Community energy projects are particularly susceptible to the increased risks that accompany most tendering mechanisms, which tend to disproportionately benefit large-scale developers with diversified portfolios, from Harnmeijer, op. cit. note 80.

83 Harnmeijer, op. cit. note 80; Rebecca Harvey, "80% drop in community owned energy following government uturns", *Co-operative News*, 7 September 2016, http://www.thenews.coop/108761/news/co-operatives/80-drop-community-owned-energy-following-government-u-turns/.

84 Shota Furuya, ISEP, personal communication with REN21, 13 March 2017.

85 Harnmeijer, op. cit. note 80.

86 Ibid.

87 Hinrichs-Rahlwes, op. cit. note 22.

88 Ibid.

89 Maria Gallucci, "The new green grid: utilities deploy 'virtual power plants'", *Yale e360*, 1 August 2016, http://e360.yale.edu/features/virtual_power_plants_aliso_canyon.

90 Holger Schneidewindt, Consumer Association of North Rhine-Westphalia (Germany), personal communication with REN21, 31 January 2017; Holger Schneidewindt, "Blockchain – brave new world for prosumers?", *Erneuebare Energien*, 21 September 2016, http://www.erneuerbareenergien.de/blockchain-brave-new-energy-world-for-prosumers/150/437/97962.

91 Richard Martin, "Renewable energy trading launched in Germany", *MIT Technology Review*, 29 December 2015, https://www.technologyreview.com/s/544471/renewable-energy-trading-launched-in-germany/.

92 Schneidewindt, personal communication, op. cit. note 90; Michael Fuhs, "More revenue for storage system owners", *PV Magazine*, 6 February 2017, https://www.pv-magazine.com/magazine-archive/more-revenue-for-storage-system-owners/; Robert Walton, "Vermont utility teams with Tesla to offer home battery installment plan", Utility Dive, 7 December 2015, http://www.utilitydive.com/news/vermont-utility-teams-with-tesla-to-offer-home-battery-installment-plan/410357/.

93 Frankfurt School-UNEP Centre and BNEF, op. cit. note 32, p. 44; Ian Clover, "Wind company Suzlon enters India solar market with 210 MW project", *PV Magazine*, 13 January 2016, https://www.pv-magazine.com/2016/01/13/wind-company-suzlon-enters-india-solar-market-with-210-mw-project_100022766/; Anindya Upadhyay, "Hybrid solar and wind systems attract turbine makers in India", *Bloomberg*, 5 September 2016, https://www.bloomberg.com/news/articles/2016-09-05/hybrid-solar-and-wind-systems-attract-turbine-makers-in-india.

94 Ibid., p. 45.

95 In **Asia,** for example, a memorandum was signed by China, the Russian Federation, the Republic of Korea and Japanese partners to begin investigating the possibility for an Asian super-grid, from Andy Colthorpe, "Asian Super Grid gets support from China, Russia, S. Korea and Japan", PV-Tech, 31 March 2016, http://www.pv-tech.org/news/asian-super-grid-could-get-go-ahead-after-china-and-russias-grid-operators. In **Africa,** planning continued for the Clean Energy Corridor, which aims to develop renewable energy projects and cross-border trade of renewable power across 20 countries stretching from Egypt to South Africa (participating countries include Angola, Botswana, Burundi, the Democratic Republic of Congo, Djibouti, Egypt, Ethiopia, Kenya, Lesotho, Malawi, Mozambique, Namibia, Rwanda, South Africa, Sudan, Swaziland, Uganda, the United Republic of Tanzania, Zambia, and Zimbabwe), from Climate Summit 2014, "Africa Clean Energy Corridor – Action Statement and Action Plan" (New York: United Nations, 23 September 2014), http://www.un.org/climatechange/summit/wp-content/uploads/sites/2/2014/09/ENERGY-Africa-Clean-Energy-Corridor.pdf. In **South America**, steps were taken during the year to connect Brazil and Uruguay's electric grids, and investigation began of an interconnected grid across the Arco Norte region of South America in part to encourage renewable energy development, from Power Technology.com, "GE commissions HVDC converter station to interconnect networks in Brazil and Uruguay", 2 September 2016, http://www.power-technology.com/news/newsge-commissions-hvdc-converter-station-to-interconnect-brazil-and-uruguays-power-networks-4995323, and from Sylvia Virginia Larrea et al., *Arco Norte Electrical Interconnection Study* (Washington, DC: Inter-American Development Bank, July 2016), https://publications.iadb.org/handle/11319/7789.

96 Saurabh Mahapatra, "ADB lends India $1 billion for renewable energy transmission network", CleanTechnica, 11 December 2015, https://cleantechnica.com/2015/12/11/adb-lends-india-1-billion-renewable-energy-transmission-network/; Ilias Tsagas, "Jordan to upgrade its network: accommodate more renewables", *PV Magazine*, 30 October 2015, https://www.pv-magazine.com/2015/10/30/jordan-to-upgrade-its-network-accommodate-more-renewables_100021799/. China diverted some investment in 2016, from Julia Pyper, "Global clean energy investment fell 18% in 2016 with slowdown in China", Greentech Media, 12 January 2017, https://www.greentechmedia.com/articles/read/global-clean-energy-investment-dropped-18-in-2016-with-slowdown-from-china; through 2020 from Michael Torsythe, "China aims to spend at least $360 billion on renewable energy by 2020", *New York Times*, 5 January 2017, https://www.nytimes.com/2017/01/05/world/asia/china-renewable-energy-investment.html.

97 Energy access value from 2014, from IEA, "Chapter 2 Extract: Energy Access", in *World Energy Outlook* 2016, op. cit. note 1, pp. 92-93; attractiveness of DRE projects from Ashwin Gambhir, Vishal Toro and Mahalakshmi Ganapathy, *Decentralised Renewable Energy (DRE) Micro-grids in India: A Review of Recent Literature* (Pune, India: Prayas Energy Group, 2012), www.vikalpsangam.org/static/media/uploads/Resources/decentralised_renewable_energy_dre_micro_grids_in_india.pdf.

98 See sources in Distributed Renewable Energy chapter.

99 IRENA, *REthinking Energy 2017* (Abu Dhabi: 2017), p. 39, http://www.irena.org/DocumentDownloads/Publications/IRENA_REthinking_Energy_2017.pdf; Ernesto Macías Galan, SolarWatt, Dresden, Germany, personal communication with REN21, 30 January 2017.

100 Ibid., both references.

101 IEA, op. cit. note 8, p. 214.

102 Ibid., p. 215.

103 Ibid., pp. 214 and 218.

104 Ibid., p. 214. Gaining shares based on an assumption that the 2.3% increase in growth rate of modern renewable energy surpasses the 1% increase in the overall consumption of heat.

105 Ibid., p. 214.
106 Ibid., p. 216.
107 Data are for 2014, from IEA, op. cit. note 8, p. 214.
108 See Biomass Energy section in Market and Industry Trends chapter. Based on analysis of data for contribution of wastes and biomass to industrial final energy contribution from 2009 to 2014, in IEA, *World Energy Outlook* (Paris: 2011-2016 editions), Annex A, "World New Policy Scenario".
109 Werner Weiss, Institute for Sustainable Technologies (AEE INTEC), Gleisdorf, Austria, personal communication with REN21, 31 January 2017; Bärbel Epp, "Miraah in Oman: 'ahead of schedule and under budget'" solarthermalworld, 25 March 2017, http://www.solarthermalworld.org/content/miraah-oman-ahead-schedule-and-under-budget; GlassPoint, "Miraah", https://www.glasspoint.com/miraah/, viewed 22 February 2017.
110 IRENA, *Renewable Energy in District Heating and Cooling* (Abu Dhabi: March 2017), p. 12, http://www.irena.org/DocumentDownloads/Publications/IRENA_REmap_DHC_Report_2017.pdf.
111 Bärbel Epp, "Denmark: New solar district heating world record", solarthermalworld, 26 January 2017, http://www.solarthermalworld.org/content/denmark-new-solar-district-heating-world-record; Weiss, op. cit. note 109.
112 Bärbel Epp, "Germany: First record-size solar district heating plant in 11 years", solarthermalworld, 27 September 2016, http://www.solarthermalworld.org/content/germany-first-record-size-solar-district-heating-plant-11-years; Riccardo Battisti, "Poland: Solar for more efficient district heating networks", solarthermalworld, 30 March 2017, http://www.solarthermalworld.org/content/poland-solar-more-efficient-district-heating-networks; Daniel Trier, PlanEnergi, Copenhagen, Denmark, personal communication with REN21, April 2017.
113 Philippe Dumas, European Geothermal Energy Council (EGEC), personal communication with REN21, March-May 2017. For more information see Geothermal Power and Heat section in Market and Industry Trends chapter.
114 Definition from Henrik Lund et al., "4th Generation District Heating (4GDH): Integrating smart thermal grids into future sustainable energy systems", *Energy*, vol. 68 (15 April 2014), pp. 1-11, http://www.sciencedirect.com/science/article/pii/S0360544214002369; trends from Miika Rama, VTT Technical Research Centre of Finland Ltd., personal communication with REN21, 16 March 2017.
115 Data are for 2014, from IEA, op. cit. note 8; Weiss, op. cit. note 109.
116 Weiss, op. cit. note 109.
117 Ibid.
118 Rama, op. cit. note 114.
119 Weiss, op. cit. note 109.
120 Ibid.
121 Gerhard Stryi-Hipp, Fraunhofer Institute for Solar Energy Systems, personal communication with REN21, 28 March 2017.
122 Ibid.
123 Ibid.
124 Ibid.
125 David Appleyard, "Hybrid solar thermal-heat pump on trial", Renewable Energy Focus, 31 August 2016, http://www.renewableenergyfocus.com/view/44671/hybrid-solar-thermal-heat-pump-on-trial/.
126 IEA, op. cit. note 8, p. 215.
127 IEA Task 53, "2015 Highlights", http://task53.iea-shc.org/data/sites/1/publications/IEA-SHC-Task53-Highlights-2015.pdf, viewed 21 March 2017; IEA Task 53, "The Future of Solar Cooling", *SHC Solar Update*, May 2016, http://task53.iea-shc.org/data/sites/1/publications/2016-05-Task53-The%20Future%20of%20Solar%20Cooling.pdf.
128 For more information and references see Solar Thermal Heating and Cooling section in Market and Industry Trends chapter.
129 Stryi-Hipp, op. cit. note 121.
130 IEA Task 53, "2015 Highlights", op. cit. note 127.
131 IEA, op. cit. note 8, p. 219.
132 Weiss, op. cit. note 109.
133 IRENA, op. cit. note 110, p. 16.
134 IEA, op. cit. note 8, p. 220.
135 Bärbel Epp, solrico, personal communication with REN21, 25 March 2017.
136 Data are for 2014; see sources for Reference Table R11.
137 IEA, op. cit. note 8, p. 214.
138 Share of renewable heating and cooling are 2015 data from Simas Gerdvila, Euroheat & Power, personal communication with REN21, 14 April 2017; growth rate from European Environment Agency (EEA), *Renewable Energy in Europe 2016* (Luxembourg: 2016), http://www.eea.europa.eu/publications/renewable-energy-in-europe-2017.
139 Share from BMWi, *Development of Renewable Energy Sources in Germany 2016* (Berlin: February 2017), http://www.erneuerbare-energien.de/EE/Redaktion/DE/Downloads/development-of-renewable-energy-sources-in-germany-2016.pdf; generation from BMWi, *Zeitreihen zur Entwicklung der erneuerbaren Energien in Deutschland* (Berlin: February 2017), p. 8, http://www.erneuerbare-energien.de/EE/Redaktion/DE/Downloads/zeitreihen-zur-entwicklung-der-erneuerbaren-energien-in-deutschland-1990-2016.pdf?__blob=publicationFile&v=12.
140 Share from EEA, op. cit. note 138; generation values are 2013 data from Swedish Energy Agency, *Energy in Sweden 2015* (Stockholm: December 2015), p. 17, https://energimyndigheten.a-w2m.se/Home.mvc?ResourceId=5545.
141 Ends Waste & Bioenergy, "Danish district heating sector consolidating", 16 February 2017, http://www.endswasteandbioenergy.com/article/1424485/danish-district-heating-sector-consolidating; solar thermal from Thomas Pauschinger, SDHptm Project, personal communication with REN21, 14 April 2017.
142 IEA, op. cit. note 8, p. 214.
143 Val Stori, Clean Energy Group, personal communication with REN21, 17 March 2017.
144 Ibid.
145 IEA, op. cit. note 8, p. 220.
146 IRENA, *Renewable Energy Market Analysis: Latin America* (Abu Dhabi: 2016), p. 54, http://www.irena.org/DocumentDownloads/Publications/IRENA_Market_Analysis_Latin_America_2016.pdf.
147 Ibid., p. 56.
148 Bärbel Epp, solrico, personal communication with REN21, 24 April 2016.
149 IEA, op. cit. note 8, p. 216. Population share data are from 2014.
150 Epp, op. cit. note 148.
151 South Africa from IEA, op. cit. note 8, p. 237; Tunisia from Epp, op. cit. note 148.
152 Sekem, "Promoting alternative energies: new solar station for SEKEMs medical center", 5 December 2016, http://www.sekem.com/en/promoting-alternative-energies-new-solar-station-for-sekems-medical-center/.
153 Bärbel Epp, "Austria: Tisun sees rising interest in solar thermal in Gulf Region", solarthermalworld, 24 January 2017, http://www.solarthermalworld.org/content/austria-tisun-sees-rising-interest-solar-thermal-gulf-region; Bärbel Epp, "Oman: Construction starts for world's largest solar steam power plant Miraah", solarthermalworld, 20 April 2016, http://www.solarthermalworld.org/content/oman-construction-starts-worlds-largest-solar-steampower-plant-miraah.
154 Bärbel Epp, "Dubai: No solar thermal system, no building permit", solarthermalworld, 4 September 2016, http://www.solarthermalworld.org/content/dubai-no-solar-thermal-system-no-building-permit.
155 Salman Zafar, "Solar energy in Jordan", EcoMENA, 30 March 2016, http://www.ecomena.org/solar-energy-jordan/.
156 Stryi-Hipp, op. cit. note 121.
157 In Africa, for example, the NDCs of Malawi, Tunisia and Zimbabwe specifically mention solar water heaters, and Seychelles has set targets for renewable household heating more broadly, from Miquel Muñoz Cabré and Youba Sokona, *Renewable Energy Investment in Africa and Nationally Determined Contributions*, Global Economic Governance Initiative Working Paper 10, November 2016, pp. 8-13, https://www.bu.edu/pardeeschool/files/2016/11/RE-NDC-Africa_Final.pdf; European Commission,

"Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources (recast)" (Brussels: 30 November 2016), pp. 6-7, https://ec.europa.eu/transparency/regdoc/rep/1/2016/EN/COM-2016-767-F1-EN-MAIN.PDF.

158 Rama, op. cit. note 114.

159 Growth rate and emissions from IEA, *Energy Technology Perspectives 2016* (Paris: 2016), http://www.iea.org/etp/; share of overall energy consumption value for 2014 from IEA, *Key World Energy Trends* (Paris: 2016), p. 6.

160 IEA, op. cit. note 8.

161 Data are from 2015, from IEA, *Energy Technology Perspectives 2016*, op. cit. note 159.

162 F.O. Licht, "Fuel Ethanol: World Production by Country", 2017. With permission from F.O. Licht/Licht Interactive Data.

163 F.O. Licht, "Biodiesel: World Production, by Country", 2017. With permission from F.O. Licht/Licht Interactive Data.

164 IRENA, *Biogas for Road Vehicles Technology Brief* (Abu Dhabi: March 2017), p. 2, http://www.irena.org/DocumentDownloads/Publications/IRENA_Biogas_for_Road_Vehicles_2017.pdf.

165 Ibid., p. 24.

166 Ibid., p. 2.

167 Heather Allen, Partnership on Sustainable, Low Carbon Transport (SLoCaT), personal communication with REN21, 5 December 2016.

168 "China plans for solar-powered cars", *E&E News*, 6 July 2016, http://www.eenews.net/climatewire/2016/07/06/stories/1060039807; Brian Publicover, "Toyota debuts new Prius with rooftop PV option in Japan", *PV Magazine*, 21 February 2017, https://www.pv-magazine.com/2017/02/21/toyota-debuts-new-prius-with-rooftop-pv-option-in-japan/; "Uganda launches Africa's first solar-powered bus", ESI Africa, 4 August 2016, https://www.esi-africa.com/news/uganda-launches-africas-first-solar-powered-bus/.

169 David Block and Paul Brooker, *2015 Electric Vehicle Market Summary and Barriers* (Orlando, FL: Electric Vehicle Transportation Center, June 2016), http://www.fsec.ucf.edu/en/publications/pdf/FSEC-CR-2027-16.pdf; Allen, op. cit. note 167.

170 Allen, op. cit. note 167.

171 IEA, op. cit. note 8, p. 104.

172 F.O. Licht, op. cit. note 162; F.O. Licht, op. cit. note 163. US Environmental Protection Agency, "Renewable Fuel Standard (RFS2) Final Rule", https://www.epa.gov/renewable-fuel-standard-program/renewable-fuel-standard-rfs2-final-rule, viewed 8 May 2017.

173 IRENA, op. cit. note 164, p. 2.

174 "RNG-Biomethane-BioCNG-BioLNG: World Biogas Association formed", NGV Global News, 25 November 2016, http://www.ngvglobal.com/blog/rng-biomethane-biocng-biolng-world-biogas-association-formed-1125#more-44511.

175 EV-Volumes, "Global Plug-in Sales for 2016", http://www.ev-volumes.com/country/total-world-plug-in-vehicle-volumes/, viewed 13 March 2017; US Department of Energy, Alternative Fuels Data Center, http://www.afdc.energy.gov/, viewed 8 March 2017. See Electric Vehicle section in Enabling Technologies chapter.

176 F.O. Licht, op. cit. note 162; Matthew Stevens, "Electric vehicle sales in Canada: 2016 final update", EV Industry, 8 February 2017, http://www.fleetcarma.com/ev-sales-canada-2016-final/.

177 F.O. Licht, op. cit. note 162; F.O. Licht, op. cit. note 163.

178 F.O. Licht, op. cit. note 162.

179 Ibid.; F.O. Licht, op. cit. note 163.

180 EV Sales, "Markets Roundup October 2016", 29 November 2016, http://ev-sales.blogspot.de/2016/11/markets-roundup-october-2016.html.

181 IRENA, op. cit. note 164, p. 2.

182 Hinrichs-Rahlwes, op. cit. note 22.

183 F.O. Licht, op. cit. note 162.

184 European Biogas Association, *EBA Annual Report 2016* (Brussels: 2017), p. 10, http://european-biogas.eu/2017/01/30/eba-annual-report-2016-is-out/; "Renewable natural gas fuel growth in Europe", NGV Global News, 1 February 2016, http://www.ngvglobal.com/blog/renewable-natural-gas-fuel-growth-in-europe-0201; "Swedish CNG soars past 70% biomethane", NGV Global News, 25 August 2015, http://www.ngvglobal.com/blog/swedish-cng-soars-past-70-biomethane-0825; Nordic Ecolabelling, "About Nordic Swan Ecolabelled: Liquid and gaseous fuels", 7th February 2017, http://www.svanen.se/Documents/remisser/Drivmedel/099e_3_0_BD.pdf.

185 IRENA, op. cit. note 164, p. 2.

186 Electric Vehicle World Sales Database, "Europe Plug-in sales for 2016", http://www.ev-volumes.com/, viewed 23 March 2017.

187 EV-Volumes, "Europe Plug-in Sales for 2016", http://www.ev-volumes.com/country/total-euefta-plug-in-vehicle-volumes-2/, viewed 30 April 2017.

188 Allen, op. cit. note 167.

189 IRENA, op. cit. note 164, p. 8.

190 "West Bengal begins biogas for buses", NGV Global News, 10 January 2017, http://www.ngvglobal.com/blog/west-bengal-begins-biogas-for-buses-0110#more-45261.

191 EV Sales, op. cit. note 180.

192 IEA, *Global EV Outlook 2016* (Paris: 2016), p. 23, https://www.iea.org/publications/freepublications/publication/Global_EV_Outlook_2016.pdf.

193 EV-Volumes, op. cit. note 175; EV Sales, "Japan December 2016", 30 January 2017, http://ev-sales.blogspot.de/2017/01/japan-december-2016.html. See also Electric Vehicles section in Enabling Technologies chapter.

194 F.O. Licht, op. cit. note 162.

195 EV Sales, op. cit. note 180.

196 Mattias Svensson, Swedish Gas Technology Center, "Biomethane, the Renewable and Domestic Automotive Fuel", presentation at NGV2014 South Africa, 2014, http://www.sgc.se/ckfinder/userfiles/files/Svensson_NGV2014_SAfrica.pdf.

197 Based on 2014 data from IEA, *World Energy Statistics 2016* (Paris: 2016), www.iea.org/statistics, as modified by REN21.

198 International Civil Aviation Organization, "Historic agreement reached to mitigate international aviation emissions", press release (Montreal; 6 October, 2016), http://www.icao.int/Newsroom/Pages/Historic-agreement-reached-to-mitigate-international-aviation-emissions.aspx.

199 Ibid.

200 Robert Boyd, International Air Transportation Administration, Montreal, personal communication with REN21, 5 December 2016.

201 Example agreements include that by Jet Blue and SG Preston, from Ibid.

202 Ibid.

203 Based on 2014 data from IEA, op. cit. note 197, as modified by REN21.

204 IRENA, *Renewable Energy Options for Shipping* (Abu Dhabi: 2015), p. 4.

205 Paul Gilbert, University of Manchester, personal communication with REN21, 6 December 2016.

206 Ibid.

207 "LNG-fuelled ferry commences operations in Australia", NGV Global News, 13 December 2016, http://www.ngvglobal.com/blog/lng-fuelled-ferry-commences-operations-in-australia-1213#more-44766; "China initiates ECAs and promotion of LNG for marine fuel", NGV Global News, 4 September 2015, http://www.ngvglobal.com/blog/china-initiates-ecas-and-promotion-of-lng-for-marine-fuel-0904#more-36847.

208 Gilbert, op. cit. note 205.

209 Percentage data from 2013, from IEA and International Union of Railways (UIC), *Railway Handbook* (Paris: 2015), p. 18.

210 Ibid., p. 26.

211 Robier van Rooij, "All Dutch trains now run 100% on wind power", CleanTechnica, 8 January 2017, https://cleantechnica.com/2017/01/08/dutch-trains-now-run-100-wind-power.

212 Ibid.

213 Daniel Fajardo Cabello, "Santiago's subway to run on solar and wind power", Solutions & Co., http://www.solutionsandco.org/project/santiagos-subway-to-run-on-solar-and-wind-power/, viewed 23 March 2017.

214 Nick Craven and Gabriel Castanares, UIC, personal communication with REN21, 14 December 2016; Merlin, "About", http://www.merlin-rail.eu/?page_id=56, viewed 12 March 2017.

215 Cornie Huizenga, SLoCaT, personal communication with REN21, 28 November 2016; Hinrichs-Rahlwes, op. cit. note 22; Jason Deign, "Which country will become the first to ban internal combustion engines", Greentech Media, 7 November 2016, https://www.greentechmedia.com/articles/read/what-country-will-become-the-first-to-ban-internal-combustion-cars.

216 Nikola Medimorec, SLoCaT, personal communication with REN21, 8 May 2017.

217 Huizenga, op. cit. note 215.

218 Ibid.; German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, *Climate Action Plan 2050, Principles and Goals of the German Government's Climate Policy, Executive Summary* (Berlin: 14 November 2016), http://www.bmub.bund.de/fileadmin/Daten_BMU/Download_PDF/Klimaschutz/klimaschutzplan_2050_kurzf_en_bf.pdf.

219 Allen, op. cit. note 167.

BIOMASS ENERGY

1 International Energy Agency (IEA), *Bioenergy How2Guide* (Paris: 2017), https://www.iea.org/publications/freepublications/publication/technology-roadmap-how2guide-for-bioenergy.html.

2 Ibid.

3 For a description of the various bioenergy options and their maturity, see, for example, IEA, *Energy Technology Perspectives 2017* (Paris: 2017); for advanced biofuels, see International Renewable Energy Agency (IRENA), *Innovation Outlook, Advanced Biofuels* (Abu Dhabi: 2016), http://www.irena.org/DocumentDownloads/Publications/IRENA_Innovation_Outlook_Advanced_Biofuels_2016_summary.pdf.

4 IEA, *Medium-Term Renewable Energy Market Report 2016* (Paris: 2016), https://www.iea.org/newsroom/news/2016/october/medium-term-renewable-energy-market-report-2016.html.

5 European Commission, *Final Report from Special Group on Advanced Biofuels: Building Up the Future* (Brussels: forthcoming 2017).

6 IEA, *Renewables Information* (Paris: 2016), http://wds.iea.org/wds/pdf/Ren_documentation.pdf.

7 Projections for 2015 and 2016 are from a linear extrapolation based on data for 2010-14 from IEA, *World Energy Outlook 2016* (Paris: 2016), http://www.worldenergyoutlook.org/publications/weo-2016/.

8 Ibid.

9 Ibid.

10 **Figure 7** based on the following sources: Total 2015 final energy consumption (estimated at 363.5 EJ) is based on 359.9 EJ for 2014 from IEA, *World Energy Statistics and Balances,* 2016 edition (Paris: 2016) and escalated by the 0.97% increase in global primary energy demand from 2014 to 2015, derived from BP, *Statistical Review of World Energy 2016* (London: 2016), http://www.bp.com/content/dam/bp/pdf/energy-economics/statistical-review-2016/bp-statistical-review-of-world-energy-2016-full-report.pdf. Traditional biomass use in 2015 of 799 Mtoe assumes an increase of 23 Mtoe from 2014 based on 2014 value of 776 Mtoe from IEA, op. cit. note 7, p. 412; 2013 value of 753 Mtoe from IEA, *World Energy Outlook 2015* (Paris: 2015), p. 361. Modern bio-heat energy values for 2014 (industrial, residential and other uses, including heat from heat plants of 13.6 EJ) from IEA, op. cit. note 4, p. 218. with 67% assigned to industrial uses (p. 226). Bio-power generation of 1.59 EJ based on 476,251 GWh of generation from IEA, idem, and converted assuming average losses of 7%.

11 IEA, op. cit. note 7. Estimates of traditional biomass use vary widely, given the difficulties of measuring or even estimating a resource that often is traded informally. For example, one source (Helena Chum et al., "Bioenergy", in Ottmar Edenhofer et al., eds., *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation* (Cambridge, UK and New York, NY: Cambridge University Press, 2011), pp. 216-17) suggests that the national databases on which the IEA statistics rely systematically underestimate fuelwood consumption, and applied a supplement of 20-40% on these estimates based on country-specific analyses in over 20 countries.

12 IEA, *World Energy Statistics and Balances*, op. cit. note 10.

13 United Nations Food and Agriculture Organization (FAO), "Forest Products Statistics", http://www.fao.org/forestry/statistics/80938/en/, viewed 7 March 2017. Conversion assumes density of 450 kilograms per m^3 (dry weight) and calorific value of 18 GJ per dry tonne, from FAO, *FAO Forest Handbook* (Rome: 2015).

14 Ibid.

15 FAO data on charcoal production for 2015 show a slight decrease compared with 2014 (52.1 million tonnes compared with 52.4 million tonnes for 2014). Given recent trends, estimated production remained close to 52 million tonnes in 2016. FAO, "Forestry production and trade", FAOSTAT database, http://www.fao.org/faostat/en/#data/FO, viewed 31 March 2017.

16 Total modern biomass use in 2016 is based on an IEA estimate of total direct supply of modern bioenergy heat in 2014 of 12.8 EJ. In addition, 0.8 EJ of renewable heat was provided via commercial heat supply (e.g., district heating, most of which is supplied by biomass); two-thirds of the heat supplied by biomass is for industrial use, per IEA, op. cit. note 4, pp. 218, 226. Growth in heat from biomass has slowed to around 1% per year in recent years; assuming continuing growth, at this rate production is estimated at 13.7 EJ in 2015 and 13.9 EJ in 2016.

17 Estimate assumes the same percent increase in capacity between 2014 and 2016 as for modern heat generation (2%) (see endnote 16), applied to the biomass heat capacity data in 2014 from GSR 2015.

18 Based on analysis of data for contribution of wastes and biomass to industrial final energy contribution from 2009 to 2014 in IEA, *World Energy Outlook* (Paris: 2011-2016 editions), Annex A "World New Policy Scenario".

19 IEA, *Energy Technology Perspectives 2016* (Paris: 2016), https://www.iea.org/publications/freepublications/publication/energy-technology-perspectives-2016---executive-summary---english-version.html. Note that a range of biomass and waste fuels is used in processes like cement manufacture. Some of these materials are of biogenic origin, but other materials originating from fossil sources are also used and should not be included in estimates of renewable fuel use.

20 IEA, op. cit. note 4.

21 Ibid.

22 Based on analysis of data for bioenergy use in industry sector in IEA, op. cit. note 18.

23 Val Stori, Clean Energy Group, Montpelier, VT, personal communication with Renewable Energy Policy Network for the 21st Century (REN21), 17 March 2017.

24 Each EU member state is obligated under the Renewable Energy Directive to develop renewable energy to meet a mandatory national target for 2020 for the share of renewables in final energy consumption. To achieve this, each country has prepared a National Renewable Energy Action Plan that includes measures to promote renewable heat. This is leading to growing efforts to encourage renewable heating, which comes primarily from biomass.

25 Based on data in IEA, op. cit. note 4, and in EurObserv'ER, *Solid Biomass Barometer 2016* (Brussels: 2016), https://www.eurobserv-er.org/solid-biomass-barometer-2016/.

26 Katie Fletcher, "Baltic boom", *Biomass Magazine*, 22 January 2016, http://biomassmagazine.com/articles/12763/.

27 John Bingham, "The Global Outlook for Wood Pellet Markets", presentation at WPAC Annual Conference, Harrison Hot Springs, BC, Canada, 20 September 2016, https://www.pellet.org/wpac-agm/images/2016/JohnBingham-The-global-outlook-for-wood-pellet-markets.pdf; Wood Pellet Association of Canada, *Global Pellet Outlook 2017* (Revelstoke, BC: 2017), https://www.pellet.org/wpac-news/global-pellet-market-outlook-in-2017.

28 Bingham, op. cit. note 27; Wood Pellet Association of Canada, op. cit. note 27.

29 European Commission, Intelligent Energy Europe Projects Database, "Development of sustainable heat markets for biogas plants in Europe (BIOGASHEAT)", https://ec.europa.eu/energy/intelligent/projects/en/projects/biogasheat, viewed 13 May 2016.

30 Gaurav Kedia, Chief Executive, Biogas India, personal communication with REN21, 26 January 2017.

31 Bio-power capacity data based on 2016 forecast data in IEA, op. cit. note 4, except for the following: United States from US Federal Energy Regulatory Commission (FERC), Office of Energy Projects, "Energy Infrastructure Update for December 2016" (Washington, DC: 2016), https://www.ferc.gov/legal/staff-reports/2016/dec-energy-infrastructure.pdf; Germany from German Federal Ministry for Economic Affairs and Energy (BMWi), *Zeitreihen zur Entwicklung der erneuerbaren Energien in Deutschland, unter Verwendung von Daten der Arbeitsgruppe Erneuerbare Energien-Statistik* (AGEE-Stat) (Dessau-Roßlau, Germany: February 2017), Table 4, http://www.erneuerbare-energien.de/EE/Redaktion/DE/Downloads/zeitreihen-zur-entwicklung-der-erneuerbaren-energien-in-deutschland-1990-2016.pdf?__blob=publicationFile&v=12; United Kingdom from UK Department for Business, Energy and Industrial Strategy, *National Statistics, Energy Trends Section 6: Renewables,* Table 6.1, updated 3 April 2017, https://www.gov.uk/government/statistics/energy-trends-section-6-renewables; Japan from Hironao Matsubara, Institute for Sustainable Energy Policies, Tokyo, Japan, personal communication with REN 21, 13

April 2017; Brazil from Empresa de Pesquisa Energética (EPE), *Brazilian Energy Balance 2016* (Rio de Janeiro: 2016), and from Ministério de Minas e Energia (MME), *Anuário Estatistico 2016* (Rio de Janeiro: EPE, 2016); India from Government of India, Ministry of New and Renewable Energy (MNRE), "Physical progress (achievements) for 2015 and 2016", http://www.mnre.gov.in/mission-and-vision-2/achievements, viewed 19 January 2017.

32 Bio-power capacity and generation do not always grow proportionately. If new capacity is added late in the year, it does not fully contribute to that year's generation, so capacity can grow faster than generation in that year. In the following year, then, generation growth can exceed that for capacity. By contrast, when growth in generation is due to co-firing of biomass (usually with coal), the co-firing capacity often is not recorded and the capacity data relate only to dedicated generation. In that case, generation may rise much faster than reported capacity. Biopower generation statistics are based on 2016 forecast data from IEA, op. cit. note 4, except for the following: US data (corrected for difference between net and gross electricity generation) from US Energy Information Administration (EIA), *Electric Power Monthly*, 24 March 2017, http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_1_01_a; Germany from BMWi, *Development of Renewable Energy Sources in Germany 2016* (Bonn: 2016), https://www.erneuerbare-energien.de/EE/Redaktion/DE/Downloads/development-of-renewable-energy-sources-in-germany-2016.pdf?__blob=publicationFile&v=13; United Kingdom from UK Department for Business, Energy and Industrial Strategy, op. cit. note 31. Data for 2016 are still subject to revision; Japan from Matsubara, op. cit. note 31; Brazil from EPE, op. cit. note 31, and from MME, op. cit. note 31.

33 **Figure B8** based on IEA data for 2005-2013 from IEA, op. cit. note 4, and on REN21 analysis of generation for 2013, 2014 and 2015, from REN 21, *Renewables Global Status Report* (Paris: 2014-2016 editions). Data for 2015 may be changed to account for updated data when these replace preliminary or provisional data.

34 US data from EIA, op. cit. note 32, corrected for difference between net and gross electricity generation.

35 US capacity data based on FERC, op. cit. note 31. However, note that EIA (EIA, *Electric Power Monthly,* February 2017, Table 6.1) shows a net reduction in US bio-power capacity for 2016, with a year-end total of 14.1 GW. The FERC number has been used for consistency with previous editions of the GSR.

36 European Commission, "Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC" (Brussels: 2009), http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32009L0028.

37 BMWi, op. cit. note 31, Tables 3 and 4.

38 UK Department for Business, Energy and Industrial Strategy, op. cit. note 31; data for 2016 are still subject to revision, notably for combustible bioenergy sources such as landfill gas. Anaerobic digestion in the UK saw strong growth in 2016: 85 new anaerobic digestion plants became operational (taking the total to over 400, which excludes traditional water treatment facilities), and 50 new plants began development. National Non Food Crops Centre (NNFCC), *Anaerobic Digestion Deployment in the UK* (York: April 2017), http://www.nnfcc.co.uk/report-anaerobic-digestion-deployment-in-the-uk.

39 IEA, op. cit. note 4.

40 Ibid. The current five-year plan has a target of achieving 15 GW by 2020, a reduction of the earlier objective of 30 GW, which exceeded what is likely to be achieved.

41 Ibid. Note that MSW contains both biogenic wastes and wastes derived from other sources. It is useful to distinguish between these to estimate the renewable fraction. A convention of taking 50% as the renewable fraction is often used, but it is frequently difficult to establish whether this distinction has been made in the statistics.

42 Matsubara, op. cit. note 31. Capacity figure does not include co-firing capacity. Bio-power expansion is fuelled mainly by forestry products including imported chips and pellets and palm kernel shells. The domestic supply chain of chips from forestry is so far limited and high-cost.

43 IEA, op. cit. note 4.

44 Government of India, MNRE, op. cit. note 31.

45 Brazil from EPE, op. cit. note 31, and from MME, op. cit. note 31.

46 Ibid.

47 Ibid.

48 Fuel ethanol data from F.O. Licht, "Fuel Ethanol: World Production by Country", 2017. Where provisional data have been replaced in the source, these have been used.

49 Based on analysis of data in F.O. Licht, op. cit. note 48, and in F.O. Licht, "Biodiesel: World Production, by Country", 2017. With permission from F.O. Licht/Licht Interactive Data.

50 **Figure 9** from F.O. Licht, op. cit. notes 48 and 49.

51 Ibid. Preliminary data for 2015 updated when necessary.

52 F.O. Licht, op. cit. note 48. Preliminary data for 2015 updated when necessary.

53 Ibid.

54 EIA, *Monthly Energy Review*, April 2017, Table 10.3, https://www.eia.gov/totalenergy/data/monthly/#renewable.

55 Fuel ethanol data from F.O. Licht, op. cit. note 48. Preliminary data for 2015 updated when necessary.

56 Ibid.

57 Ibid.

58 IEA Bioenergy Task 39, *The Potential of Biofuels in China* (Paris: 2016), http://task39.sites.olt.ubc.ca/files/2013/05/The-Potential-of-biofuels-in-China-IEA-Bioenergy-Task-39-September-2016.pdf.

59 "China unveils plan to beef up ethanol production by 2020", Biofuels International, 6 December 2016, http://biofuels-news.com/display_news/11487/China_unveils_plan_to_beef_up_ethanol_production_by_2020/.

60 Fuel ethanol data from F.O. Licht, op. cit. note 48. Preliminary data for 2015 updated when necessary.

61 Ibid.

62 Fuel ethanol data from F.O. Licht, op. cit. note 48. Preliminary data for 2015 updated when necessary.

63 F.O. Licht, "Biodiesel: World Production, by Country", op. cit. note 49. Preliminary 2015 data that appeared in GSR 2015 have been updated where necessary.

64 Ibid.

65 Ibid.

66 Ibid.

67 Ibid.

68 IEA, op. cit. note 4.

69 F.O. Licht, "Biodiesel: World Production, by Country", op. cit. note 49.

70 US Department of Agriculture (USDA), Foreign Agricultural Service (FAS), Global Agricultural Information Network (GAIN), *Argentina Biofuels Annual 2016* (Washington, DC: 21 July 2016), https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Buenos%20Aires_Argentina_7-21-2016.pdf; F.O. Licht, "Biodiesel: World Production, by Country", op. cit. note 49.

71 F.O. Licht, "Biodiesel: World Production, by Country", op. cit. note 49.

72 Ibid.

73 German data from BMWI, op. cit. note 31, p. 9; other data from F.O. Licht, "Biodiesel: World Production, by Country", op. cit. note 49. Note that F.O. Licht estimates German biodiesel production at 3.0 billion litres. Preliminary 2015 data that appeared in GSR 2015 have been updated where necessary.

74 Meghan Sapp, "New rules to ensure Indonesia achieves 20% blending target", Biofuels Digest, 25 October 2016, http://www.biofuelsdigest.com/bdigest/2016/10/25/new-rules-to-ensure-indonesia-achieves-20-biodieselblending/; F.O. Licht, "Biodiesel: World Production, by Country", op. cit. note 49.

75 F.O. Licht, "Biodiesel: World Production, by Country", op. cit. note 49; USDA, FAS, GAIN, *China Biofuels Annual* (Washington, DC: 7 February 2017), https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Beijing_China%20-%20Peoples%20Republic%20of_1-18-2017.pdf.

76 F.O. Licht, "Biodiesel: World Production, by Country", op. cit. note 49.

77 Ibid.

78 Based on data in US Environmental Protection Agency, "RIN Generation and Renewable Fuel Volume Production by Fuel Type from January 2017", https://www.epa.gov/fuels-registration-reporting-and-compliance-help/spreadsheet-rin-generation-and-renewable-fuel-0, posted February 2017.

79 Ibid.

80 Detailed 2014 results for Germany and Sweden, with data extrapolated from 2014 to 2016, from European Commission, Eurostat, SHARES database, http://ec.europa.eu/eurostat/web/energy/data/shares.

81 "Dong Energy makes Studstrup plant run on wood pellets instead of coal", Bioenergy Insight, 13 October 2016, http://www.bioenergy-news.com/display_news/11180/dong_energy_makes_studstrup_plant_run_on_wood_pellets_instead_of_coal/.

82 Drax, "Drax given green light to complete biomass upgrade, saving 12 million tonnes of carbon every year", press release (Selby, North Yorkshire, UK: 19 December 2016), https://www.drax.com/press_release/drax-given-green-light-complete-biomass-upgrade-saving-12-million-tonnes-carbon-every-year/. Among many other examples, in Vienna the power plants consume around 190,000 tonnes of biomass, from Wien Energie, "Simmering biomass power plant", https://www.wienenergie.at/eportal3/ep/channelView.do?pageTypeId=72164&channelId=-51556, viewed 1 May 2017.

83 William Strauss, Future Metrics, "Industrial Wood Pellets in Japan: Market Drivers and Potential Demand", presentation at Sixth International Pellet Exporting Conference, Miami, FL, 6-8 November 2017, http://www.futuremetrics.info/wp-content/uploads/2016/11/Japan%20Markets%20-%20William%20Strauss%20-%20FutureMetrics%20-%20USIPA%202016.pdf; "Japan prepares for biomass power plant surge and increases imports of wood chips", Bioenergy Insights, 27 February 2017, http://www.bioenergy-news.com/display_news/11938/japan_prepares_for_biomass_power_plant_surge_and_increases_imports_of_wood_chips/.

84 Wood Pellet Association of Canada, op. cit. note 27.

85 Ibid.

86 Ibid.

87 EIA, "Monthly Densified Biomass Fuel Report", https://www.eia.gov/biofuels/biomass/, viewed 28 April 2017.

88 Wood Pellet Association of Canada, op. cit. note 27.

89 Wood Pellet Association of Canada, "Prospects for 2017", https://www.pellet.org/wpac-news/prospects-for-pellet-producers-in-2017, viewed 1 May 2017.

90 Fletcher, op. cit. note 26.

91 Drax Biomass, "About us", http://www.draxbiomass.com/about-us/, viewed 1 May 2017.

92 "Pellet Plants – Operational", *Biomass Magazine*, http://biomassmagazine.com/plants/listplants/pellet/US/Operational/, updated 26 January 2017.

93 Fletcher, op. cit. note 26.

94 Duncan Brack, *The Impacts of the Demand for Woody Biomass for Power and Heat on Climate and Forests* (London: Chatham House, 23 February 2017), https://www.chathamhouse.org/publication/impacts-demand-woody-biomass-power-and-heat-climate-and-forests; IEA Bioenergy, "IEA Bioenergy response to Chatham House report 'Woody Biomass for Power and Heat: Impacts on the Global Climate'", 13 March 2017, http://www.ieabioenergy.com/publications/iea-bioenergy-response/.

95 European Commission, "Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources" (Brussels: 30 November 2016), http://eurlex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52016PC0767R%2801%29.

96 OFGEM, "Biomass sustainability", https://www.ofgem.gov.uk/environmental-programmes/ro/applicants/biomass-sustainability, viewed 1 May 2017; Stine Leth Rasmussen, Danish Energy Association, "The Danish Industry Agreement for Sustainable Biomass", undated presentation, https://ens.dk/sites/ens.dk/files/Bioenergi/the_danish_industry_agreement.pdf.

97 IEA Bioenergy Task 32 and Task 40, "Torrefaction", joint webinar, 26 October 2016, http://www.ieabcc.nl/news/IEA-Bioenergy-torrefaction-webinar.pdf; IEA Bioenergy Task 32, *Status Overview of Torrefaction Technologies, 2015* (Paris: 2015), http://www.ieabcc.nl/publications/IEA_Bioenergy_T32_Torrefaction_update_2015b.pdf; IEA Bioenergy Task 40, *Possible Effects of Torrefaction on Biomass Trade* (Paris: 2016), http://task40.ieabioenergy.com/wp-content/uploads/2013/09/t40-torrefaction-2016.pdf.

98 "Bioenergy torrefaction: rich rewards", *Bioenergy Insights*, September/October 2016, p. 26, http://www.biomasstorrefaction.org/wp-content/uploads/2016/09/A-flexible-biomass-torrefaction-plant-has-recently-been-unveiled-in-Canada.pdf; see also Airex website, http://www.airex-energy.com/en/.

99 Scandinavian Biopower Oy, "Scandinavian Biopower to invest in a biocoal plant in Mikkeli Finland – construction works to start late 2017", press release (Mikkeli, Finland: 29 November 2016), http://www.biomasstorrefaction.org/wp-content/uploads/2016/12/20161129-Bio-coal-plant-RELEASE-FINAL-VERSION-DEF.pdf.

100 "U.S. ethanol plants", *Ethanol Producer Magazine*, updated 23 January 2016, http://www.ethanolproducer.com/plants/listplants/US/Existing/Sugar-Starch; Brazil from Connectas, "The ethanol Czars", undated, http://connectas.org/project/et/en/art1.html.

101 See, for example: "Shell and Cosan beef up sugarcane ethanol JV in Brazil", Biofuels International, 23 November 2016, http://biofuels-news.com/display_news/11405/shell_and_cosan_beef_up_sugarcane_ethanol_jv_in_brazil/; Honeywell UOP, "Renewable fuels", https://www.uop.com/processing-solutions/renewables/; UPM Biofuels website, http://www.upmbiofuels.com; Neste Oil, "Neste Renewable Diesel", https://www.neste.com/na/en/customers/products/renewable-products/neste-my-renewable-diesel.

102 EIA, "Petroleum and other liquids, fuel exports by destination, fuel ethanol", https://www.eia.gov/dnav/pet/pet_move_expc_a_EPOOXE_EEX_mbbl_a.htm, viewed 14 March 2017.

103 "US ethanol exports to china poised to collapse with 30% tariff", Biofuels News, 1 February 2017, http://biofuels-news.com/display_news/11796/us_ethanol_exports_to_china_poised_to_collapse_with_30_ta/.

104 EIA, "Monthly biodiesel production report", December 2016, https://www.eia.gov/biofuels/biodiesel/production/.

105 USDA, FAS, GAIN, op. cit. note 70.

106 IRENA, *Bioethanol in Africa: The Case for Technology Transfer and South-South Cooperation* (Abu Dhabi: 2016), http://www.irena.org/DocumentDownloads/Publications/IRENA_Bioethanol_in_Africa_2016.pdf.

107 The measures include a USD 246 million Green Fund to support the development of projects, supported by the World Bank, the UK's Department for International Development and UN Environment, to help the country meet international emissions reductions commitments, as well as a call for international strategic investors. Meghan Sapp, "Nigeria all in for biofuel future", Biofuels Digest, 18 October 2017, http://www.biofuelsdigest.com/bdigest/2016/10/18/nigeria-all-in-for-biofuel-future/; Meghan Sapp, "Nigeria announces $246 million in Green Bonds for 19 projects including jatropha biofuels", Biofuels Digest, 16 November 2016, http://www.biofuelsdigest.com/bdigest/2016/11/16/nigeria-announces-246-million-in-green-bonds-for-19-projects-including-jatropha-biofuels/; Meghan Sapp, "Nigeria Issues call for strategic biofuels investors to implement projects", Biofuels Digest, 6 April 2016, http://www.biofuelsdigest.com/bdigest/2016/04/06/nigeria-issues-call-for-strategic-biofuels-investors-toimplement-projects/.

108 Meghan Sapp, "Nigeria's Cross River to get $2.5 million cassava ethanol plant", Biofuels Digest, 26 May 2016, http://www.biofuelsdigest.com/bdigest/2016/05/26/nigerias-cross-river-to-get-2-5-million-cassava-ethanolplant/; "NNPC planning a $300m ethanol plant in Nigeria", Biofuels International 21 July 2016, http://biofuels-news.com/display_news/10789/nnpc_planning_a_300m_ethanol_plant_in_nigeria/; Meghan Sapp, "Union Dicon Salt agrees with Delta State to develop 10,000 hectares of cassava and processing", Biofuels Digest, 7 September 2016, http://www.biofuelsdigest.com/bdigest/2016/09/07/union-dicon-salt-agrees-with-delta-state-to-develop-10000-hectares-of-cassava-and-processing/.

109 Lydia Heida, "Biofuels Nigeria signs deal for 16.5 million biodiesel plant in Kogi State", Biofuels Digest, http://www.biofuelsdigest.com/bdigest/2017/02/20/biofuels-nigeria-ltd-signs-deal-for-16-5-million-biodieselplant-in-kogi-state/.

110 Meghan Sapp, "US and China team to invest $62.5 million in South African sweet sorghum project", Biofuels Digest, 11 May 2016, http://www.biofuelsdigest.com/bdigest/2016/05/11/us-and-china-team-to-invest-62-5-million-in-south-african-sweet-sorghum-project/; Blume Distillation LLC, "Ethala Biofuels Joint-Development Agreement in Durban, South Africa", press release (Johannesburg: 2 December 2015), https://www.blumedistillation.com/ethala-biofuels-joint-development-agreement-in-durban-south-africa/.

111 For a fuller rationale see, for example, IRENA, op. cit. note 3. **Figure 10** based on various publications on bioenergy, on IRENA, op. cit. note 3, and on IEA, op. cit. note 3.

112 See, for example, the description of a range of advanced biofuels value chains at European Biofuels Technology Platform, "The EIBI Value Chains", http://biofuelstp.eu/eibi.html#valuechains, viewed 1 May 2017.

113 See New Zealand Institute of Chemistry, "Tall oil production and processing", http://nzic.org.nz/ChemProcesses/forestry/4G.pdf, viewed 1 May 2017.

114 American Institute of Chemical Engineering, "Is Finland's Neste the world's first 21st century oil company?" 2 February 2016, https://www.aiche.org/chenected/2016/01/finlands-neste-worlds-first-21st-century-oil-company.

115 Renewable Energy Group, "REG announces several milestones", 2 March 2017, http://www.regi.com/news/2017/03/02/reg-announces-several-milestones.

116 Beta Renewables, "Projects: Alpha", http://www.betarenewables.com/en/projects/alpha, viewed 14 March 2017.

117 North European Oil Trade, "Current projects", http://www.neot.fi/en/neot-en/current-projects, viewed 1 May 2017.

118 DuPont, "DuPont and New Tianlong Industry Co., Ltd. sign historic deal to bring cellulosic ethanol technology to China", press release (Changchu, China: 16 July 2015), http://www.dupont.com/corporate-functions/media-center/press-releases/dupont-NTL-sign-historic-deal-cellulosic-ethanol-tech-china.html.

119 PTI, "India gets its first 2G Ethanol plant in Uttarakhand", *Economic Times*, 22 April 2016, http://economictimes.indiatimes.com/news/economy/agriculture/india-gets-its-first-2g-ethanol-plant-in-uttarakhand/articleshow/51948347.cms.

120 Meghan Sapp, "MOUs for five second generation ethanol plants in India signed", Biofuels Digest, 7 December 2016, http://www.biofuelsdigest.com/bdigest/2016/12/07/mous-for-five-second-generation-ethanol-plants-in-india-signed/.

121 Jim Lane, "Sugar, sugar: Toray, Mitsui set out to build monster cellulosic sugar plant in Asia", Biofuels Digest, 16 January 2016, http://www.biofuelsdigest.com/bdigest/2017/01/16/sugar-sugar-toray-mitsui-set-out-to-build-monster-cellulosic-sugar-plant-in-asia/.

122 Enerkem, "Enerkem Alberta biofuels", http://enerkem.com/facilities/enerkem-alberta-biofuels/, viewed 1 May 2017.

123 European Commission, op. cit. note 5.

124 IRENA, *Biofuels for Aviation: Technology Brief* (Abu Dhabi: 2017), https://www.irena.org/DocumentDownloads/Publications/IRENA_Biofuels_for_Aviation_2017.pdf.

125 The two new pathways are Alcohol to Jet based on isobutanol (ATJ), and Alcohol to Jet Synthetic Paraffinic Kerosene (ATJ-SPK), which is created from isobutanol derived from renewable feedstocks such as sugar, maize and forest wastes. The other fuels are: Synthesised Iso-parafins (SIP) which are produced by converting sugars into jet fuel, Hydro-processed Esters and Fatty Acids Synthetic Paraffinic Kerosene (HEFA-SPK), which use fats, oils and greases, and Fischer-Tropsch Synthetic Paraffinic Kerosene (FT-SPK) and Fischer-Tropsch Synthetic Kerosene with Aromatics (FT-SKA). Both fuels use various sources of renewable biomass such as MSW, agricultural and forestry wastes, wood and energy crops.

126 IRENA, op. cit. note 124; Chelsea Harvey, "United Airlines is flying on biofuels. Here's why that's a really big idea", *Washington Post*, 11 March 2016, https://www.washingtonpost.com/news/energy-environment/wp/2016/03/11/united-airlines-is-flying-on-biofuels-heres-why-thats-a-really-big-deal/?utm_term=.1c3b08c4bf1a.

127 SkyNRG, "Sky Green Fund and Swedavia enable sustainable aviation fuel flights from Stockholm Arlanda Airport", press release (Stockholm: 3 January 2017), http://skynrg.com/wp-content/uploads/2017/01/20170103_Press_Release_SkyNRG-Fly-Green-Fund-and-Swedavia-enable-sustainable-jet-fuel-flights-from-Stockholm-Arlanda-Airport.pdf.

128 Advanced Biofuel USA, "US Air Force to produce biofuels for US DoD applications", 2 September 2016, http://advancedbiofuelsusa.info/us-air-force-to-produce-biofuels-for-us-dod-applications/; US Navy, "Great Green Fleet", http://greenfleet.dodlive.mil/energy/great-green-fleet/, viewed 1 May 2017.

129 The initiative involves a joint venture between Good Fuels Marine NRG and ship manufacturers Boskalis and Wärtsilä (Finland). GoodFuels, "Boskalis on Bio: Sustainable Marine Biofuel Initiative", http://goodfuels.com/marine/boskalis-on-bio/.

130 European Biofuels Technology Platform, "Use of biofuels in shipping", http://www.biofuelstp.eu/shipping-biofuels.html, viewed 1 May 2017.

131 Jim Lane, "Ocean going vessels going green", Biofuels Digest, 22 November 2016, http://www.biofuelsdigest.com/bdigest/2016/11/22/ocean-going-vessels-going-green/.

132 Mattias Svensson, *Country Report Sweden* (Berlin: IEA Bioenergy Task 37, 2015), http://task37.ieabioenergy.com/country-reports.html?file=files/daten-redaktion/download/publications/countryreports/2015/Sweden_Country_Report_Berlin_10-2015.pdf; Clare T. Lukehurst, *UK Country Report* (Berlin: IEA Bioenergy Task 37, 2015), http://task37.ieabioenergy.com/country-reports.html?file=files/datenredaktion/download/publications/country-reports/2015/United_Kingdom_Country_Report_Berlin_10-2014.pdf.

133 Analysis based on data in IEA, op. cit. note 12.

134 "BP buys Clean Energy Fuels' biomethane arm", Bioenergy Insight, 2 March 2017, http://www.bioenergy-news.com/display_news/11952/bp_buys_clean_energy_fuels_biomethane_arm/.

135 "Suez buys share in biogas business", ENDS Waste and Bioenergy, 27 September 2017, http://www.endswasteandbioenergy.com/article/1410359/suez-buys-share-biogas-business.

136 Xergi, "Xergi among Danish Gazelle companies", 14 December 2016, http://www.xergi.com/news/xergi-among-danish-gazelle-companies.html.

137 Kedia, op. cit. note 30.

138 "Green & Smart brings its first wholly-owned Malaysian biopower plant online", Bioenergy Insight, 19 December 2017, http://www.bioenergy-news.com/display_news/11578/green__smart_brings_its_first_whollyowned_malaysian_biopower_plant_online/; see also Green & Smart, "Green & Smart raises £4mln in AIM listing to build palm oil biogas plants in Malaysia", 12 May 2016, http://www.proactiveinvestors.co.uk/companies/stocktube/5019/green-smart-raises-4mln-in-aim-listing-to-buildpalm-oil-biogas-plants-in-malaysia-5019.html.

139 "New energy-from-waste plant launched in South Africa", Bioenergy Insight, 26 January 2017, http://www.bioenergy-news.com/display_news/11761/new_energyfromwaste_plant_launched_in_south_africa/.

140 "First African grid connected biogas powered electricity plant comes on line in Kenya", Bioenergy Insight, 11 January 2017, http://www.bioenergy-news.com/display_news/11654/first_african_gridconnected_biogaspowered_electricity_plant_comes_online_in_kenya/.

GEOTHERMAL POWER AND HEAT

1 End-2015 capacity data for Iceland, Japan, Mexico and New Zealand from International Energy Agency (IEA) Geothermal, *Annual Report 2015* (Taupo, New Zealand: February 2017), http://iea-gia.org/wp-content/uploads/2017/02/2015-IEA-Geothermal-Annual-Report.pdf; Italy from Antonello Di Pardo, Gestore dei Servizi Energetici S.p.A. (GSE), personal communication with REN21, April 2017, and from GSE, *Rapporto Statistico – Energia da fonti rinnovabili in Italia – Anno 2015* (Rome: March 2017), http://www.gse.it/it/Statistiche/RapportiStatistici/Pagine/default.aspx; end-2015 capacity data for other countries from inventory of existing and installed capacity in 2015 from Geothermal Energy Association (GEA), per Benjamin Matek, GEA, personal communication with the Renewable Energy Policy Network for the 21st Century (REN21), March-May 2016; capacity additions in 2016 by country from sources noted elsewhere in this section. Electricity generation based on global average capacity factor of 66.45% in 2014, derived from Ruggero Bertani, "Geothermal power generation in the world: 2010-2014 update report", *Proceedings of the World Geothermal Congress 2015, Melbourne, Australia: 19-25 April 2015*. Heat capacity and output is an extrapolation from five-year growth rates calculated from generation and capacity data for 2009 and 2014, from John W. Lund and Tonya L. Boyd, "Direct utilization of geothermal energy 2015 worldwide review", *Geothermics*, vol. 60 (March 2016), pp. 66-93, http://dx.doi.org/10.1016/j.geothermics.2015.11.004.

2 End-2015 capacity data for Iceland, Japan, Mexico and New Zealand from IEA Geothermal, op. cit. note 1; Italy from Di Pardo, op. cit. note 1, and from GSE, op. cit. note 1; end-2015 capacity data for other countries from inventory of existing and installed capacity in 2015 from GEA, op. cit. note 1; capacity additions in 2016 by country from sources noted elsewhere in this section.

3 Capacity additions in 2016 by country from sources noted elsewhere in this section. **Figure 11** based on end-2015 capacity data for Iceland, Japan, Mexico and New Zealand from IEA Geothermal, op. cit. note 1; Italy from Di Pardo, op. cit. note 1, and from GSE, op. cit. note 1; end-2015 capacity data for other countries from inventory of existing and installed capacity in 2015 from GEA, op. cit. note 1; capacity additions in 2016 by country from sources noted elsewhere in this section.

4 End-2015 capacity data for Iceland, Japan, Mexico and New Zealand from IEA Geothermal, op. cit. note 1; Italy from Di Pardo, op. cit. note 1, and from GSE, op. cit. note 1; end-2015 capacity data for other countries from inventory of existing and installed capacity in 2015 from GEA, op. cit. note 1; capacity additions in 2016 by country from sources noted elsewhere in this section. **Figure 12** from idem.

5 Capacity of 1.44 GW at end of 2015 from Indonesian Ministry of Energy and Mineral Resources, "Pemerintah Targetkan Kapasitas Terpasang PLTP 1.751 MW Selama 5 Tahun", press release (Jakarta: 8 January 2016), https://www.esdm.go.id/en/media-center/news-archives/pemerintah-targetkan-kapasitas-terpasang-pltp-1751-mw-selama-5-tahun; capacity of 1.64 GW at end-2016 from Indonesian Ministry of Energy and Mineral Resources, "Sistem Satu Data Tekan Biaya Eksplorasi Panas Bumi", press release (Jakarta: 15 February 2017), https://www.esdm.go.id/en/media-center/news-archives/sistem-satu-data-tekan-biaya-eksplorasi-panas-bumi.

6 Toshiba Corporation and Ormat Technologies Inc., "One of the world's largest geothermal power plants commences commercial operation", press release (Reno, NV and Tokyo: 22 March 2017), http://www.toshiba.co.jp/about/press/2017_03/pr2201.htm.

7 Capacity of 1.44 GW at end-2015 from Indonesian Ministry of Energy and Mineral Resources, "Pemerintah Targetkan Kapasitas Terpasang PLTP 1.751 MW Selama 5 Tahun", op. cit. note 5; capacity of 1.64 GW at end-2016 from Indonesian Ministry of Energy and Mineral Resources, "Sistem Satu Data Tekan Biaya Eksplorasi Panas Bumi", op. cit. note 5.

8 Indonesian Ministry of Energy and Mineral Resources, "Sistem Satu Data Tekan Biaya Eksplorasi Panas Bumi", op. cit. note 5; Indonesian Ministry of Energy and Mineral Resources, "Tiga Terobosan Pengembangan Panasbumi", press release (Jakarta: 10 August 2016), https://www.esdm.go.id/en/media-center/news-archives/tiga-terobosan-pengembangan-panasbumi; Ayomi Amindoni, "Govt prepares feed-in tariff mechanism to boost geothermal energy", *Jakarta Post*, 11 August 2016, http://www.thejakartapost.com/news/2016/08/11/govt-prepares-feed-in-tariff-mechanism-to-boost-geothermal-energy.html.

9 Philippe Dumas, European Geothermal Energy Council (EGEC), personal communication with REN21, March-May 2017; capacity of 820.9 MW and 31 plants at end-2016 and capacity of 623.9 MW and 21 plants at end-2015 from Turkish Electricity Transmission Company (TEİAŞ), http://www.teias.gov.tr.

10 Generation from TEİAŞ, http://www.teias.gov.tr.

11 Dumas, op. cit. note 9.

12 Toshiba Corporation, "Toshiba expands green footprint in Turkey", press release (Tokyo: 13 September 2016), http://www.toshiba.co.jp/about/press/2016_09/pr1301.htm.

13 Ormat Technologies Inc., "Ormat announces commercial operation of Plant 4 in Olkaria III in Kenya, expanding complex capacity to nearly 140 MW", press release (Reno, NV: 4 February 2016), http://www.ormat.com/news/latest-items/ormat-announces-commercial-operation-plant-4-olkaria-iii-kenya-expanding-complex-c.

14 Capacity in 2015 of about 600 MW from GEA, op. cit. note 1.

15 Juan Luis Del Valle, Grupo Dragon, "Private Geothermal Projects in Mexico – Development and Challenges", presentation at GEA US and International Geothermal Energy Showcase, Washington, DC, 17 March 2016; Francisco Rojas, "Grupo Dragon to commission 25.5 MW Unit 3 at Domo de San Pedro in Mexico", ThinkGeoEnergy, 21 April 2016, http://www.thinkgeoenergy.com/grupo-dragon-to-commission-25-5-mw-unit-3-at-domo-de-san-pedro-in-mexico.

16 Luis C.A. Gutiérrez-Negrín, "Mexico: Exploratory drilling, more exploration permits, second electricity auction", International Geothermal Association (IGA), *IGA News*, no. 105 (October-December 2016), www.geothermalenergy.org.

17 Ibid.

18 "Small geothermal plants gaining steam in Japan", *Nikkei Asian Review*, 27 February 2017, http://asia.nikkei.com/Business/Companies/Small-geothermal-plants-gaining-steam-in-Japan.

19 Mayumi Negishi, "Japan's shift to renewable energy loses power", *Wall Street Journal*, 14 September 2016, https://www.wsj.com/articles/japans-shift-to-renewable-energy-loses-power-1473818581; Junko Movellan, "Popular hot springs in Japan co-exist with binary geothermal power plants", Renewable Energy World, 14 December 2015, http://www.renewableenergyworld.com/articles/2015/12/popular-hot-springs-in-japan-co-exist-with-binary-geothermal-power-plants.html; ElectraTherm, "ElectraTherm Power+ generator exceeds 3,000 hours in Japan", press release (Reno, NV: 29 August 2016), https://electratherm.com/geothermal-in-japan-3000; total additions of 0.6 MW from Hironao Matsubara, Institute for Sustainable Energy Policies, Tokyo, personal communication with REN21, April 2017.

20 Negishi, op. cit. note 19; Movellan, op. cit. note 19.

21 "Geothermal power promises energy boon for Japan, but hurdles remain", *The Mainichi*, 24 July 2016, http://mainichi.jp/english/articles/20160724/p2a/00m/0na/002000c.

22 Ibid.

23 Generation from US Energy Information Administration (EIA), *Electric Power Monthly*, March 2017, Table ES1.B, http://www.eia.gov/electricity/monthly; installed nameplate capacity from GEA, op. cit. note 1; net capacity from EIA, op. cit. this note, Table 6.2.B.

24 Anna Wall and Katherine Young, *Doubling Geothermal Generation Capacity by 2020: A Strategic Analysis* (Golden, CO: National Renewable Energy Laboratory (NREL), January 2016), https://energy.gov/sites/prod/files/2016/01/f28/NREL%20Doubling%20Geothermal%20Capacity.pdf.

25 Benjamin Matek, *2016 Annual U.S. & Global Power Production Report* (Washington, DC: GEA, March 2016), http://geo-energy.org/reports/2016/2016%20Annual%20US%20Global%20Geothermal%20Power%20Production.pdf.

26 Jed Macapagal, "FIT for geothermal plants pushed", *Malaya Business Insight*, 17 August 2016, http://www.malaya.com.ph/business-news/business/fit-geothermal-plants-pushed.

27 Amy R. Remo, "Group seeks perks for new geothermal technology", *Philippine Daily Inquirer*, 17 August 2016, http://business.inquirer.net/213590/group-seeks-perks-for-geothermal-technology.

28 Asian Development Bank, "ADB backs first climate bond in Asia

in landmark $225 million Philippines deal", press release (Manila: 29 February 2016), https://www.adb.org/news/adb-backs-first-climate-bond-asia-landmark-225-million-philippines-deal.

29 China National Energy Administration (CNEA), *13th Five-Year-Plan for Geothermal Power* (Beijing: 6 February 2017), http://www.nea.gov.cn/136035635_14863708180701n.pdf.

30 Ibid.; Zheng Xin, "Sinopec to harvest more heat from earth", *China Daily*, 15 February 2017, http://europe.chinadaily.com.cn/business/2017-02/15/content_28202201.htm.

31 "Malaysia's first geothermal power plant to open in Tawau", *The Star*, 8 August 2016, http://www.thestar.com.my/metro/community/2016/08/08/steaming-up-some-extra-energy-malaysias-first-geothermal-power-plant-to-open-in-tawau/; Eric Bagang, "Sabah home to Malaysia's first geothermal power plant", *New Sabah Times*, 6 August 2016, http://www.newsabahtimes.com.my/nstweb/fullstory/8452.

32 Linda Archibald, "M'sia boldly explores geothermal", *The Malaysian Reserve*, 14 October 2016, http://themalaysianreserve.com/new/story/m%E2%80%99sia-boldly-explores-geothermal.

33 Mannvit, "Velika Ciglena geothermal power plant contract", press release (Kopavogur, Iceland: 23 December 2015), http://www.mannvit.com/news/velika-ciglena-geothermal-power-plant-contract; Joseph Bonafin, Turboden, "The Velika Ciglena Geothermal Project – Turboden 16 MW Binary Plant", presentation at the Iceland Geothermal Conference, Reykjavik, 28 April 2016, http://www.geothermalconference.is/files/presentations/joseph-bonafin---igc-2016_atti.pdf.

34 Ibid., both references.

35 GEA, op. cit. note 1.

36 Reykjavik Geothermal, "Corbetti Geothermal Power", http://www.rg.is/static/files/about-us/rg-corbettigeothermalpower.pdf, viewed 31 March 2017; Alexander Richter, "Corbetti projects signs 500 MW PPA with Ethiopian state utility", ThinkGeoEnergy, 27 July 2016, http://www.thinkgeoenergy.com/corbetti-project-signs-500-mw-ppa-with-ethiopian-state-utility/.

37 International Finance Corporation, "Ethiopia's full steam push for an energy breakthrough", 14 January 2016, http://www.ifc.org/wps/wcm/connect/news_ext_content/ifc_external_corporate_site/news+and+events/news/za_ifc_geothermal_ethiopia_fiani.

38 "Ethiopia: Geothermal energy heats up with royalty payments exemption", AllAfrica, 2 August 2016, http://allafrica.com/stories/201608030493.html.

39 Naser Al Wasmi, "Abu Dhabi's Dh55m loan to St Vincent for geothermal power", *The National*, 2 February 2016, http://www.thenational.ae/uae/environment/abu-dhabis-dh55m-loan-to-st-vincent-for-geothermal-power; "ADFD signs AED55 million loan agreement with St. Vincent and the Grenadines to support key renewable energy project", *MENA Herald*, 2 February 2016, https://menaherald.com/en/economy/energy/adfd-signs-aed55-million-loan-agreement-st-vincent-grenadines-support-key-renewable-energy-project/.

40 Government of the Commonwealth of Dominica, "New Zealand invests in Dominica's exploration of geothermal energy", press release (New York: 21 September 2016), http://cbiu.gov.dm/new-zealand-invests-in-dominicas-exploration-of-geothermal-energy.

41 Ormat Technologies Inc., "Ormat announces closing of acquisition of the Bouillante Geothermal Power Plant in the Island of Guadeloupe", press release (Reno, NV: 5 July 2016), http://www.ormat.com/news/latestitems/ormat-announces-closing-acquisition-bouillante-geothermalpower-plant-island-guadel.

42 Data for 2014 from Lund and Boyd, op. cit. note 1. Capacity and generation for 2016 are extrapolated from 2014 values (from sources) by weighted-average growth rate across eight categories of geothermal direct use: space heating, bathing and swimming, greenhouse heating, aquaculture, industrial use, snow melting and cooling, agricultural drying and other.

43 Lund and Boyd, op. cit. note 1.

44 Ibid.

45 Ibid.

46 Ibid.

47 Ibid.

48 Ibid.

49 Ibid.

50 Ibid.

51 Ibid.

52 Dumas, op. cit. note 9.

53 Ibid.

54 Stadtwerke München GmbH, "Vision: Fernwärme aus regenerativen Energien", viewed 2 May 2017, https://www.swm.de/privatkunden/unternehmen/energie/vision-fernwarme.html; Bundesverband Geothermie, "Tiefe Geothermieprojekte in Deutschland", February 2017, http://www.geothermie.de/fileadmin/useruploads/wissenswelt/Projekte/Projektliste_Tiefe_Geothermie_2017.pdf.

55 Bundesverband Geothermie, op. cit. note 54.

56 ENGIE, "ENGIE wins public service delegation contract for a new geothermal heating network in the Plaine Rive Droite area of Bordeaux", press release (Paris: 12 January 2017), http://www.engie.com/en/journalists/press-releases/geothermal-bordeaux.

57 Roquette, "Roquette inaugurating the Rittershoffen deep geothermal power plant", press release (Lestrem, France: 7 June 2016), https://www.roquette.com/media-center/press-center/roquette-inaugurating-the-rittershoffen-deep-geothermal-power-plant; Albert Genter, ES-Géothermie, "The Rittershoffen Case Study (France)", presentation at the Iceland Geothermal Conference, Reykjavik, 26-29 April 2016, http://www.geothermalconference.is/files/presentations/a4---albert-genter-igc-case-studies.pdf.

58 Ibid., both references.

59 Genter, op. cit. note 57.

60 CNEA, op. cit. note 29.

61 Ibid.

62 United Nations Economic Commission for Europe, "UNFC is now applicable to geothermal energy resources", press release (Geneva: 5 October 2017), http://www.unece.org/?id=43987.

63 See, for example, "Atlas diversifies into geothermal wells drilling on low oil prices", *Business Daily*, 5 February 2015, http://www.ipsos.co.ke/NEWBASE_EXPORTS/KPLC/150206_Business%20Daily_19_91b5b.pdf; P. Dumas, M. Antics, and P. Ungemach, *Report on Geothermal Drilling* (Brussels: Geoelec, March 2013), http://www.geoelec.eu/wp-content/uploads/2011/09/D-3.3-GEOELEC-report-on-drilling.pdf.

64 See, for example, Matek, op. cit. note 25.

65 Chevron Corporation, "Chevron announces sale of geothermal operations", press release (San Ramon, CA: 23 December 2016), https://www.chevron.com/stories/chevron-announces-sale-of-geothermal-operations.

66 Ayala Energy and Infrastructure Group, "AC Energy completes acquisition of Chevron's Indonesia geothermal assets", April 2017, http://www.ayala-energyinfra.com/ac-energy-completes-acquisition-of-chevrons-indonesia-geothermal-assets/; Danessa Rivera, "AC Energy seals purchase of Chevron assets", *Philippine Star*, 4 April 2017, http://www.philstar.com/business/2017/04/04/1687328/ac-energy-seals-purchase-chevron-assets.

67 Ormat Technologies Inc., "Ormat and Toshiba sign strategic collaboration agreement", press release (Reno, NV and Tokyo: 14-15 October 2015), http://www.ormat.com/news/latest-items/ormat-and-toshiba-sign-strategic-collaboration-agreement.

68 Mitsubishi Hitachi Power Systems, "Mitsubishi Hitachi Power Systems commences operation, aims to become global leader in thermal power generation systems", 3 February 2014, https://www.mhps.com/en/news/20140203.html; Chisaki Watanabe, "MHI, Hitachi venture eyes Africa, Latin America for geothermal", *Bloomberg*, 24 November 2016, https://www.bloomberg.com/news/articles/2016-11-24/mhi-hitachi-venture-eyes-africa-latin-america-for-geothermal.

69 Watanabe, op. cit. note 68.

70 Iceland Deep Drilling Project, "The drilling of the Iceland Deep Drilling Project geothermal well at Reykjanes has been successfully completed", February 2017, http://iddp.is/wp-content/uploads/2017/02/IDDP-2-Completion-websites-IDDP-DEEPEGS2.pdf; Iceland Deep Drilling Project, "SAGA Report No. 10", 24 June 2016, http://iddp.is/wp-content/uploads/2016/07/SAGA-REPORT-No-10.pdf.

71 Bjarni Mar Juliusson, "The Sulfix project", presentation at the Iceland Geothermal Conference, Reykjavik, 26-29 April 2016,

http://www.geothermalconference.is/files/presentations/a3---bjarni-mar-juliusson-----the-sulfix-project.pdf; Bjarni Mar Juliusson et al., "Tackling the challenge of H2S emissions", *Proceedings of the World Geothermal Congress 2015, Melbourne, Australia: 19-25 April 2015*, https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/02062.pdf.

72 Juliusson, "The Sulfix project", op. cit. note 71.

73 Juerg M. Matter et al., "Rapid carbon mineralization for permanent disposal of anthropogenic carbon dioxide emissions", *Science*, 10 June 2016, http://science.sciencemag.org/content/352/6291/1312.full.

74 Juliusson, op. cit. note 71, both references; Rhea Healy, "Haldor Topsoe and HS Orka hf sign contract for CO_2 capture plant from geothermal sources in Iceland", gasworld, 25 April 2016, https://www.gasworld.com/newplant-to-capture-co2-from-geothermal-facility/2010320.article.

75 Alison Holm, Dan Jennejohn and Leslie Blodgett, *Geothermal Energy and Greenhouse Gas Emissions* (Washington DC: GEA, November 2012), http://geo-energy.org/reports/GeothermalGreenhouseEmissionsNov2012GEA_web.pdf.

76 Erik B. Layman, "Geothermal projects in Turkey: extreme greenhouse gas emissions rate comparable to or exceeding those from coal-fired plants", *Proceedings of the 42nd Workshop on Geothermal Reservoir Engineering, Stanford University, 13-15 February 2017*, https://pangea.stanford.edu/ERE/db/GeoConf/papers/SGW/2017/Layman.pdf.

77 Niyazi Aksoy et al., "CO_2 emissions from geothermal power plants in Turkey", *Proceedings of the World Geothrmal Congress 2015, Melbourne, Australia: 19-25 April 2015*, https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/02065.pdf.

78 Anna Hirstenstein, "These clean energy projects pollute more than coal power plants", *Bloomberg*, 20 July 2016, https://www.bloomberg.com/news/articles/2016-07-21/these-clean-energy-projects-pollute-more-than-coal-power-plants; Climate Bonds Initiative, "Geothermal", https://www.climatebonds.net/standard/geothermal, viewed March 2017.

79 Ecofys, Ernst & Young Turkey and the Middle East Technology University, "Assessing the use of CO_2 from natural sources for commercial purposes in Turkey", 6 July 2016, http://www.ecofys.com/en/publications/assessing-the-commercial-use-of-co2-from-natural-sources-in-turkey/.

80 Enel, "Enel begins operations at world's first commercial geothermal-hydro hybrid power plant", press release (Rome: 6 December 2016), https://www.enel.it/en/media/press/d201612-enel-begins-operations-at-worlds-first-commercial-geothermal-hydro-hybrid-power-plant-.html.

81 US Department of Energy (DOE), "EERE success story – DOE-funded project is first permanent facility to coproduce electricity from geothermal resources at an oil and gas well", 12 May 2016, https://energy.gov/eere/success-stories/articles/eere-success-story-doe-funded-project-first-permanent-facility-co.

82 DOE, *2016 Annual Report – Geothermal Technologies Office* (Washington, DC: March 2017), https://www.energy.gov/sites/prod/files/2017/03/f34/GTO%202016%20Annual%20Report_1.pdf.

83 DOE, "What is an Enhanced Geothermal System (EGS)?" fact sheet (Washington, DC: May 2016), https://energy.gov/sites/prod/files/2016/05/f31/EGS%20Fact%20Sheet%20May%202016.pdf.

84 Bergur Sigfússon and Andreas Uihlein, *2015 JRC Geothermal Energy Status Report* (Petten, The Netherlands: European Commission Joint Research Centre, 2015), https://setis.ec.europa.eu/sites/default/files/reports/2015_jrc_geothermal_energy_status_report.pdf.

85 Ibid.

02

HYDROPOWER

1 Global capacity estimate based on International Hydropower Association (IHA), *2017 Key Trends in Hydropower* (London: April 2017), http://www.hydropower.org, and on IHA, personal communication with REN21, March-April 2017. Total installed capacity is 1,246 GW (31.5 GW added), less 150 GW of pumped storage (6.4 GW added).

2 Country data from the following sources: **China:** total capacity, capacity growth, utilisation and investment from China CNEA, summary of national electric industry statistics for 2016, http://www.nea.gov.cn/2017-01/16/c_135986964.htm; capacity additions in 2016, including pumped storage, from China Electricity Council, annual report on national power system, 25 January 2017, http://www.cec.org.cn/yaowenkuaidi/2017-01-25/164285.html; capacity, including pumped storage, at year-end 2015 from CNEA, *13th Five-Year-Plan for Hydro Power Development* (Beijing: 29 November 2016), http://www.nea.gov.cn/135867663_14804701976251n.pdf; generation of 1,193.4 TWh and annual growth of 5.6% from National Bureau of Statistics of China, "Statistical communiqué of the People's Republic of China on the 2016 national economic and social development", press release (Beijing: 28 February 2017), http://www.stats.gov.cn/english/PressRelease/201702/t20170228_1467503.html. **Brazil:** 5,292 MW (5,002 MW large hydro, 203 MW small hydro and 87 MW very small hydro) added in 2016, from National Agency for Electrical Energy (ANEEL), "Resumo geral dos novos empreendimentos de geração", http://www.aneel.gov.br/documents/655816/15224356/Resumo_Geral_das_Usinas_março_2017.zip, updated March 2017; large hydro capacity is listed as 91,499 MW at end-2016, small (1-30 MW) hydro as 4,941 MW and very small (less than 1 MW) hydro as 484 MW (compared to 398 MW in the previous year), for a total of 96,925 MW; generation from National Electrical System Operator of Brazil (ONS), "Geração de energia", http://www.ons.org.br/historico/geracao_energia.aspx. **United States:** capacity from US Energy Information Administration (EIA), *Electric Power Monthly*, February 2017, Tables 6.2.B and 6.3, http://www.eia.gov/electricity/monthly; generation from idem, Table 1.1. **Canada:** data for 2015 only from Statistics Canada, "Table 127-0009 installed generating capacity, by class of electricity producer", http://www5.statcan.gc.ca/cansim; generation for 2015 only from idem, "Table 127-0002 electric power generation, by class of electricity producer". **Russian Federation:** capacity and generation from System Operator of the Unified Energy System of Russia, *Report on the Unified Energy System in 2016* (Moscow: 31 January 2017), http://www.so-ups.ru/fileadmin/files/company/reports/disclosure/2017/ups_rep2016.pdf. **India:** installed capacity in 2016 (units larger than 25 MW) of 43,139 MW from Government of India, Ministry of Power, Central Electricity Authority (CEA), "All India installed capacity (in MW) of power stations", December 2016, http://www.cea.nic.in/reports/monthly/installedcapacity/2016/installed_capacity-12.pdf; capacity additions in 2016 (greater than 25 MW) of 415 MW from idem, "Executive summary of the power sector (monthly)", http://www.cea.nic.in/monthlyarchive.html; installed capacity in 2016 (<25 MW) of 4,325 MW from Government of India, Ministry of New and Renewable Energy (MNRE), "Physical progress (achievements)", http://www.mnre.gov.in/mission-and-vision-2/achievements/, viewed 19 January 2017; capacity additions in 2016 (<25 MW) of 148 MW based on difference of year-end 2016 figure (above) and year-end 2015 figure (4,177 MW) from MNRE, idem; generation for plants larger than 25 MW (120.4 TWh) from Government of India, CEA, "Executive summary of the power sector (monthly)", op. cit. this note; output from hydro plants smaller than 25 MW (8.2 TWh) from idem, "Renewable energy generation report", http://www.cea.nic.in/monthlyarchive.html. **Norway:** capacity and generation from Statistics Norway, https://www.ssb.no, and from Norwegian Water Resources and Energy Directorate, https://www.nve.no/Media/5258/ny_kraft_tillatelser_og_utbygging_4kv_16.pdf. **Figure 13** based on capacity and generation sources provided in this note.

3 Estimate based on IHA, op. cit. note 1, and on IHA, *Hydropower Status Report 2016* (London: May 2016), http://www.hydropower.org.

4 IHA, op. cit. note 1.

5 Capacity values by country from sources provided in endnote 2 and from IHA, op. cit. note 1. **Figure 14** based on idem.

6 See text and sources throughout this section.

7 Total capacity, capacity growth, utilisation and investment from CNEA, op. cit. note 2; capacity additions in 2016, including pumped storage, from China Electricity Council, op. cit. note 2; capacity, including pumped storage, at year-end 2015 from CNEA, *13th Five-Year-Plan,* op. cit. note 2.

8 Ibid., all references.

9 Growth of 6.2% and resource conditions from China Electricity Council, op. cit. note 2; generation of 1,193.4 TWh and annual growth of 5.6% from National Bureau of Statistics of China, op. cit. note 2.

10 CNEA, summary of national electric industry statistics for 2016, op. cit. note 2.

11 CNEA, *13th Five-Year-Plan,* op. cit. note 2.

12 ANEEL, op. cit. note 2.

13 Generation from ONS, op. cit. note 2.

14 ANEEL, "Relatório de acompanhamento da implantação de empreendimentos de geração", October 2016, http://www.aneel.gov.br/boletim-da-expansao-da-oferta.

15 Ibid.; ANEEL, "Acompanhamento das centrais geradoras hidrelétricas", March 2017, http://www.aneel.gov.br/documents/655816/15224356/Ralie_UHE_mar_17.pdf.

16 ANEEL, op. cit. note 14; ANEEL, op. cit. note 15.

17 Sebastian Espinoza, Instituto Nacional de Eficiencia Energética y Energías Renovables (INER), Quito, Ecuador, personal communication with REN21, December 2016; doubling of capacity based on International Renewable Energy Agency (IRENA), *Renewable Energy Statistics 2017* (Abu Dhabi: 2017), http://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Capacity_Statistics_2017.pdf.

18 "Ecuador's largest hydro plant built by China inaugurated", *Xinhua*, 14 April 2016, http://news.xinhuanet.com/english/2016-04/14/c_135277722.htm; China Gezhouba Group Co., Ltd, "Ecuadorian president attended the power generation ceremony of three generator units of Sopladora hydropower station", *China Daily*, 25 August 2016, http://www.chinadaily.com.cn/m/gezhouba/2016-08/25/content_27110790.htm.

19 Government of Peru, Organismo Supervisor de la Inversión en Energía y Minería, inventory of hydropower projects, http://www.osinergmin.gob.pe/empresas/electricidad/proyectos/generacion, viewed May 2017; Rumbo Minero, "Hidroeléctrica Chaglla inicia operación comercial", http://www.rumbominero.com/noticias/energia/hidroelectrica-chaglla-inicia-operacion-comercial/; BNAmericas, *Central Hidroeléctrica Cerro del Águila*, https://www.bnamericas.com/project-profile/es/cerro-del-aguila-hydro-plant-hidroelectrica-cerro-del-aguila; IHA, *2016 Hydropower Status Report* (London: May 2016), http://www.hydropower.org.

20 Salini Impregilo, "Ethiopia inaugurates tallest RCC dam in world built by Salini Impregilo", press release (Milan: 17 December 2016), https://www.salini-impregilo.com/en/press/press-releases/ethiopia-inaugurates-tallest-rcc-dam-in-world-built-by-salini-impregilo.html.

21 "Ethiopia: Gibe III feeds grid with 800 MW", ESI Africa, 14 September 2016, https://www.esi-africa.com/news/ethiopia-gibe-iii-feeds-grid-with-800mw/; "Hydropower Ethiopia: Gibe III to come online mid 2015", ESI Africa, 20 March 2015, https://www.esi-africa.com/news/hydropower-ethiopia-gibe-iii-online-mid-2015; "Gibe III hydro plant: Ethiopia rolls out power generation", ESI Africa, 1 September 2015, https://www.esi-africa.com/news/gibe-iii-hydro-plant-ethiopia-rolls-out-power-generation/.

22 "Gibe III hydro plant: Ethiopia rolls out power generation", op. cit. note 21; "Ethiopia uses Chinese transformers to bolster power transmission", ESI Africa, 18 August 2014, https://www.esi-africa.com/news/ethiopia-uses-chinese-transformers-to-bolster-power-transmission/.

23 IHA, op. cit. note 19; IHA, *2017 Key Trends in Hydropower*, op. cit. note 1.

24 Vietnam Electricity Corporation – National Electricity Center, press release (Hanoi: 16 November 2016), http://www.nldc.evn.vn/FullNewsg/6/He-thong-dien/default.aspx; Vietnam Electricity Corporation – National Electricity Center, press release (Hanoi: 23 June 2016), http://www.nldc.evn.vn/newsg/6/1727/To-may-2-Thuydien-Lai-Chau-Chinh-thuc-hoa-luoi/default.aspx; Vietnam Electricity Corporation – National Electricity Center, press release (Hanoi: 16 December 2015), http://www.nldc.evn.vn/

newsg/6/1690/Hoa-luoi-to-may-so-1-Nha-may-Thuy-dien-Lai-Chau/default.aspx.

25 "Huoi Quang hydropower plant's second turbine becomes operational", Vietnam Plus, 20 June 2016, http://en.vietnamplus.vn/huoi-quang-hydropower-plants-second-turbine-becomes-operational/94975.vnp; "Cốc San power plant opens", *Vietnam News*, 9 June 2016, http://vietnamnews.vn/society/297917/coc-san-powerplant-opens.html.

26 Lao PDR Ministry of Energy and Mines website, http://laoenergy.la; IHA, personal communication with REN21, April 2017.

27 Tenaga Nasional, "Ulu Jelai hydroelectric project to boost TNB's hydro installed capacity to 2,533 MW", press release (Kuala Lumpur: 9 August 2016), https://www.tnb.com.my/assets/press_releases/PRESS_RELEASE_-_ULU_JELAI_HYDROELECTRIC_PROJECT_TO_BOOST_TNBS_HYDRO_INSTALLED_CAPACITY_TO_2%2C533MW_09082016.pdf; "New source of green power", *The Star*, 24 September 2016, http://www.thestar.com.my/metro/community/2016/09/24/new-sources-of-power-two-dams-in-tasik-kenyir-to-add-265mw-to-national-grid/.

28 Capacity at end-2016 of 26.7 GW from TEİAŞ website, http://www.teias.gov.tr; increase of 0.8 GW based on total capacity of 25.9 GW at end-2015 reported in 2016 by same source.

29 Generation from TEİAŞ website, https://ytbs.teias.gov.tr.

30 Capacity additions in 2016 (units larger than 25 MW) of 415 MW from Government of India, Ministry of Power, CEA, "Executive summary of the power sector (monthly)", op. cit. note 2; capacity additions in 2016 (<25 MW) of 148 MW based on difference of year-end 2016 figure (4,325 MW) from Government of India, MNRE, op. cit. note 2, and year-end 2015 figure (4,177 MW) from MNRE, idem.

31 Installed capacity in 2016 (units larger than 25 MW) of 43,139 MW from Government of India, Ministry of Power, CEA, "All India installed capacity (in MW) of power stations", op. cit. note 2; installed capacity in 2016 (<25 MW) of 4,325 MW from Government of India, MNRE, op. cit. note 2.

32 Generation for plants larger than 25 MW (120.4 TWh) from Government of India, CEA, "Executive summary of the power sector (monthly)", op. cit. note 2; output from hydropower plants smaller than 25 MW (8.4 TWh) from idem, "Renewable energy generation report", http://www.cea.nic.in/monthlyarchive.html.

33 EIA, op. cit. note 2, Tables 6.2.B and 6.3; US Federal Energy Regulatory Commission, "Energy Infrastructure Update for December 2016" (Washington, DC: December 2016), https://www.ferc.gov/legal/staff-reports/2016/dec-energy-infrastructure.pdf.

34 Annual generation data from EIA, op. cit. note 2, Table 1.1.

35 California output data from EIA, *Electric Power Monthly with Data for December 2016* (Washington, DC: February 2017), Table 1.10.B, p. 37, https://www.eia.gov/electricity/monthly/; US Department of Energy (DOE), "Record precipitation, snowpack in California expected to increase hydro generation in 2017", Today in Energy, 23 March 2017, https://www.eia.gov/todayinenergy/detail.php?id=30452.

36 Office of the Governor, State of California, "Governor Brown takes action to bolster dam safety and repair transportation and water infrastructure", press release (Sacramento: 24 February 2017), https://govnews.gov.ca.gov/news.php?id=19696; California Department of Water Resources, "Oroville spillway incident overview", http://www.water.ca.gov/oroville-spillway/index.cfm.

37 Based on 2016 year-end capacity of 48,086 MW from System Operator of the Unified Energy System of Russia, op. cit. note 2, and 47,855 MW at the end of 2015, from System Operator of the Unified Energy System of Russia, *Report on the Unified Energy System in 2016* (Moscow: 1 February 2016), http://www.so-ups.ru/fileadmin/files/company/reports/disclosure/2016/ups_rep2015.pdf.

38 RusHydro, "RusHydro launches Zaragizhskaya small hydropower plant in the South of Russia", press release (Moscow: 29 December 2016), http://www.eng.rushydro.ru/press/news/102279.html; RusHydro, "RusHydro inaugurates Zelenchukskaya hybrid hydropower plant in the South of Russia", press release (Moscow: 23 December 2016), http://www.eng.rushydro.ru/press/news/102176.html.

39 System Operator of the Unified Energy System of Russia, monthly operational data for December 2016, http://www.so-ups.ru/fileadmin/files/company/reports/ups-review/2017/ups_review_dec16.pdf; RusHydro, "RusHydro's Kamskaya hydropower plant's capacity uprated by 14% after modernization", press release (Moscow: 1 February 2016), http://www.eng.rushydro.ru/press/news/99866.html.

40 System Operator of the Unified Energy System of Russia, op. cit. note 2; System Operator of the Unified Energy System of Russia, op. cit. note 37.

41 RusHydro, "RusHydro Group announces its operating results for the 4Q and FY2016", press release (Moscow: 30 January 2017), http://www.eng.rushydro.ru/press/news/102405.html.

42 World Bank, "Overview on hydropower", http://www.worldbank.org/en/topic/hydropower/overview, viewed May 2017.

43 World Bank, *Accelerating Climate-Resilient and Low-Carbon Development: Progress Report on the Implementation of the Africa Climate Business Plan* (Washington, DC: October 2016), http://documents.worldbank.org/curated/en/229241478495138849/Africa-Region-Accelerating-climate-resilient-and-low-carbon-development-progress-report-on-the-implementation-of-the-Africa-climate-business-plan.

44 Ibid., pp. 75-76.

45 World Bank, "World Bank Group suspends financing to the Inga-3 Basse Chute Technical Assistance Project", press release (Washington, DC: 25 July 2016), http://www.worldbank.org/en/news/press-release/2016/07/25/world-bank-group-suspends-financing-to-the-inga-3-basse-chute-technical-assistance-project; World Bank, "Inga-3 Basse Chute and Mid-size Hydropower Development Technical Assistance Project", 20 March 2014, http://www.worldbank.org/en/country/drc/brief/inga-3-basse-chute-and-mid-size-hydropower-development-technical-assistance-project; "DR Congo seeks managers, accountant for 4,800-MW Inga 3 Basse Chute, medium hydro projects", HydroWorld, 21 September 2015, http://www.hydroworld.com/articles/premium-content/2015/09/dr-congo-seeks-managers-accountant-for-4-800-mw-inga-3-basse-chute-medium-hydro-projects.html.

46 World Bank, "World Bank Group suspends financing…", op. cit. note 45.

47 International Energy Agency (IEA), *World Energy Outlook 2016* (Paris: 2016), p. 508.

48 IHA, 2017 *Key Trends in Hydropower*, op. cit. note 1.

49 Eskom, "Ingula: powering South Africa's economy", press release (Johannesburg: 8 March 2017), http://www.eskom.co.za/news/Pages/Marr8.aspx.

50 Ibid.

51 Axpo, "Festive inauguration of the Muttsee dam", press release (Baden, Switzerland: 9 September 2016), http://www.axpo.com/axpo/ch/en/news/news/medienmitteilungen/2016/staumauer-muttsee-feierlich-eingeweiht.html.

52 João Graça Gomes, Portuguese Renewable Energy Association (APREN), personal communication with REN21, February-April 2017; Energias de Portugal (EDP), http://a-nossa-energia.edp.pt/centros_produtores/index.php; Alexandre Ferreira da Silva et al., "Developing the Baixo Sabor pumped storage cascade in Portugal", HydroWorld, 1 April 2017, http://www.hydroworld.com/articles/print/volume-25/issue-2/features/developing-the-baixo-sabor-pumped-storage-cascade-in-portugal.html.

53 EDP, op. cit. note 52; DOE, DOE Global Energy Storage Database, http://www.energystorageexchange.org, viewed 4 May 2017.

54 João Graça Gomes, APREN, personal communication with REN21, February 2017; Directorate General for Energy and Geology, *Estatísticas Rápidas*, no. 146 (3 March 2017), http://www.dgeg.pt.

55 "Key Canary Islands infrastructure completed for Soria-Chira pumped storage hydro project", Renewable Energy World, 17 October 2016, http://www.renewableenergyworld.com/articles/2016/10/key-canary-islands-infrastructure-completed-for-soria-chira-pumped-hydro-project.html; Red Eléctrica de España, "Soria-Chira pumped-storage hydropower plant", http://www.ree.es/en/activities/unique-projects/soria-chira-pumped-storage-hydropower-plant.

56 Naturspeicher website, http://www.naturspeicher.de/en/index.php, viewed March 2017.

57 RusHydro, op. cit. note 39.

58 See, for example, GE, *Powering the Digital Transformation of*

Electricity (Boston: 2016), https://www.ge.com/digital/sites/default/files/Power%20Digital%20Solutions%20Product%20Catalog.pdf.

59 IHA, *2017 Key Trends in Hydropower*, op. cit. note 1.

60 Ibid.

61 Climate Bonds Initiative, "Hydropower", https://www.climatebonds.net/hydropower; Sean Kidney, "Launch of Hydropower Technical Working Group: developing new criteria for green investment: science based focus on climate mitigation and adaptation for hydro energy", Climate Bonds Initiative, 19 July 2016, https://www.climatebonds.net/2016/07/launch-hydropower-technical-working-group-developing-new-criteria-green-investment-science.

62 Hydropower Equipment Association, Brussels, personal communication with REN21, February 2015.

63 China Electricity Council, review of global hydropower activity, http://www.cec.org.cn/yaowenkuaidi/2016-01-27/148495.html.

64 Dongfang, "Inauguration ceremony for GIBE III hydroelectric power plant", press release (Chengdu, China: 17 December 2016), http://dongfang.com.cn/index.php?s=/home/article/detail/id/1106.html; Andritz, "Coca Codo Sinclair – largest hydropower plant of Ecuador under construction", Hydro News, no. 24 (2013), https://www.andritz.com/index/hydro/hydronews/hy-hydro-news-24/hy-24-19-coca-codo-sinclair.htm.

65 GE, *2016 Annual Report* (Boston: 2016), p. 42, http://www.ge.com/ar2016/assets/pdf/GE_AR16.pdf.

66 Andritz, *Annual Report 2016* (Graz, Austria: 2017), pp. 51 and 57, http://www.andritz.com/gr-andritz-financial-report-2016_en.pdf.

67 Voith, Annual Report 2016 (Heidenheim, Germany: December 2016), pp. 35, 55, 64-65, http://voith.com/en/Voith_GB_2016_e.pdf.

68 Ibid., p. 55.

69 Axpo, "Axpo strongly impairs Limmern pumped-storage power plant – further value adjustments required as prices are likely to remain low", press release (Baden, Switzerland: 19 September 2016), http://www.axpo.com/axpo/ch/en/news/news/medienmitteilungen/2016/wertberichtigungen2016.html; Axpo, op. cit. note 51.

70 Axpo, op. cit. note 51.

OCEAN ENERGY

1 The definition of ocean energy used in this report does not include offshore wind power or marine biomass energy.

2 International Renewable Energy Agency (IRENA), Renewable *Capacity Statistics 2017* (Abu Dhabi: April 2017), http://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Capacity_Statistics_2017.pdf.

3 Ocean Energy Systems (OES), *Annual Report 2016* (Lisbon: April 2017), p. 173, https://report2016.ocean-energy-systems.org.

4 See, for example, Ibid., Executive Summary.

5 "Tidal lagoon: £1.3bn Swansea Bay project backed by review", *BBC News*, 12 January 2017, http://www.bbc.com/news/uk-wales-38571240.

6 UK Department of Energy & Climate Change (DECC), "Review of tidal lagoons", press release (London: 10 February 2016), https://www.gov.uk/government/news/review-of-tidal-lagoons; Charles Hendry, *The Role of Tidal Lagoons – Final Report*, December 2016, https://hendryreview.files.wordpress.com/2016/08/hendry-review-final-report-english-version.pdf.

7 OES, op. cit. note 3, p. 173.

8 European Commission (EC), Ocean Energy Forum, *Ocean Energy Strategic Roadmap – Building Ocean Energy for Europe* (Brussels: November 2016), https://webgate.ec.europa.eu/maritimeforum/en/node/3962.

9 "Administrators seek buyer for Tidal Energy Ltd", *BBC News*, 24 October 2016, http://www.bbc.com/news/uk-wales-south-west-wales-37752750.

10 Nova Innovation, "Nova & ELSA third turbine deployed in Shetland tidal array – a world showcase for Scottish renewable innovation", press release (Edinburgh: 23 February 2017), https://media.wix.com/ugd/36770a_87c2b2545db246c7b2fd7707b239077c.docx?dn=Nova%20T3%20Press%20Release%2023rd%20Feb%202017.docx; Nova Innovation, "Nova Innovation deploys world's first fully operational offshore tidal array in Scotland", press release (Edinburgh: no date), https://media.wix.com/ugd/efc58c_651189c778284074bc41d080564bcdf8.docx?dn=NOVA%20INNOVATION%20DEPLOYS%20WORLDS%20FIRST%20TIDAL%20ARRAY.docx.

11 Scotrenewables Tidal Power, "Scotrenewables installs world's largest tidal turbine at EMEC for first time", press release (Edinburgh: 13 October 2016), http://www.emec.org.uk/press-release-scotrenewables-installs-worlds-largest-tidal-turbine-at-emec-for-first-time/.

12 Scotrenewables Tidal Power, "SR2000", http://www.scotrenewables.com/technology-development/sr2000, viewed 27 April 2017; Scotrenewables Tidal Power, "The Concept", http://www.scotrenewables.com/technology-development/the-concept, viewed 27 April 2017.

13 Atlantis Resources, "Meygen update – full power generation form turbine #1", press release (Edinburgh: 6 December 2016), https://www.atlantisresourcesltd.com/2016/12/07/meygen-update-full-power-generation-turbine-1.

14 Atlantis Resources, "MeyGen Update – AR1500 turbine deployed in record time", press release (Edinburgh: 20 February 2017), https://www.atlantisresourcesltd.com/2017/02/20/2225; Atlantis Resources, "MeyGen Update – AR1500 turbine generating to the grid", press release (Edinburgh: 24 February 2017), https://www.atlantisresourcesltd.com/2017/02/24/meygen-update-ar1500-turbine-generating-grid.

15 Atlantis Resources, "MeyGen Update – AR1500 turbine deployed in record time", op. cit. note 14.

16 Sabella SAS, "Fin de la première campagne d'essai de D10", 15 July 2016, http://www.sabella.fr/fiche.php?id=257; Sabella SAS, "Sabella D10, 1re hydrolienne à injecter de l'électricité sur le réseau électrique français", 7 November 2015, http://www.sabella.fr/fiche.php?id=252.

17 OpenHydro, "OpenHydro deploys second Paimpol-Bréhat turbine", press release (Dublin: 30 May 2016), http://www.openhydro.com/OpenHydro/media/Documents/News%20PDFs/30-May-2016.pdf; OpenHydro, "The first of two OpenHydro tidal turbines on EDF's Paimpol-Bréhat site successfully deployed", press release (Dublin: 20 January 2016), http://www.openhydro.com/OpenHydro/media/Documents/News%20PDFs/20-Jan-2016.pdf.

18 Cape Sharp Tidal, "Cape Sharp Tidal now powers Nova Scotia homes and businesses", 22 November 2016, http://capesharptidal.com/firstpower.

19 Ibid.

20 Minas Tidal, "Nova Scotia attracts international tidal energy players", press release (Halifax, NS: 12 July 2016), http://minastidal.com/nova-scotia-attracts-international-tidal-energy-players; Black Rock Tidal Power, "BRTP tidal power platform to be fabricated by Aecon", press release (Halifax: 18 May 2016), http://www.blackrocktidalpower.com/fr/news; OES, op. cit. note 3, p. 63.

21 Technalia, "Oceantec deployed at BiMEP its first wave energy converter", 13 October 2016, http://www.tecnalia.com/en/energy-and-environment/news/oceantec-deployed-at-bimep-its-first-wave-energy-converter.htm; Oceantec website, http://www.oceantecenergy.com, viewed 27 April 2017.

22 Basque Energy Agency (EVE), "Marine energy", http://www.eve.eus/Proyectos-energeticos/Proyectos/Energia-Marina.aspx, viewed 25 April 2017; OES, op. cit. note 3, p. 143.

23 Eco Wave Power, "The future is here: Europe's first grid connected wave energy array", press release (Tel Aviv: 1 June 2016), http://www.multivu.com/players/uk/7851451-eco-wave-europe-first-grid-connected-energy; "Israeli wave energy player gets industry accolades", Tidal Energy Today, 21 March 2016, http://tidalenergytoday.com/2016/03/21/israeli-wave-energy-player-gets-industry-accolades.

24 Waves4Power, "6 months at Runde", 9 August 2016, http://www.waves4power.com/w4p-news-updates/1706; Seabased, "Wave power generated to Nordic electricity grid!", 21 January 2016, http://www.seabased.com/en/newsroom/218-wave-power-generated-to-nordic-electricity-grid.

25 Seabased, op. cit. note 24.

26 Fred. Olsen & Co. website, http://www.boltwavepower.com, viewed 27 April 2017; Fred. Olsen & Co., "6 month of continuous power export", 20 January 2017, http://www.boltwavepower.com/6-month-of-continuous-power-export.

27 Northwest Energy Innovations, "Northwest Energy Innovations launches wave energy device in Hawai'i", 9 June 2015, http://azurawave.com/northwest-energy-innovations-launches-wave-energy-device-in-hawaii; Tim Ramsey, US Department of Energy (DOE), "United States Department of Energy: Status of Wave Energy Deployments and Data Collection," presentation at International Conference on Ocean Energy 2016, Edinburgh, 23-25 February 2016, https://www.icoe-conference.com/publication/a5-united-states-department-of-energy-status-of-wave-energy-system-deplyments-and-data-collection/; Steve Dent, "Wave generator supplies US electrical grid for the first time", Engadget, 7 July 2015, https://www.engadget.com/2015/07/07/wave-generator-hawaii-power-grid.

28 US National Renewable Energy Laboratory (NREL), "National Wind Technology Center begins first validation of wave energy conversion device", press release (Golden, CO: 13 January 2017), http://www.nrel.gov/news/press/2017/41776.

29 Korea Research Institute of Ships & Ocean Engineering, "Development of wave energy converters applicable to breakwater and connected to micro-grid with energy storage system", 9 February 2017, http://www.kriso.re.kr/eng/user/3400ms; OES, op. cit. note 3, p. 132.

30 OES, op. cit. note 3, p. 133.

31 "World's first 3.4-megawatt modular tidal current power generator put into use", *People's Daily*, 16 August 2016, http://en.people.cn/n3/2016/0816/c98649-9100823.html.

32 OES, op. cit. note 3, p. 72.

33 China's State Oceanic Administration, announcement of the 13th Five-Year Plan on ocean energy, 1 January 2017, http://www.soa.gov.cn/zwgk/zcgh/kxcg/201701/t20170112_54473.html.

34 Ibid.

35 EC, op. cit. note 8; Ocean Energy Europe, "Ocean Energy Europe: innovative finance needed to build an innovative industry", press release (Brussels: 8 November 2016), http://www.oceanenergyeurope.eu/en/communication/industry-news/33-oee-publications/501-press-release-ocean-energy-europeinnovative-finance-needed-to-build-an-innovative-industry.

36 Interreg NWE, "FORESEA programme awards support to ten offshore renewable energy technology developers", press release (Lille, France: 9 November 2016), http://www.nweurope.eu/projects/project-search/funding-ocean-renewable-energy-through-strategic-european-action/1st-call-for-applications/press-release-foresea-programme-awards-support-to-ten-offshore-renewable-energy-technology-developers/; Interreg NWE, "FORESEA: Project Summary", http://www.nweurope.eu/projects/project-search/funding-ocean-renewable-energy-through-strategic-european-action/2nd-call-for-applications, viewed 23 April 2017.

37 Wave Energy Scotland, "Wave energy technology projects awarded £2M," 21 September 2016, http://www.waveenergyscotland.co.uk/news-events/wave-energy-technology-projects-awarded-2m.

38 Wave Energy Scotland, "£3m investment in wave energy projects", 10 January 2017, http://www.waveenergyscotland.co.uk/news-events/3m-investment-in-wave-energy-projects.

39 AW-Energy, "EIB to bank WaveRoller commercialization project", 6 July 2016, http://aw-energy.com/eib-to-bank-waveroller-commercialisation-project.

40 DOE, "Northwest National Marine Renewable Energy Center will support innovation in wave energy technologies", press release (Washington, DC: 21 December 2016), https://energy.gov/articles/energy-department-announces-investment-wave-energy-test-facility; total net utility-scale generation in 2016 from US Energy Information Administration, *Electric Power Monthly*, February 2017, Table 1.1, https://www.eia.gov/electricity/monthly/current_year/february2017.pdf.

41 OES, op. cit. note 3, pp. 10, 109-111; Centro Mexicano de Innovación en Energía Océano website, http://cemieoceano.mx/index.html, viewed 24 April 2017.

42 Nathalie Almonacid, Marine Energy Research & Innovation Center (MERIC), personal communication with REN21, February 2017; MERIC, "Nuestro trabajo", http://www.meric.cl/nuestro-trabajo, viewed 25 April 2017.

43 Andrea Copping et al., *Annex IV 2016 State of the Science Report: Environmental Effects of Marine Renewable Energy Development Around the World* (Richland, WA: Ocean Energy Systems and Pacific Northwest National Laboratory, April 2016), http://tethys.pnnl.gov/publications/state-of-the-science-2016.

44 Ibid.

45 OES, *Consenting Process of Ocean Energy – Update on Barriers and Recommendations* (Lisbon: July 2016), https://www.ocean-energy-systems.org/library/oes-reports/consenting/document/consenting-processes-for-ocean-energy-barriers-and-recommendations-2016-/.

46 Tidal Energy Ltd., "Wales steps forward in marine renewable energy as the country's first full-scale tidal energy demonstration device is installed", press release (Cardiff: 13 December 2015), http://www.tidalenergyltd.com/?p=2418; "Administrators seek buyer for Tidal Energy Ltd", op. cit. note 9; Institution of Mechanical Engineers, "Tidal Energy hits back at its critics", 11 January 2017, http://www.imeche.org/news/news-article/tidal-energy-hits-back-at-its-critics.

SOLAR PHOTOVOLTAICS

1 At least 75 GW added from International Energy Agency (IEA) Photovoltaic Power Systems Programme (PVPS), *Snapshot of Global Photovoltaic Markets 2016* (Paris: April 2017), p. 4, http://www.iea-pvps.org/fileadmin/dam/public/report/PICS/IEA-PVPS_-__A_Snapshot_of_Global_PV_-_1992-2015_-_Final_2_02.pdf. Note that some countries report data officially in alternating current (AC) (e.g., Canada, Chile, Japan since 2012, and Spain); these data were converted to direct current (DC) by relevant sources provided in this section for consistency across countries. Most utility-scale solar PV plants built in 2016 have an AC-DC ratio between 1.2 and 1.5, from IEA PVPS, op. cit. this note. The GSR 2017 attempts to report all solar PV data in DC units, and only capacity that is in operation at year's end. Number of panels based on average of 270 watts per panel, from Gaëtan Masson, Becquerel Institute and IEA PVPS, personal communications with REN21, March-May 2016.

2 Market increase relative to 2015 based on data from IEA PVPS, *Snapshot of Global Photovoltaic Markets 2015* (Paris: April 2016), http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/IEA-PVPS_-__A_Snapshot_of_Global_PV_-_1992-2015_-_Final.pdf; from SolarPower Europe, "2015: A positive year for solar", press release (Brussels: 3 March 2016), http://www.solarpowereurope.org/media/press-releases/; and from IEA PVPS, op. cit. note 1. Larger than total five years earlier based on cumulative world capacity of 70 GW (69,876.2 MW) at the end of 2011, from IEA PVPS, op. cit. this note, p. 68.

3 At least 303 GW, from IEA PVPS, op. cit. note 1, p. 7. **Figure 15** based on data from IEA PVPS, *Trends in Photovoltaic Applications, 2016: Survey Report of Selected IEA Countries Between 1992 and 2015* (Paris: 2016), http://www.ieapvps.org/fileadmin/dam/public/report/national/Trends_2016_-_mr.pdf, and from IEA PVPS, op. cit. note 1.

4 Fourth consecutive year based on 2015 being the third consecutive year, from Masson, op. cit. note 1; share of global additions based on data from SolarPower Europe, "What's next for solar in Europe?" press release (Brussels: 7 March 2017), http://www.solarpowereurope.org/media/press-releases/, and from country-specific sources cited in this section.

5 About 85% calculated based on data from IEA PVPS, op. cit. note 1, p. 15; the share of the top five was 84%, from SolarPower Europe, personal communication with REN21, 1 April 2017; rankings of top 10 from IEA PVPS, op. cit. note 1, and of top five also from SolarPower Europe, op. cit. this note.

6 IEA PVPS, op. cit. note 1, p. 10, and national data and sources cited elsewhere in this section. **Figure 16** based on data from IEA PVPS, op. cit. note 3, p. 68, on IEA PVPS, op. cit. note 1 and on national data for China, Japan, United States and Germany cited elsewhere in this section.

7 IEA PVPS, op. cit. note 1, p. 4; Anand Gupta, "PV Market Alliance announces the 2016 PV market at 75 GW and a stable market in 2017", EQ International, 19 January 2017, https://www.eqmagpro.com/pv-market-alliance-announces-the-2016-pv-market-at-75-gw-and-a-stable-market-in-2017/; SolarPower Europe, *Global Market Outlook for Solar Power: 2015-2019* (Brussels: 2015).

8 Every continent and 24 countries from IEA PVPS, op. cit. note 1, p. 5; 114 countries based on Chris Werner et al., "Latest developments in global installed photovoltaic capacity and identification of hidden growth markets", 2016, cited in IEA PVPS, op. cit. note 3. Note that 196 countries had solar PV installations by the end of 2015, from Chris Werner et al., *Global Photovoltaics in 2015 – Analysis of Current Solar Energy Markets and Hidden Growth Regions*, paper for 32nd European Photovoltaic Solar Energy Conference, Munich, June 2016, https://www.researchgate.net/publication/304540589_Global_Photovoltaics_in_2015_-_Analysis_of_Current_Solar_Energy_Markets_and_Hidden_Growth_Regions.

9 IEA PVPS, op. cit. note 1, p. 12, and from Becquerel Institute, provided by Philippe Macé, Becquerel Institute, personal communication with REN21, 10 May 2017.

10 Masson, op. cit. note 1; SolarPower Europe, *Global Market Outlook for Solar Power: 2016-2020* (Brussels: 2016); Gregory F. Nemet et al., *Characteristics of Low-Priced Solar Photovoltaic Systems in the United States* (Berkeley, CA: Lawrence Berkeley National Laboratory (LBNL), January 2016), p. 1, https://emp.lbl.gov/sites/all/files/lbnl-1004062.pdf. In many markets, including in Africa, Asia and Latin America, solar PV is viewed as a way to meet renewable energy and climate mitigation targets quickly and cost-effectively, from Mohit Anand, GTM Research, cited in Mike Munsell, "GTM Research: Global solar PV installations grew 34% in 2015", Sonnenseite, 23 January 2016, http://www.sonnenseite.com/en/energy/gtm-research-global-solar-pv-installations-grew-34-in-2015.html.

11 Cost-effective through tenders, from Gaëtan Masson, Becquerel Institute and IEA PVPS, personal communication with REN21, 28 February 2017; energy access from, for example, International Renewable Energy Agency (IRENA), *Solar PV in Africa: Costs and Markets* (Abu Dhabi: September 2016), p. 9, https://www.irena.org/DocumentDownloads/Publications/IRENA_Solar_PV_Costs_Africa_2016.pdf. See Distributed Renewable Energy chapter for more information.

12 IEA PVPS, op. cit. note 3, pp. 37-38; Jennifer Runyon, "Solar outlook 2017: the global market marches on", *Renewable Energy World*, January/February 2017, pp. 14-17; Masson, op. cit. note 11; Paula Mints, "Notes from the Solar Underground: 2016 – what just happened?" SPV Market Research, 8 December 2016, https://paulamspv.com/2016/12/04/notes-from-the-solar-underground-2016-what-just-happened/; Mike Munsell, "5 trends that will shape the global solar market for the rest of the year", Greentech Media, 3 August 2016, http://www.greentechmedia.com/articles/read/5-Trends-that-Will-Shape-the-Global-Solar-Market-In-Q2-2016.

13 China added 34.54 GW for a year-end total of 77.42 GW, from Dazhong Xiao, "2016 photovoltaic power generation statistics", China National Energy Board, 4 February 2017, http://www.nea.gov.cn/2017-02/04/c_136030860.htm (using Google Translate). China added 34.53 GW for a year-end total of 78.07 GW, from IEA PVPS, op. cit. note 1, p. 15. **Figure 17** based on country-specific data and on sources provided throughout this section, and on data for Italy and Spain from IEA PVPS, op. cit. note 1.

14 "China to slow green growth for first time after record boom", *Bloomberg*, 22 September 2016, http://www.bloomberg.com/news/articles/2016-09-22/china-to-rein-in-green-growth-for-first-time-after-record-boom; Frank Haugwitz, Asia Europe Clean Energy (Solar) Advisory Company, Ltd. (AECEA), personal communication with REN21, 8 May 2017.

15 Joe Ryan, "Solar industry braces with looming glut eroding panel prices", *Bloomberg*, 23 August 2016, https://www.bloomberg.com/news/articles/2016-08-23/solar-industry-braces-as-looming-glut-threatens-to-erode-prices; Gaëtan Masson, "Market booms, overcapacities and 2016 as the beginning of a new PV market cycle", Becquerel Institute, 10 November 2016, http://becquerelinstitute.org/market-booms-overcapacities-and-2016-as-the-beginning-of-a-new-pv-market-cycle/; Haugwitz, op. cit. note 14. China installed an estimated 20 GW during the first six months of 2016, although some of this was for experimental rooftop and installations in poor areas, which do not count toward the target, from Roberto Labastida, "Advanced module technologies moving onto the main stage", Renewable Energy World, 31 October 2016, http://www.renewableenergyworld.com/articles/2016/10/advanced-module-technologies-moving-onto-the-main-stage.html.

16 Haugwitz, op. cit. note 14; SolarPower Europe, op. cit. note 5.

17 Top market and installations based on data from Xiao, op. cit. note 13; "no-go" area from AECEA, *Briefing Paper – China Solar PV Development, January 2017*, p. 1; Xinjiang's 2016 installations exceeded government guiding targets by 300%, from idem.

18 Xiao, op. cit. note 13. The nine provinces were Shandong (3.22 GW added), Henan (2.44 GW), Anhui (2.25 GW), Hebei (2.03 GW), Jiangxi (1.85 GW), Shanxi (1.83 GW), Zhejiang (1.75 GW), Hubei (1.38 GW) and Jiangsu (1.23 GW), from idem.

19 Figure of 86% based on data from Ibid.; of the total in operation at end-2016, 67.1 GW was classified as large-scale plants and 10.33 GW as distributed. Pushing for distributed and grid inadequacy from IEA-PVPS, op. cit. note 3, p. 43, http://www.iea-pvps.org/fileadmin/dam/public/report/national/Trends_2016_-_mr.pdf. The distributed market increased by more than 200%, from AECEA, op. cit. note 17, p. 1; note that "distributed" in China includes projects that are ground-mounted up to 20 MW and that meet various conditions, per Frank Haugwitz, AECEA, personal communication with REN21, 17 February 2017.

20 Up 11-fold based on cumulative capacity of 6,750 MW at end-2012, from IEA PVPS, op. cit. note 3, p. 68; grid congestion

and delays from, for example, "China's NDRC order grid operators to purchase curtailed solar power in congested regions", *PV Magazine*, 1 June 2016, https://www.pv-magazine.com/2016/06/01/chinas-ndrc-order-grid-operators-to-purchase-curtailed-solar-power-in-congested-regions_100024816/; Feifei Shen, "China's grid operator blames bad planning for idled renewable energy", Renewable Energy World, 1 April 2016, http://www.renewableenergyworld.com/articles/2016/04/china-s-grid-operator-blames-bad-planning-for-idled-renewable-energy.html.

21 Challenge in 2015 from China National Energy Board, cited in China Electricity Council, "2015 PV-related statistics", 6 February 2016, http://www.cec.org.cn/yaowenkuaidi/2016-02-05/148942.html (using Google Translate); inadequate transmission from Paula Mints, "Notes from the Solar Underground: The solar roller coaster and those along for the ride – First Solar, SunPower, Q-Cells", Renewable Energy World, 1 September 2016, http://www.renewableenergyworld.com/articles/2016/08/notes-from-the-solar-underground-the-solar-roller-coaster-and-those-along-for-the-ride-first-solar-sunpower-q-cells.html.

22 Minimum guaranteed hours from Julie Zhu, "Solar power's time to shine in China", *Finance Asia*, 14 June 2016, http://www.financeasia.com/News/426847,solar-powers-time-to-shine-in-china.aspx; "China's NDRC order grid operators to purchase curtailed solar power in congested regions", *PV Magazine*, 1 June 2016, https://www.pv-magazine.com/2016/06/01/chinas-ndrc-order-grid-operators-to-purchase-curtailed-solar-power-in-congested-regions_100024816/; Max Dupuy and Xuan Wang, "China's string of new policies addressing renewable energy curtailment: an update", Regulatory Assistance Project, 8 April 2016, http://www.raponline.org/featured-work/chinasstring-of-new-policies-addressing-renewable-energy-curtailment-an; "China ban on new coal power eases clean energy waste, WRI says", *Bloomberg*, 29 April 2016, http://www.bloomberg.com/news/articles/2016-04-29/china-ban-on-new-coal-power-eases-clean-energy-waste-wri-says; transmission lines from Li Ying, "Blowing in the wind", China Dialogue, 31 March 2016, https://www.chinadialogue.net/article/show/single/en/8965-Blowing-in-the-wind; Cathy Chen and David Stanway, "China pushes for mandatory integration of renewable power", *Reuters*, 28 March 2016, http://www.reuters.com/article/us-china-power-renewables-idUSKCN0WU0RF; Feifei Shen, "China's grid blames bad planning for idled renewable energy", *Bloomberg*, 30 March 2016, http://www.bloomberg.com/news/articles/2016-03-30/china-s-grid-blames-bad-planning-for-idled-renewable-energy.

23 Figure of 66.2 TWh and 1% of annual generation from Xiao, op. cit. note 13; increase based on 39.2 TWh of generation in 2015, from China National Energy Board, op. cit. note 21.

24 In 2016, the United States added 11,269.6 MW of solar PV capacity (utility-scale plus small-scale), 8,738.1 MW of wind power capacity, and 7,532.2 MW of natural gas capacity, from US Energy Information Administration (EIA), *Electric Power Monthly with Data for December 2016* (Washington, DC: February 2017), Table 6.1, https://www.eia.gov/electricity/monthly/current_year/february2017.pdf. The country added 7,748 MW of solar power capacity, 8,689 MW of natural gas capacity and 7,865 MW of wind power capacity, from US Federal Energy Regulatory Commission (FERC), "Office of Energy Projects Energy Infrastructure Update for December 2016" (Washington, DC: 2016), https://www.ferc.gov/legal/staff-reports/2016/dec-energy-infrastructure.pdf. Note that all EIA data are net additions; both FERC and EIA report lower capacity additions for solar PV and wind power because they omit plants with a total generator nameplate capacity below 1 MW.

25 The United States added 14,762 MW in 2016, up from 7,501 MW of additions in 2015, for a total of 40.9 GW at end-2016, from GTM Research, personal communication with REN21, 2 May 2017, and from GTM Research, cited in US Solar Energy Industries Association (SEIA), "Solar Market Insight Report 2016 Year in Review", http://www.seia.org/research-resources/solar-market-insight-report-2016-year-review, viewed 2 May 2017. The country added 7,864.9 MW of utility-scale solar PV plus 3,404.7 MW of small-scale for a total of 11.269.6 MW added in 2016, and a year-end cumulative capacity of 32,953.5 MW, from EIA, op. cit. note 24. Note that EIA data omit plants with a total generator nameplate capacity below 1 MW. The country added 14.73 GW for a total of 40.3 GW, from IEA PVPS, op. cit. note 1, p. 15.

26 GTM Research and SEIA, *U.S. Solar Market Insight 2016 Year in Review*, Executive Summary (Boston: March 2017), pp. 7, 9, https://www.greentechmedia.com/research.

27 Ibid., p. 9; Georgia third largest installer without additional subsidies from Cheryl Katz, "Northern lights: large-scale solar power is spreading across the U.S.", *Yale e360*, 23 March 2017, http://e360.yale.edu/features/northern-lights-utility-scale-solar-power-spreading-across-the-us.

28 GTM Research and SEIA, op. cit. note 26, p. 11.

29 The utility sector installed an estimated 10,593 MW in 2016, from Ibid., pp. 11, 13. An estimated 4,032 MW of projects were in construction by year's end and other 13,762 MW were moving forward with signed PPAs, from idem, p. 13.

30 Ibid., p. 12; see also Katz, op. cit. note 27. The share of the market represented by voluntary procurement (not driven by government mandate) is becoming increasingly significant for utilities and corporate customers, due to falling prices, from Shayle Kann, GTM Research, cited in Herman K. Trabish, "As solar booms, utilities look to build new business models with strategic investments", Utility Dive, 14 March 2017, http://www.utilitydive.com/news/as-solar-booms-utilities-look-to-build-new-business-models-with-strategic/437899/. About half of new utility-scale projects in 2016 were built because of state renewable energy mandates, but only 36% of the projects in development by early 2017 were driven by such policies; almost all new procurement as of early 2017 was non-mandate driven, from GTM Research, *U.S. Solar Market Insight 2016 Year in Review*, cited in Trabish, op. cit. this note.

31 GTM Research and SEIA, op. cit. note 26, p. 12. Large corporate customers accounted for about 10% of the 10.593 MW of large-scale capacity installed during 2016, through a combination of direct access programmes, contracts for difference and green tariff programmes, from idem, pp. 11-12.

32 Ibid., pp. 5, 11. The states were California and Massachusetts.

33 Ibid., pp. 5, 8, 10. The slowdown also was due partly to declining incentives, although these were offset somewhat by falling prices, from David Renne, International Solar Energy Society, personal communication with REN21, 10 April 2017.

34 GTM Research and SEIA, op. cit. note 26, p. 10.

35 GTM Research, *U.S. Solar Market Insight 2016 Year in Review*, cited in Trabish, op. cit. note 30; establish own programmes from, for example, North Carolina Clean Energy Technology Center, *The 50 State of Solar: Q1 2016 Quarterly Report* (Raleigh, NC: April 2016), https://nccleantech.ncsu.edu/wp-content/uploads/50-SoS-Q1-2016_Final.pdf.

36 SolarPower Europe, op. cit. note 10, p. 13. Regulatory disputes and more on the net metering debate from, for example: Paula Mints, "Notes from the Solar Underground: the US utility war against metering", Renewable Energy World, 23 February 2016, http://www.renewableenergyworld.com/articles/2016/02/notes-from-the-solar-underground-the-us-utility-war-against-net-metering.html; Mints, op. cit. note 12; Krysti Shallenberger, "Utilities are getting ready for life with distributed generation – report", *E&E News*, 11 August 2015, http://www.eenews.net/energywire/2015/08/11/stories/1060023259; GTM Research and SEIA, *U.S. Solar Market Insight: 2015 Year in Review*, Executive Summary (Washington, DC: March 2016), p. 8.

37 Down 20% based on 10,811 MWdc added in 2015, from IEA PVPS, op. cit. note 3, p. 68, and on 8.6 GWdc added in 2016 for a total of 42.75 GW, from IEA PVPS, op. cit. note 1, p. 15, and from Gaëtan Masson, op. cit. note 1. Japan added 6,836 MWac for a year-end total of 36,961 MWac (including 9,235 MWac of residential systems (under 10 kW), 17,037 MWac of systems >10 kW and <1 MW, and 10,688 MWac of capacity >1 MW), from Japan Ministry of Economy Trade and Industry (METI), provided by Hironao Matsubara, Institute for Sustainable Energy Policies (ISEP), personal communication with REN21, 28 April 2017.

38 BMI Research, cited in Anne Beade, "Sun setting on Japan's solar energy boom", *Japan Times*, 30 November 2016, http://www.japantimes.co.jp/news/2016/11/30/business/sun-setting-japans-solar-energy-boom/; Chisaki Watanabe and Stephen Stapczynski, "Japan's solar boom showing signs of deflating as subsidies wane", *Bloomberg*, 5 July 2016, https://www.bloomberg.com/news/articles/2016-07-06/japan-s-solar-boom-showing-signs-of-deflating-as-subsidies-wane.

39 Beade, op. cit. note 38.

40 Brian Publicover, "Distributed-generation takes the lead in Japan's new power capacity development", Solar Asset Management, 18

May 2016, http://solarassetmanagement.asia/news/2016/5/18/distributed-generation-takes-the-lead-in-japans-new-power-capacity-development; residential sector's share (based on projects <10 kW), from METI, provided by Matsubara, op. cit. note 37.

41 Increased interest from Publicover, op. cit. note 40; number of residential systems from Bloomberg New Energy Finance (BNEF), cited in idem.

42 Junko Movellan, "Japan passes FIT peak: now what for 87 GW renewable queue, 2030 energy mix?" Renewable Energy World, 25 November 2015, http://www.renewableenergyworld.com/articles/2015/11/japan-passes-fit-peak-now-what-for-87-gw-re-queue-2030-energy-mix.html; Joe Jackson, "Despite nuclear fears, Japan solar energy sector slow to catch on", *Al Jazeera*, 23 January 2016, http://america.aljazeera.com/articles/2016/1/23/japan-solar-energy-nuclear-fears.html. Rules introduced in 2015 allowed Japan's power companies to stop accepting power from solar PV plants, including some uncompensated curtailments; these rules were cited as a barrier to investment in solar PV during 2015 due to concerns about uncertainty and the potential for lost income, from Andy Colthorpe, "Japan's FIT degression back to previous levels as utility curtails solar output", PV-Tech, 23 February 2016, https://www.pv-tech.org/news/japans-fit-degression-back-to-previous-levels-as-utility-curtails-solar-out.

43 Andy Colthorpe, "Asian super grid gets support from China, Russia, S. Korea and Japan", PV-Tech, 31 March 2016, http://www.pv-tech.org/news/asian-super-grid-could-get-go-ahead-after-china-and-russias-grid-operators.

44 Share for 2012 from Watanabe and Stapczynski, op. cit. note 38. Japan's power mix as measured by what is purchased and produced by the nation's 10 regional utilities. The data for 2012 are drawn from government and industry sources. Share for 2016 is based on METI data and provided by Matsubara, op. cit. note 37. In 2016, Japan's solar PV systems generated 46.3 TWh, including self-consumption (for most but not all of 2016), and Japan's total power generation (including non-utility generation) was 1,044.9 TWh, from METI, idem.

45 IEA PVPS, op. cit. note 1, pp. 10, 15. India joined the top five markets list in 2015, adding 2 GW that year, mainly in the form of utility-scale systems awarded through tenders, from SolarPower Europe, op. cit. note 10, p. 14.

46 India added about 3.97 GW for a total of 9.01 GW, from IEA PVPS, op. cit. note 1, p. 15; added 4,112.53 MW for a year-end total of 9,055.41 MW (including grid-connected and off-grid), based on data from Government of India, Ministry of New and Renewable Energy (MNRE), "Physical progress (achievements)", data as on 31 December 2016, http://www.mnre.gov.in/mission-and-vision-2/achievements, viewed 19 January 2017, and from MNRE, ""Physical progress (achievements)", data as on 31 December 2015, viewed 1 February 2016, and assuming that India had 225 MW of CSP capacity (with no additions) in both years (see CSP section and Reference Table R7); added an estimated 4.9 GW (up from 2 GW in 2015) for a total surpassing 10 GW, from "2016 was a great year for the Indian solar industry but the best is yet to come", Bridge to India, 19 December 2016, http://www.bridgetoindia.com/2016-great-year-indian-solar-industry-best-yet-come/. Year-end capacity was 9,018 MW, and India had a project pipeline of 14,030 MW as of December 2016, from Mercom Capital Group, "Mercom Exclusive: Top 10 Indian states account for 90 percent of the country's large-scale solar installations and pipeline: a state by state analysis", December 2016, http://mercomcapital.com/top-10-indian-states-account-for-90-percent-of-the-countrys-large-scale-solar-installations-and-pipeline-a-state-by-state-analysis.

47 Top states and capacities of Tamil Nadu (1,577 MW), Rajasthan (1,324 MW), Gujarat (1,101 MW) and Andhra Pradesh (1,009 MW) from Mercom Capital Group, op. cit. note 46; Tamil Nadu leads all other states for capacity due to lack of reliable electricity from the grid and high consumer awareness, from Jyoti Gulia, "Rooftop solar market in India witnessing rapid growth but 2022 target seems elusive", Bridge to India, 31 May 2016, http://www.bridgetoindia.com/rooftop-solar-market-in-india-witnessing-rapid-growth-but-2022-target-seems-elusive/.

48 Ramanathapuram, "Adani's 648-MW solar plant inaugurated", *The Hindu*, updated 1 November 2016, http://www.thehindu.com/news/national/tamil-nadu/Adani's-648-MW-solar-plant-inaugurated/article14993341.ece; ABB, "ABB connects power to the Indian grid from one of the world's largest solar plants", press release (Zurich: 13 June 2016), http://www.abb.com/cawp/seitp202/5c93aa475c87e687c1257fcd003a9096.aspx; "India unveils the world's largest solar power plant", *Al Jazeera*, 30 November 2016, http://www.aljazeera.com/news/2016/11/india-unveils-world-largest-solar-power-plant-161129101022044.html. The project is made up of five plants in a single location, from ABB, op. cit. this note, and comprises 2.5 million solar modules, from Ramanathapuram, op. cit. this note.

49 Tom Kenning, "India hits 10GW of solar – Bridge to India", PV-Tech, 18 November 2016, https://www.pv-tech.org/news/india-hits-10gw-of-solar-bridge-to-india.

50 Bridge to India, cited in Ibid.; "OPEX model takes hold in India but faces a key challenge", Bridge to India, 17 October 2016, http://www.bridgetoindia.com/opex-model-takes-hold-india-faces-key-challenge/; "2016 was a great year...", op. cit. note 46; the rooftop market passed 1 GW in September 2016, from idem.

51 Challenges include the fact that most rooftops are flat and thus not optimal for solar, from Ian Clover, "ADB extends loan for India solar rooftops to $500m", *PV Magazine*, 5 October 2016, https://www.pv-magazine.com/2016/10/05/adb-extends-loan-for-india-solar-rooftops-to-500m_100026365/; most households lack funds or unshaded, appropriate rooftop space, from Ian Clover, "Rooftop PV and manufacturing: the next two hurdles for Indian solar", *PV Magazine*, 9 September 2016, https://www.pv-magazine.com/2016/09/09/rooftop-pv-and-manufacturing-the-next-two-hurdles-for-indian-solar_100026054/; and grid interconnection regulations and processes remain challenging despite fact that most states have net or gross metering policies for rooftop solar (poor implementation of polices), from "Poor implementation of net-metering policies poses a major challenge for rooftop solar", Bridge to India, 7 November 2016, http://www.bridgetoindia.com/poor-implementation-net-metering-policies-poses-major-challenge-rooftop-solar/. India's National Solar Mission targets 100 GW solar by 2022, of which 40 GW should be rooftop capacity, from Gulia, op. cit. note 47. India's target will be aided by the Solar Rooftop Investment Programme, which reached USD 1 billion in funding during 2016. In late 2016, the Asian Development Bank and Clean Technology Fund (multi-donor funding agency) announced USD 500 million in funding for India's Solar Rooftop Investment Programme, on top of USD 300 million equity investment and USD 200 million in commercial bank loans, from Ian Clover, "ADB extends loan for India solar rooftops to $500m", *PV Magazine*, 5 October 2016, https://www.pv-magazine.com/2016/10/05/adb-extends-loan-for-india-solar-rooftops-to-500m_100026365/. The World Bank also provided funding for solar PV in India, lending more than USD 1 billion over the fiscal year 2017, from World Bank, "Solar energy to power India of the future", 30 June 2016, http://www.worldbank.org/en/news/feature/2016/06/30/solar-energy-to-power-india-of-the-future.

52 "What will it take for India to achieve its massive renewable energy goals?" *Renewable Energy World*, March/April 2016, p. 14. States with high renewable energy penetration, particularly Tamil Nadu and Rajasthan, already are experiencing significant grid curtailment, which is affecting return on investment, from "Tamil Nadu takes top slot for solar capacity in India", Bridge to India, 22 August 2016, http://www.bridgetoindia.com/tamil-nadu-takes-top-slot-for-solar-capacity-in-india/, and from "Solar developers stay away from Tamil Nadu tender", Bridge to India, 28 November 2016, http://www.bridgetoindia.com/solar-developers-stay-away-tamil-nadu-tender/.

53 Kenning, op. cit. note 49.

54 Added 850 MW for a total of 4.35 GW, from IEA PVPS, op. cit. note 1, p. 15; and added 0.9 GW for a total of 4.5 GW, from Jaehong Seo, KOPIA, presentation for International Green Energy Conference 2017, Daegu, Republic of Korea, 5-6 April 2017, provided by Haugwitz, op. cit. note 14.

55 The Philippines had an installation target of 500 MW, and Thailand had a 1.7 GW target, from Florence Tan et al., "Factbox – on the sunny side: Southeast Asian nations push into solar", *Reuters*, 2 November 2016, http://uk.reuters.com/article/uk-asia-solar-power-factbox-idUKKBN12X095; the Philippines added 756 MW for total of 0.9 GW, and Thailand added 726 MW for a total of 2.15 GW, from IEA PVPS, op. cit. note 1, p. 15; pause in procurement from Jason Deign, "Thai solar looks abroad amid lull in national procurement", Solar Plaza, 8 April 2016, http://www.solarplaza.com/channels/markets/11506/thai-solar-looks-abroad-amid-lull-national-procurement/. In the first six months of 2016, the Philippines added 520 MW of solar PV (second

only to new coal-fired generating capacity), from Philippines Department of Energy, Electrical Power Industry Management Bureau, "January – June 2016 Power Situation Highlights", (undated), https://www.doe.gov.ph/sites/default/files/pdf/electric_power/2016_power_situation_highlight_jan_to_june.pdf. In addition, Turkey added 584 MW for total of 832 MW, and Malaysia added 54 MW for a total of 286 MW, from IEA PVPS, op. cit. note 1, p. 15.

56 Pakistan had several large (100 MW and larger) plants under construction, but some were stalled due to the FIT reduction at the end of 2015, from Aamir Saeed, "Solar scale-up in Pakistan hits roadblock after payments slashed", *Reuters*, 20 September 2016, http://planetark.org/wen/74770%20. Vietnam had more than 30 large-scale (with capacities ranging 20-300 MW) projects at various stages of development by late 2016, but investors were awaiting finalisation of a national FIT before going forward with many of these projects, from Tom Kenning, "Vietnam has 30 large-scale solar projects under development but FiT needed", PV-Tech, 2 November 2016, https://www.pv-tech.org/news/vietnam-has-30-large-scale-solar-projects-under-development-but-fit-needed.

57 Masson, op. cit. note 1. More than 32 times based on end-2016 capacity and EU (28 countries) net maximum solar PV capacity of 3,280 MW at end-2006, from Eurostat, "Infrastructure – electricity – annual data" (Environment and Energy/Energy/Energy Statistics – infrastructure/), updated 16 February 2017.

58 Global increase from SolarPower Europe, op. cit. note 4, and from IEA PVPS, op. cit. note 1; EU decline based on additions (7.5 GW) in 2015 from IEA PVPS, op. cit. note 2, and on additions in 2016 from SolarPower Europe, op. cit. note 5.

59 EU decline due largely to reduction in the United Kingdom, from Agora Energiewende, *Energy Transition in the Power Sector in Europe: State of Affairs in 2016* (Berlin: January 2017), p. 13, https://www.agora-energiewende.de/fileadmin/Projekte/2017/EU_Jahresauswertung_2016/Agora_State_of_Affairs_EU_2016_WEB.pdf; Michael Schmela, "European solar market installs 1.56 GW in third quarter 2016, down 10% year-on-year", SolarPower Europe, undated, http://www.solarpowereurope.org/index.php?id=705, viewed 27 February 2017. The United Kingdom accounted for the entire EU market decline, from Masson, op. cit. note 1. Other markets with increases included Belgium, Germany, Italy, the Netherlands and Portugal, from idem.

60 Based on data from SolarPower Europe, op. cit. note 5, and on country-specific data and sources provided in this section. The EU installed 5,683.3 MW in 2016, and the United Kingdom, Germany and France added a combined 3,951 MW, from idem.

61 The Netherlands, Italy and Belgium (with the Netherlands leading for capacity additions among these countries), from SolarPower Europe, op. cit. note 5, and from IEA PVPS, op. cit. note 1, p. 15. Other European countries that added capacity include Switzerland, Austria, Denmark, Sweden, Portugal, Spain, Norway and Finland (with Switzerland installing the most among these countries, and Finland the least), from idem.

62 SolarPower Europe, "2015: A positive year for solar", press release (Brussels: 3 March 2016), http://www.solarpowereurope.org/media/press-releases/. Self-consumption is becoming the primary driver for distributed PV, from Michael Schmela, SolarPower Europe, "SolarPower Webinar: Market report and solar developments in Europe", 23 March 2016, https://www.youtube.com/watch?v=_wVUpCAN9BU. However, self-consumption policies are complicated, particularly in France, Germany and Spain, and thus are not supporting solar PV deployment, from Masson, op. cit. note 1. The list of countries constraining self-consumption in some way is long (e.g., Austria, Belgium, France, Germany, Spain), from SolarPower Europe, *Solar Market Report & Membership Directory 2016 Edition* (Brussels: April 2016), pp. 17-18.

63 Alexandre Roesch, SolarPower Europe, personal communication with REN21, 17 March 2016; Masson, op. cit. note 1.

64 Mix in Germany and elsewhere from IEA-PVPS, op. cit. note 3, p. 66.

65 Roesch, op. cit. note 63; Masson, op. cit. note 1; SolarPower Europe, op. cit. note 10.

66 The United Kingdom added 1.97 GW from SolarPower Europe, op. cit. note 5, and added 1.97 GW for a total of 11.63 GW, from IEA PVPS, op. cit. note 1, p. 15; added 2,039 MW in 2016 for total of 11,727 MW, based on data for end-2015 and end-2016 from UK Department for Business, Energy & Industrial Strategy, "Solar Photovoltaics Deployment in the UK February 2017", updated 30 March 2017, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/585828/Solar_photovoltaics_deployment_March_2017.xlsx; and added 2.4 GW for a total of 11,562 MW, from UK Department for Business, Energy & Industrial Strategy, *National Statistics, Energy Trends Section 6: Renewables*, updated 30 March 2017, Table 6.1, pp. 63, 69, https://www.gov.uk/government/statistics/energy-trends-section-6-renewables.

67 UK Department for Business, Energy & Industrial Strategy, "Solar Photovoltaics Deployment in the UK December 2016", https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/585828/Solar_photovoltaics_deployment_December_2016.xlsx, viewed 19 February 2017; UK Department for Business, Energy & Industrial Strategy, National Statistics, Energy Trends Section 6, op. cit. note 66.

68 Simon Evans, "Analysis: UK solar beats coal over half a year", CarbonBrief, 4 October 2016, https://www.carbonbrief.org/analysis-uk-solar-beats-coal-over-half-year. Solar PV generated an estimated 6,964 GWh of electricity from April through September, while coal generated 6,342 GWh during this period, from idem. Figure of 3% for the year, based on 10,292 GWh of solar PV generation, from UK Department for Business, Energy & Industrial Strategy, *National Statistics, Energy Trends Section 6*, op. cit. note 66, p. 69, and total UK generation of 338.58 TWh (and total supplied was 336.89 TWh) from UK Department for Business, Energy & Industrial Strategy, *National Statistics, Energy Trends Section 5: Electricity*, p. 57, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/604090/Electricity.pdf.

69 France added 559 MW for a total of 7.13 GW, from IEA PVPS, op. cit. note 1, p. 15; and added 559 MW for a total of 7.1 GW from SolarPower Europe, op. cit. note 5; France added 576 MW in 2016 for a total of 6,772 MW, from LeRéseau de transport d'électricité (RTE), *Synthèse press – Bilan électrique français 2016* (Paris: undated), http://www.rte-france.com/sites/default/files/2016_bilan_electrique_synthese.pdf.

70 Germany had a year-end total of 41,275 MW, up from 39,799 MW at end-2015, implying net additions of 1,476 MW, from Bundesministerium für Wirtschaft und Energie (BMWi), *Zeitreihen zur Entwicklung der erneuerbaren Energien in Deutschland, unter Verwendung von Daten der Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat) (Stand: Februar 2017)*, p. 7, http://www.erneuerbare-energien.de/EE/Redaktion/DE/Downloads/zeitreihen-zur-entwicklung-der-erneuerbaren-energien-in-deutschland-1990-2016.pdf; and added 1.52 GW for a total of 41.22 GW, from IEA PVPS, op. cit. note 1, p. 15. Official target (EEG corridor) of 2.4-2.6 GW, from BMWi, *Erneuerbare Energien in Deutschland, Daten zur Entwicklung im Jahr 2015* (Berlin: February 2015), p. 4, http://www.erneuerbare-energien.de/EE/Redaktion/DE/Downloads/erneuerbare-energien-in-zahlen-2015.pdf. Germany's installed capacity was below target due partly to delays in investment decisions (related to the expected removal of EU import duties on Chinese panels). In 2016, 300 MW was auctioned under the pilot auctions. From 2017 on, the auctioning volume for solar PV projects >750 kW is 500 MW per year; it is expected that the remaining capacity will be smaller (mainly residential and commercial) applications under the fixed feed-in premium, from Rina Bohle Zeller, Vestas, personal communication with REN21, April 2017.

71 BMWI and German Federal Network Agency (Bundesnetzagentur), "Federal Network Agency launches Germany's first cross-border PV auction with Denmark", press release (Berlin: 12 October 2016), http://www.bmwi.de/Redaktion/EN/Pressemitteilungen/2016/20161012-federal-network-agency-launches-germany-s-first-cross-border-PV-auction-with-denmark.html.

72 Bundesnetzagentur, "Geöffnete Ausschreibung mit dem Königreich Dänemark", updated 21 December 2016, https://www.bundesnetzagentur.de/DE/Sachgebiete/ElektrizitaetundGas/Unternehmen_Institutionen/ErneuerbareEnergien/Ausschreibungen/Internat_Ausschreibungen/PV_Daenemark_23_11_2016/23112016_PV_DK_node.html.

73 Sebastian Hermann, German Environment Agency, Dessau, Germany, personal communication with REN21, 1 February 2017; EuPD Research in Martin Ammon, "Status quo and potentials for the residential segment", presentation at European PV and Energy Storage Market Briefing, Frankfurt, 16 February 2017, slides 20, 21.

74 Data for 2014 and 2015 include only installations within the government-owned KfW development bank's subsidy scheme and are sourced from Kai-Philipp Kairies et al./ Speicher Monitoring, *Wissenschaftliches Mess- und Evaluierungsprogramm Solarstromspeicher, Jahresbericht 2016* (Aachen: Stromrichtertechnik und Elektrische Antriebe, RWTH Aachen University, 2016), prepared for BMWi, pp. 8, 45, http://www.speichermonitoring.de/fileadmin/user_upload/Speichermonitoring_Jahresbericht_2016_Kairies_web.pdf; share for 2016 from Hermann, op. cit. note 73; 80% from SolarPower Europe, op. cit. note 5; EuPD Research in Ammon, op. cit. note 73. See also Jason Deign, "Developers see large opportunity in Germany's commercial storage market, both with and without solar", Greentech Media, 3 August 2016, https://www.greentechmedia.com/articles/read/germany-commercial-storage-market-takes-off. Germany installed just over 19,000 battery systems in 2015, from Nigel Morris, "Battery storage: Is Australia on track to be the world's biggest market?" One Step off the Grid, 8 February 2017, https://onestepoffthegrid.com.au/battery-storage-australia-track-world-biggest-market/; and about 25,355 home storage systems were installed during 2016, from EuPD Research in Ammon, op. cit. note 73.

75 Data based on year-end 2015 total of 4,939.134 MW and on year-end 2016 totals of 5,783.963 MW reported installed and 5,794.371 MW estimated installed, for estimated additions of 855 MW, all from Australian PV Institute (APVI), "Australian PV market since April 2001", http://pv-map.apvi.org.au/analyses, viewed 2 May 2017. Australia added 839 MW for a total of 5.9 GW, from IEA PVPS, op. cit. note 1, p. 15.

76 Masson, op. cit. note 1; Jonathan Pearlman, "Australia taking solar power to the next level", *Straits Times*, 31 January 2016, http://www.straitstimes.com/asia/australianz/australia-taking-solar-power-to-the-next-level; SolarPower Europe, op. cit. note 62, p. 21. About 1.5 million households had rooftop solar PV, with the highest share (nearly 30%) in Queensland, from Pearlman, op. cit. this note.

77 APVI, op. cit. note 75, viewed 9 March 2017.

78 APVI, "Percentage of dwellings with a PV system by state/territory", funded by the Australian Renewable Energy Agency, updated 24 November 2016, pv-map.apvi.org.au, viewed 10 March 2017. As of late 2016, 30.4% of dwellings in Queensland had solar PV installations, followed by South Australia (29.5%), West Australia (23.8%), Victoria (14.7%), New South Wales (14.6%), Australian Capital Territory (13.5), Tasmania (12.7%) and New Territories (10%), from idem.

79 Jo Chandler, "Despite hurdles, solar power in Australia is too robust to kill", *Yale e360*, 11 June 2015, http://e360.yale.edu/features/despite_hurdles_solar_power_in_australia_is_too_robust_to_kill; see also Peter Maloney, "One good year deserves another: energy storage in 2016", *Renewable Energy World*, January/February 2016, pp. 51-57, http://digital.renewableenergyworld.com/renewableenergyworld/20160102/?pg=53#pg53.

80 IEA PVPS, op. cit. note 3, p. 19.

81 Chandler, op. cit. note 79.

82 Morris, op. cit. note 74; SunWiz, *2017 Battery Market Report*, cited in Sophie Vorrath, "Solar + storage installs set to treble on back of 'exceptional' battery market growth", REnew Economy, 2 February 2017, http://reneweconomy.com.au/solar-storage-installs-set-to-treble-on-back-of-exceptional-battery-market-growth-26042/. In addition, community solar projects began incorporating battery storage in 2016, from Jason Deign, "Australian Government and energy retailers back community solar-plus-storage projects", Greentech Media, 4 May 2016, https://www.greentechmedia.com/articles/read/arena-funds-battery-plant-in-australias-greenest-ever-neighborhood.

83 IEA PVPS, *Trends 2015 in Photovoltaic Applications: Survey Report of Selected IEA Countries between 1992 and 2014* (Paris: 2015), pp. 11, 30, http://www.iea-pvps.org/fileadmin/dam/public/report/national/IEA-PVPS_-_Trends_2015_-_MedRes.pdf; France, Italy and the United Kingdom from SolarPower Europe, op. cit. note 5.

84 Ibid., pp. 11, 30; Anindya Upadhyay, "India opens market for solar battery makers such as Tesla", Renewable Energy World, 15 March 2016, http://www.renewableenergyworld.com/articles/2016/03/india-opens-market-for-solar-battery-makers-such-as-tesla.html; Andrew Burger, "Solar Academy helps pico, home solar take root in Malawi", Renewable Energy World, 22 December 2016, http://www.renewableenergyworld.com/articles/2016/12/solar-academy-helps-pico-home-solar-take-root-in-malawi.html.

85 See, for example, Andrew Slavin, "Mining takes up 60% of Latin America's solar PV market, demand only to rise", Energy and Mines, 28 July 2016, http://energyandmines.com/2016/07/mining-takes-up-60-of-latin-americas-solar-pv-market-demand-only-to-rise/; *Mercatus, Mercatus Global Advanced Energy Insights Report, Volume IV* (San Mateo, CA: 2016), p. 11, http://sunspec.org/wp-content/uploads/2016/04/EnergyInsightsReportVolIV.pdf; Sushma Udipi Nagendran, "4 charts explaining Latin America's impending solar boom", Greentech Media, 10 March 2017, https://www.greentechmedia.com/articles/read/explaining-latin-americas-impending-solar-boom1.

86 Tenth globally from IEA PVPS, op. cit. note 1, p. 15; thanks to mining industry from, for example, Slavin, op. cit. note 85; Tom Kenning, "Chile: 1GW of solar and the road to 70% renewables by 2050", PV-Tech, 1 March 2016, https://www.pv-tech.org/features/chile-1gw-of-solar-and-the-road-to-70-renewables-by-2050; William Pentland, "Solar power thrives in Chile, no subsidies needed", *Forbes*, 7 November 2015, https://www.forbes.com/sites/williampentland/2015/11/07/solar-power-thrives-in-chile-no-subsidies-needed/#41e375853987. See also Gram Slattery, "Exclusive: Chile copper firms try to rejig contracts to tap renewable energy", *Reuters*, 7 December 2016, http://www.reuters.com/article/us-chile-energy-renewables-idUSKBN13W2L9. **Figure 18** based on country-specific data and on sources provided throughout this section.

87 Chile added 746 MW for total of 1.61 GW, from IEA PVPS, op. cit. note 1, p. 15; and added 821 MW in 2016, from SolarPower Europe, op. cit. note 5. As of December 2016, Chile had 1,041 MW of PV capacity in operation and 1,238 MW under construction, from Comisión Nacional de Energía, *Reporte Mensual ERNC, vol. 5* (Santiago, Chile: January 2017), pp. 3, 5, https://www.cne.cl/wp-content/uploads/2015/06/RMensual_ERNC_v201701.pdf.

88 Mexico added 150 MW for a total of 320 MW, from IEA PVPS, op. cit. note 1, p. 15; and added about 300 MW, from SolarPower Europe, op. cit. note 5.

89 Driven largely by tenders from SolarPower Europe, op. cit. note 5. Mexico's first energy auction was held in 2016, with results presented by the Mexican Energy Control Centre (CENACE) on 28 March 2017, and yielded 12 approved solar PV projects totalling 2.191 GW, to be built in the states of Yucatán, Baja California Sur, Jalisco, Aguascalientes, Guanajuato and Coahuila, and to be contracted by July 2017, from Emilio Soberón, Mexico Low Emission Development Program of the US Agency for International Development, personal communication with REN21, April 2017. An estimated 100 MW of distributed solar was installed in 2016, double the installations of 2015, bringing total to 220 MW, from Conermex, Mexico Secretary of Energy, cited in Blanca Díaz López, "Mexico to reach 460 MW of distributed solar by the end of 2017", *PV Magazine*, 1 February 2017, https://www.pv-magazine.com/2017/02/01/mexico-to-reach-460-mw-of-distributed-solar-by-the-end-of-2017/; and almost one-third of the market, at close to 50 MW, from Nagendran, op. cit. note 85.

90 Talbert Navia, Amanda Sewell and José Avila, "Argentina launches innovative renewables program", Renewable Energy World, 30 June 2016, http://www.renewableenergyworld.com/articles/2016/06/argentina-launches-innovative-renewables-program.html; Tom Kenning, "Argentina renewables tender receives 2,834MW of solar submissions", PV-Tech, 6 September 2016, https://www.pv-tech.org/news/argentina-renewables-tender-receives-submissions-for-2834mw-solar.

91 Alexandre Spatuzza, "Wind and solar fury as Brazil tender axe 'threatens investment'", Recharge News, updated 19 December 2016, http://www.rechargenews.com/wind/1200014/wind-and-solar-fury-as-brazil-tender-axe-threatens-investment. About 3 GW of projects had been awarded through tenders by end-2015 but, as of a year or so later, only 19 of 111 solar projects had begun construction, and several companies were negotiating with the government to cancel their licences and waive penalties for delays, from Luciano Costa, "Brazil solar energy drive stalled by high costs, strict rules", *Reuters*, 31 January 2017, http://www.reuters.com/article/us-brazil-power-solar-idUSKBN15F2L8. As of late November 2016, construction had started only on the ENEL and Canadian Solar projects and several projects were struggling to obtain financing, from Camila Ramos, Clean Energy Latin America (CELA), Brazil, personal communication with REN21, 30 November 2016.

92 See, for example, Kenning, op. cit. note 86; Robert Muhn, Yingli Chile, cited in Junko Movellan, "The 2016 global PV outlook: U.S. and Asian markets strengthened by policies to reduce CO2", *Renewable Energy World*, January/February 2016, pp. 34-40, http://www.renewableenergyworld.com/articles/2016/01/the-2016-global-pv-outlook-u-s-and-asian-markets-strengthened-by-policies-to-reduce-co2.html; IHS Markit, "Latin America on track to install 2.7 GW of solar-PV capacity in 2016, IHS Markit says", press release (London: 19 July 2016), http://news.ihsmarkit.com/press-release/technology/latin-america-track-install-27-gw-solar-pv-capacity-2016-ihs-markit-says; Nagendran, op. cit. note 85.

93 Susan Kraemer, "What is driving the Middle East solar market?" Renewable Energy World, 6 July 2016, http://www.renewableenergyworld.com/articles/print/volume-19/issue-8/features/solar/what-is-driving-the-middle-east-solar-market.html; Anthony Dipaola, "Saudi Arabia to revive its solar power program at smaller scale", Renewable Energy World, 25 May 2016, http://www.renewableenergyworld.com/articles/2016/05/saudi-arabia-to-revive-its-solar-power-program-at-smaller-scale.html; "Egypt's renewable energy sector offers $6 bln investment opportunity", *Al Arabiya*, 11 January 2016, http://english.alarabiya.net/en/business/energy/2016/01/11/Egypt-s-renewable-energy-sector-offers-6b-investment-opportunity-.html; Salman Zafar, "Renewable energy prospects in Kuwait", EcoMENA, 23 January 2017, http://www.ecomena.org/tag/shagaya-renewable-energy-park/. Jordan also is turning to solar energy to help meet surge in electricity demand due to influx of Syrian refugees, and Jordan's rooftop sector (driven by net metering) reached 100 MW by end-2015, from Ian Clover, "Jordan turns to solar to relieve stress of refugee crisis", *PV Magazine*, 22 February 2016, http://www.pv-magazine.com/news/details/beitrag/jordan-turns-to-solar-to-relieve-stress-of-refugee-crisis_100023315/.

94 Israel added 130 MW for a year-end total of 910 MW, from IEA PVPS, op. cit. note 1, p. 15.

95 Jordan from the following sources: Conor Ryan, "Scatec Solar's 10MW project in Jordan reaches commercial operation", PV-Tech, 21 June 2016, https://www.pv-tech.org/news/scatec-solars-10mw-project-in-jordan-reaches-commercial-operation; "52.5 MW PV power plant provides 1% electricity to Jordan", Energy Trend, 11 October 2016, http://pv.energytrend.com/news/52_5MW_PV_Power_Plant_Provides_1_percent_Electricity_to_Jordan.html; Christian Roselund, "Enerray, Desert Technologies put 23.1 MW-DC PV plant online in Jordan", *PV Magazine*, 2 December 2016, https://www.pv-magazine.com/2016/12/02/enerray-desert-technologies-put-23-1-mw-dc-pv-plant-online-in-jordan_100027095/. In addition to the 52.5 MWac Shams Ma'an plant commissioned in September 2016, Jordan also had all 12 projects (200 MW) from the first round of tenders come online in 2016, from Samer Zawaydeh, Jordan Energy Chapter EDAMA, Association of Energy Engineers, personal communication with REN21, April 2017. Kuwait from JinkoSolar, "JinkoSolar supplies solar PV modules for the first integrated renewable project in Kuwait", press release (Shanghai: 31 August 2016), http://www.prnewswire.com/news-releases/jinkosolar-supplies-solar-pv-modules-for-the-first-integrated-renewable-project-in-kuwait-300320600.html, and from Zafar, op. cit. note 93. United Arab Emirates from "Mohammed inaugurates Phase 2 of Solar Park", *Gulf Today*, 20 March 2017, http://gulftoday.ae/portal/3952a41e-6aed-429e-b427-c1983cfb8ce0.aspx.

96 Jordan, Saudi Arabia and the UAE signed tenders, from *MENA Solar Market Outlook for 2017* (Berlin: 2016), http://www.apricum-group.com/wp-content/uploads/2016/12/MENA-Solar-Outlook-2017.pdf; Jordan also from "Jordan invites bids for 200 MW PV capacity and 100 MW wind power", *Taiyang News*, 15 November 2016, http://taiyangnews.info/markets/jordan-opens-tender-round-3/; Iran from Sam Pothecary, "BPVA signs agreement with Iran to coordinate the development of 1GW of solar", *PV Magazine*, 19 July 2016, https://www.pv-magazine.com/2016/07/19/bpva-signs-agreement-with-iran-to-coordinate-the-development-of-1-gw-of-solar_100025466/; Sam Pothecary, "German company signs PPA for 100 MW solar plant in Iran", *PV Magazine*, 14 June 2016, https://www.pv-magazine.com/2016/06/14/german-company-signs-ppa-for-100-mw-solar-plant-in-iran_100024970/.

97 See, for example, Burger, op. cit. note 84; Maina Waruru, "Kenya taps solar to power digital learning", Renewable Energy World, 18 July 2016, http://www.renewableenergyworld.com/articles/2016/07/kenya-taps-solar-to-power-digital-learning.html; Kizito Makoye, "Solar panels power business surge – not just lights – in Tanzania", *Reuters*, 19 April 2016, http://www.reuters.com/article/us-tanzania-solar-energy-idUSKCN0XG1VX; Chris Mfula, "Zambia to diversify generation mix as drought hits hydropower", *Lusaka Times*, 10 May 2016, https://www.lusakatimes.com/2016/05/10/zambia-diversify-generation-mix-drought-hits-hydropower/. Zambia is expanding its non-hydropower renewable capacity to reduce reliance on hydropower, which has experienced a decline in output due to drought, from idem.

98 I. Nygaard, U.E. Hansen and T.H. Larsen, *The Emerging Market for Pico-Scale Solar PV Systems in Sub-Saharan Africa: From Donor-Supported Niches Toward Market-Based Rural Electrification* (Copenhagen: UNEP DTU Partnership, 2016), http://www.sun-connect-news.org/fileadmin/DATEIEN/Dateien/New/Market-Pico-Solar_WEB.pdf.

99 South Africa added 536 MW for a total of 1,450 MW, and Algeria installed some 50 MW, from IEA PVPS, op. cit. note 1, p. 5; South Africa added 505 MW, Algeria added 171 MW, and Senegal added 43 MW, all based on data for end-2016 and end-2015, from IRENA, *Renewable Capacity Statistics 2017* (Abu Dhabi: 2017), p. 24, http://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Capacity_Statistics_2017.pdf.

100 For example, projects in Burkina Faso, Ghana, Kenya and Nigeria, from Nellie Peyton, "Africa battles to get big solar projects on grid", *Reuters*, 4 August 2016, http://www.reuters.com/article/us-africa-solar-idUSKCN10F18I; also Egypt, from IEA PVPS, op. cit. note 1, p. 5.

101 Ghana from Peyton, op. cit. note 100, from Tom Kenning, "Ghana to update feed-in tariffs to last 20 years", PV-Tech, 20 April 2016, http://www.pv-tech.org/news/ghana-to-update-feed-in-tariffs-to-last-20-years, and from "Newly constructed 20MW power plant in Ghana begins operation", *Construction Review Online*, 25 April 2016, https://constructionreviewonline.com/2016/04/newly-constructed-20mw-power-plant-in-ghana-begins-operation/; Senegal from "Senegal in renewables drive as new solar park unveiled", *Daily Mail*, 22 October 2016, http://www.dailymail.co.uk/wires/afp/article-3863222/Senegal-renewables-drive-new-solar-park-unveiled.html; Uganda from Michael Oduor, "Uganda launches 10 MW solar power plant", *Africa News*, 26 December 2016, http://www.africanews.com/2016/12/26/uganda-launches-10-mw-solar-power-plant/, and from "Uganda Soroti solar power plant comes online", ESI Africa, 13 December 2016, https://www.esi-africa.com/news/uganda-soroti-solar-power-plant-comes-online/.

102 Algeria launched a tender for 4 GW, from IEA PVPS, op. cit. note 1, p. 5; Egypt from Andy Colthorpe, "Egypt extends deadline for West of Nile 200MW PV tender", PV-Tech, 17 June 2016, https://www.pv-tech.org/news/egypt-extends-deadline-for-west-of-nile-200mw-pv-tender, and from Ilias Tsagas, "Egypt and Jordan: solar tenders shuffle onwards", *PV Magazine*, 17 June 2016, https://www.pv-magazine.com/2016/06/17/egypt-and-jordan-solar-tenders-shuffle-onwards_100025060/; Kenya from "2016 Kenya REA solar PV diesel hybrid plants supply tender", Biasharapoint East Africa, 9 August 2016, http://biasharapoint.com/blog/2016-kenya-rea-solar-pv-diesel-hybrid-plants-supply-tender/; Morocco from "Masen invites bids for 400MW solar power project", Trade Arabia, 6 January 2016, http://www.tradearabia.com/news/OGN_298116.html; Nigeria signed its first solar power PPAs in July for 14 large-scale plants after four years of negotiations, from Peyton, op. cit. note 100; the plants will total nearly 1 GW of solar PV capacity, from "Movements in Nigeria's PV market as PPAs get signed", *PV Magazine*, 5 July 2016, https://www.pv-magazine.com/2016/07/05/movements-in-nigerias-pv-market-as-ppas-get-signed_100025267/; Gabriel Ewepu and Ediri Ejoh, "Solar power devt: investors commit $2.5bn into 14 projects", Vanguard, 22 July 2016, http://www.vanguardngr.com/2016/07/solar-power-devt-investors-commit-2-5bn-in-14-projects/; "Nigeria: Pan Africa Solar signs Nigeria's first U.S.$146 million investment", All Africa, 8 July 2016, http://allafrica.com/stories/201607080705.html; Zambia from Brian Eckhouse and Anna Hirtenstein, "Cheapest solar in Africa comes to Zambia through World Bank plan", *Bloomberg*, 13 June 2016, https://www.bloomberg.com/news/articles/2016-06-13/cheapest-solar-in-africa-comes-to-zambia-through-world-bank-plan, and from International Finance Corporation (IFC), "Scaling Solar's first auction in Zambia sets new regional benchmark for low-cost solar power", press release (Lusaka, Zambia: 13 June 2016), http://

ifcextapps.ifc.org/IFCExt/Pressroom/IFCPressRoom.nsf/0/E5F6A9E9D7C08B5A85257FD100651286; winning bids were USD 0.0602 per kWh for a 45 MW plant and USD 0.0784 per kWh for a 28 MW plant, from Eckhouse and Hirtenstein, op. cit. this note. Many of these projects are being developed and financed through the World Bank's Scaling Solar programme; see http://www.scalingsolar.org/.

103 IEA-PVPS, op. cit. note 3, p. 12.

104 Runyon, op. cit. note 12; SolarPower Europe, op. cit. note 10, p. 23. Residential markets are located primarily in Australia, several countries in the EU, Japan and the United States. In 2015, the global solar rooftop segment declined by 1 GW relative to 2014, from idem.

105 IEA-PVPS, op. cit. note 10, p. 14. **Figure 19** from IEA-PVPS, op. cit. note 3, p. 12 , and 2016 based on preliminary estimates from Becquerel Institute, provided by Philippe Macé, Becquerel Institute, personal communication with REN21, 15 May 2017.

106 IEA-PVPS, op. cit. note 3, pp. 12, 67.

107 Mercatus, op. cit. note 85.

108 Data derived from Denis Lenardic, pvresources, personal communication with REN21, March-April 2017; Denis Lenardic, "Large-scale PV power plants – Top50", updated 19 March 2017, http://www.pvresources.com/en/pvpowerplants/top50pv.php; Denis Lenardic, "Large-scale PV power plants – Ranking 51-100", updated 19 March 2017, http://www.pvresources.com/en/pvpowerplants/top100pv.php; Denis Lenardic, "Large-scale PV power plants – Ranking 101-150", updated 19 March 2017, http://www.pvresources.com/en/pvpowerplants/top150pv.php.

109 Ibid., all references.

110 The project in Yanchi, Ningxia was completed in June 2016, from Huawei, "1 GW ground-mounted Smart PV plant in Yanchi, China", http://www.huawei.com/en/all-products/Solar/References/Yanchi, viewed 19 March 2017.

111 Wiki-Solar, "Another record year for utility-scale solar takes cumulative capacity close to 100 GW", 2 March 2017, http://wiki-solar.org/library/public/170302_Utility-solar_2016_figures_near_100GW.pdf. An estimated 55 GW of such plants are in Asia, 22.7 GW in North and Central America, 16.6 GW in Europe, 3 GW in South America, 1.9 GW in Africa, and 0.3 GW in Australasia and Oceania, from idem.

112 See, for example, Sarah Butler, "Marks & Spencer crowdfunds solar panels for its stores", *The Guardian* (UK), 16 June 2016, https://www.theguardian.com/business/2016/jun/16/m-and-s-crowdfunds-solar-panels-stores-marks-and-spencer; Aaron Pressman, "Solar power from Apple could light up your home", *Fortune*, 4 August 2016, http://fortune.com/2016/08/04/apple-approval-solar-electricity/; Joseph Bebon, "More major companies commit to 100% renewables", *Solar Industry Magazine*, 20 September 2016, http://solarindustrymag.com/more-major-companies-commit-to-100-renewables; "Leon moves to 100% renewable energy", *Eat Out Magazine*, 23 August 2016, http://eatoutmagazine.co.uk/leon-moves-100-renewable-energy; Katherine Tweed, "72% of corporations are actively procuring clean energy", Greentech Media, 21 June 2016, https://www.greentechmedia.com/articles/read/72-of-large-companies-are-actively-procuring-clean-energy; Cassie Werber, "These companies now run on 100% renewable power", Quartz Media, 12 May 2016, http://qz.com/682669/these-companies-now-run-on-100-renewable-power/; The White House, "Fact sheet: U.S. hosts world's energy ministers to scale up clean energy and drive implementation of the Paris Agreement", press release (Washington, DC: 2 June 2016), https://obamawhitehouse.archives.gov/the-press-office/2016/06/02/fact-sheet-us-hosts-worlds-energy-ministers-scale-clean-energy-and-drive.

113 For example, only 10 new community energy organisations were registered in the United Kingdom during the first eight months of 2016, compared to 76 during 2015; the decline was attributed to changes in government policies, from Co-operatives UK, "New data reveals 80 per cent drop in community-owned energy following government U-turns", press release (Manchester: updated 19 October 2016), https://www.uk.coop/newsroom/new-data-reveals-80-cent-drop-community-owned-energy-following-government-u-turns; see also Fiona Harvey, "Just 10 new community energy schemes registered after Tories cut subsidies", *The Guardian* (UK), 12 September 2016, https://www.theguardian.com/environment/2016/sep/12/just-10-new-community-energy-schemes-registered-after-tories-cut-subsidies.

114 See, for example: Jason Deign, "Australian Government and energy retailers back community solar-plus-storage projects", Greentech Media, 4 May 2016, https://www.greentechmedia.com/articles/read/arena-funds-battery-plant-in-australias-greenest-ever-neighborhood; ReneSola, "ReneSola connects 26MW of solar projects to UK grid", press release (Shanghai: 5 July 2016), http://www.prnewswire.com/news-releases/renesola-connects-26mw-of-community-solar-projects-to-uk-grid-300293816.html; Adilya Zaripova, "Finland to add more PV using community solar model", *PV Magazine*, 29 April 2016, http://www.pv-magazine.com/news/details/beitrag/finland-to-add-more-pv-using-community-solar-model_100024372/; in Finland, shared solar PV projects represent about 13% of the country's solar power production, from idem. United States from Chris Martin, "It's the dawn of the community solar farm", *Bloomberg*, 16 August 2016, https://www.bloomberg.com/news/articles/2016-08-16/no-rooftop-no-problem-as-solar-gardens-pop-up-in-communities. At least 16 states and Washington, DC, have legislation to support community projects, from Andrea Romano and Karin Corfee, "Community solar on the rise – tips for utilities developing programs", Renewable Energy World, 22 November 2016, http://www.renewableenergyworld.com/articles/2016/11/community-solar-on-the-rise-tips-for-utilities-developing-programs.html.

115 ISEP, "Community power growing in Japan and world-wide", *REN21 Newsletter*, March 2017. ISEP uses the same definition of community power as the World Wind Energy Association (WWEA): "Community power" is defined as having at least two of the following criteria: local stakeholders (individuals or a group) own the majority or all of the project; control over voting rests with the community-based organisation, made up of local stakeholders; the majority of social and environmental benefits are distributed locally, from WWEA, "WWEA defines community power", 23 May 2011, http://www.wwindea.org/communitypowerdefinition/.

116 Australia from, for example, Deign, op. cit. note 114. United States from, for example, Romano and Corfee, op. cit. note 114; First Solar, "First Solar books 121MW in community solar sales", press release (Tempe, AZ: 3 August 2016), http://investor.firstsolar.com/releasedetail.cfm?ReleaseID=982664; Jennifer Runyon, "14-MW community solar array now online in Massachusetts", Renewable Energy World, 22 November 2016, http://www.renewableenergyworld.com/articles/2016/11/14-mw-community-solar-array-now-online-in-massachusetts.html.

117 **Honduras** generated 880.8 GWh of electricity with solar PV in 2016, and total net generation (including imports) was 8,977.6 GWh, making the solar PV share 9.8%, up from 4.8% in 2015, from Empresa Nacional de Energía Eléctrica (ENEE), *Boletín Estadistíco Diciembre 2016* (Tegucigalpa: 2016), p. 5, http://www.enee.hn/planificacion/2016/Boletines/BOLETIN%20%20DICIEMBRE%202016.pdf, in January 2017, Honduras' share of solar PV was 10.8%, from ENEE, *Boletín Estadistíco Enero 2017* (Tegucigalpa: 2017), p. 7, http://www.enee.hn/planificacion/2017/boletines/Boletin%20Estadistico%20(Enero%202017).pdf; in **Italy,** solar PV generated 22,545 GWh of electricity in 2016 (down from 22,587 GWh in 2015) out of total consumption of 310,251 GWh in 2016 (down from 316,897 GW in 2015), from Terna, *Rapporto mensile sul Sistema Elettrico* (Rome: December 2016), p. 13, http://download.terna.it/terna/0000/0893/13.PDF; **Greece** based on 3,686.6 GWh of solar PV generation (of which 511.6 GWh was from rooftop systems), which amounted to 7.2% of total electricity consumption, from Greek Operator for Electricity Market, Independent Power Transmission Operator, provided by Ioannis Tsipouridis, R.E.D. Pro Consultants S.A., Athens, personal communication with REN21, 21 April 2017; **Germany** generated 6.4% of its electricity with solar PV in 2016, down from 6.5% in 2015, from BMWi, *Zeitreihen zur Entwicklung...*, op. cit. note 70, pp. 41-42.

118 Countries with 2% or more based on IEA PVPS, op. cit. note 1, pp. 12, 13. Countries with at least 4% are Honduras, Italy, Greece, Germany, Japan and Belgium, from idem; Japan also from Matsubara, op. cit. note 37. At least 12 countries had enough to meet more than 5% at end-2015, including Honduras, Kiribati, Italy, St. Helena, Germany, Greece, Cabo Verde, Guinea-Bissau, Solomon Islands, Equitorial Guinea, Sierra Leone and Comoros, from IEA-PVPS, op. cit. note 3, p. 54.

119 IEA PVPS, op. cit. note 1, p. 14. Estimate for electricity generation is theoretical calculation based on average yield and installed solar PV capacity as of 31 December 2016. Solar PV capacity in operation at the end of 2016 was enough to produce an estimated 1.8% of global electricity generation assuming close to optimum siting, orientation and average weather conditions, from IEA PVPS, op. cit. note 1, pp. 12, 13.

120 GTM Research and SEIA, op. cit. note 26, p. 15.

121 IEA PVPS, op. cit. note 3, p. 58; Masson, op. cit. note 11; Mints, op. cit. note 12; Paula Mints, "3@3 on Solar PV: Solar at $0.25 a watt explained", video, Renewable Energy World, 16 February 2017, http://www.renewableenergyworld.com/articles/2017/02/3-3-on-solar-pv-solar-at-0-25-a-watt-explained.html; "Innovations in solar plant assembly drive costs towards $1 per watt in 2017", PV Insider, 12 October 2016, http://analysis.pv-insider.com/innovations-solar-plant-assembly-drive-costs-towards-1-watt-2017.

122 Figures of 29% and USD 0.41 per watt based on global quarterly blended c-Si module prices, from GTM Research, personal communication with REN21, April 2017; historic lows from Mints, op. cit. note 12.

123 Masson, op. cit. note 11. Low module prices below production costs for several tier 1 companies by late 2016, such that even the most competitive producers were having difficulty making a profit, from Masson, op. cit. note 15; Paula Mints, "3@3 on Solar PV: Falling prices, commodization, Middle East", video, Renewable Energy World, 28 September 2016, http://www.renewableenergyworld.com/articles/2016/09/3-3-on-solar-pv-falling-prices-commoditization-middle-east.html; Mints, op. cit. note 21. See also David Ferris, "Fending off China, U.S. manufacturer SunPower slashes jobs", *E&E News*, 8 December 2016, http://www.eenews.net/energywire/2016/12/08/stories/1060046870; Runyon, op. cit. note 12.

124 Mints, op. cit. note 121; Mints, op. cit. note 123.

125 Factors driving down costs from Frankfurt School-UNEP Collaborating Centre for Climate & Sustainable Energy Finance and BNEF, *Global Trends in Renewable Energy Investment 2017* (Frankfurt: April 2017), p. 17, http://fs-unep-centre.org/publications/global-trends-renewable-energy-investment-2016; faster than expected from SolarPower Europe, op. cit. note 10, p. 8; IEA-PVPS, op. cit. note 3, p. 58. See also Lazard, "Levelized cost of energy analysis 10.0", 15 December 2016, https://www.lazard.com/perspective/levelized-cost-of-energy-analysis-100/, and US Department of Energy (DOE), Office of Energy Efficiency & Renewable Energy (EERE), "Energy Department announces more than 90% achievement of 2020 SunShot goal, sets sights on 2030 affordability targets", 14 November 2016, https://energy.gov/eere/articles/energy-department-announces-more-90-achievement-2020-sunshot-goal-sets-sights-2030. The central estimate for LCOE of solar PV without tracking in the second half of 2016 was USD 101 per MWh, down 17% in one year, from Frankfurt School-UNEP Centre and BNEF, op. cit. this note, pp. 16-17.

126 See, for example, BNEF, *Climatescope 2016: The Clean Energy Country Competitiveness Index* (London and Washington, DC: December 2016), p. 1, http://global-climatescope.org/en/download/reports/climatescope-2016-report-en.pdf; Frankfurt School-UNEP Centre and BNEF, op. cit. note 125, p. 19; SolarPower Europe, op. cit. note 10, p. 10; World Economic Forum, *Renewable Infrastructure Investment Handbook: A Guide for Institutional Investors* (Geneva: December 2016), p. 6, http://www3.weforum.org/docs/WEF_Renewable_Infrastructure_Investment_Handbook.pdf. Solar PV was more attractive than new natural gas in the United States as of 2016, from Mark Bolinger and Joachim Seel, *Utility-scale Solar 2015: An Empirical Analysis of Project Cost, Performance, and Pricing Trends in the United States* (Berkeley, CA: LBNL, August 2016), Executive Summary, https://emp.lbl.gov/sites/all/files/lbnl-1006037_report.pdf; solar PV and wind power provide the cheapest new sources of generation capacity in South Africa, per GreenCape, *Utility-scale Renewable Energy – 2017 Market Intelligence Report* (Cape Town: 2017), p. 12, http://www.greencape.co.za/assets/Uploads/GreenCape-Renewable-Energy-MIR-2017-electronic-FINAL-v1.pdf; costs of solar power are well below retail power prices in Australian capital cities, from Australian Climate Council, *State of Solar 2016: Globally and in Australia* (Potts Point, New South Wales: 2017), https://www.climatecouncil.org.au/uploads/4127a8c364c1f9fa8ab096b04cd93f78.pdf. The average global LCOE for coal has been around USD 100 per MWh for more than a decade, while solar generating costs have fallen from about USD 600 per MWh a decade ago to USD 300 per MWh around 2011 to close to or below USD 100 per MWh by late 2016, from World Economic Forum, op. cit. this note, p. 6. Solar PV also is competing with wind power in some markets, beating out wind in the first and second power auctions in Mexico in 2016, from FTI Intelligence, "Vestas returns to no. 1 spot in global wind turbine supplier ranking in 2016", Intelligence Spark – Energy Insights, 21 February 2017.

127 Frankfurt School-UNEP Centre and BNEF, op. cit. note 125, p. 19.

128 See, for example, Mints, op. cit. note 12; Anna Hirtenstein, "New record set for world's cheapest solar, now undercutting coal", *Bloomberg*, 3 May 2016, http://www.bloomberg.com/news/articles/2016-05-03/solar-developers-undercut-coal-with-another-record-set-in-dubai; Vanessa Dezem, "Solar sold in Chile at lowest ever, half price of coal", *Bloomberg*, 19 August 2016, https://www.bloomberg.com/news/articles/2016-08-19/solar-sells-in-chile-for-cheapest-ever-at-half-the-price-of-coal; Anthony Dipaola, "Cheapest solar on record offered as Abu Dhabi expands renewables", *Bloomberg*, 19 September 2016, https://www.bloomberg.com/news/articles/2016-09-19/cheapest-solar-on-record-said-to-be-offered-for-abu-dhabi.

129 Argentina from Steve Sawyer, Global Wind Energy Council, personal communication with REN21, 29 November 2016; Chile from Dezem, op. cit. note 128, and from Tom Kenning, "Solar takes at least 6% of Chile's largest power auction with record low tariffs", PV-Tech, 18 August 2016, http://www.pv-tech.org/news/chile-auction-establishes-renewables-without-subsidy; India from Tom Kenning, "Indian solar tariffs reach 'surprise' new low of INR4.34/kWh", PV-Tech, 19 January 2016, https://www.pv-tech.org/news/indian-solar-tariffs-reach-surprise-new-low-of-inr-4.34-kwh-from-fortum; Tom Kenning, "Solar bids in India's Rajasthan near record low as 16 developers go below five rupees", PV-Tech, 13 July 2016, https://www.pv-tech.org/news/solar-bids-in-indias-rajasthan-near-record-low-as-16-developers-go-below-fi; "Record low tariff in Rewa improves growth prospects for solar in India", Bridge to India, 13 February 2017, http://www.bridgetoindia.com/record-low-tariff-rewa-improves-growth-prospects-solar-india/; Jordan and Saudi Arabia from "Saudi Arabia seeks $50bn of solar, wind investments; Jordan agrees $60/MWh PV prices", New Energy Update, 17 January 2017, http://analysis.newenergyupdate.com/pv-insider/saudi-arabia-seeks-50bn-solar-wind-investments-jordan-agrees-60mwh-pv-price; "South Africa's active solar regions to multiply as firms factor in grid risk", PV Insider, 30 March 2016, http://analysis.pv-insider.com/south-africas-active-solar-regions-multiply-firms-factor-grid-risk; United Arab Emirates from Hirtenstein, op. cit. note 128, from Dipaola, op. cit. note 128, and from "DEWA signs power purchase agreement with Masdar for 800MW solar project", Energy Business Review, 29 November 2016, http://solar.energy-business-review.com/news/dewa-to-power-purchase-agreement-with-masdar-for-800mw-solar-project-291116-5682193.

130 "China said to mull bigger cut in solar prices in some regions", *Bloomberg*, 28 September 2016, http://www.bloomberg.com/news/articles/2016-09-28/china-said-to-mull-bigger-cut-in-solar-prices-in-some-regions-itmjnwlj; Danish Energy Agency, "Historically low prices offered in Danish tender of aid for solar PV", press release (Copenhagen: 12 December 2016), https://ens.dk/en/press#/pressreleases/historically-low-prices-offered-in-danish-tender-of-aid-for-solar-pv-1688406; Germany from Craig Morris, "German solar auctions: low prices, little built", http://www.erneuerbareenergien.de/german-solar-auctions-low-prices-little-built/150/436/97174/, and from SolarPower Europe, op. cit. note 4. Even in Germany's seasoned market, average solar power prices in tenders fell around 25% in about 18 months, from idem. At the same time, however, only 27% of Germany's winning bids as of April 2015 were up 16 months later, from Morris, op. cit. this note. In Zambia, for example, low tariffs have been achieved through the IFC's Scaling Solar Program, from

IFC, "Scaling Solar delivers low-cost clean energy for Zambia", press release (Lusaka, Zambia and Washington, DC: June 2016), http://www.ifc.org/wps/wcm/connect/news_ext_content/ifc_external_corporate_site/news+and+events/news/scaling+solar+delivers+low+cost+clean+energy+for+zambia.

131 Bolinger and Seel, op. cit. note 126; David Ferris, "Solar power crosses threshold, gets cheaper than natural gas", *E&E News*, 21 August 2015, https://www.eenews.net/stories/1060023749; Richard A. Kessler, "Texas PV – the fastest draw in the west", Recharge News, 29 October 2016, http://www.rechargenews.com/solar/1182574/texas-pv-the-fastest-draw-in-the-west.

132 Expectations that technology costs would fall, from Jess Shankleman and Chris Martin, "Solar could beat coal to become the cheapest power on Earth", *Bloomberg*, 3 January 2017, https://www.bloomberg.com/news/articles/2017-01-03/for-cheapest-power-on-earth-look-skyward-as-coal-falls-to-solar; cost of capital and low operating costs from Arnulf Jäger-Waldau, European Commission, Brussels, personal communication with REN21, April 2017.

133 SolarPower Europe, op. cit. note 10, p. 11.

134 See, for example, Anindya Upadhyay, "Fortum financing solar spares India banks made wary by SunEdison", *Bloomberg*, 1 May 2016, https://www.bloomberg.com/news/articles/2016-05-02/fortum-financing-solar-spares-india-banks-made-wary-by-sunedison; Mints, op. cit. note 123; Cédric Philibert, IEA, cited in "Follow the sun: solar power is reshaping energy production in the developing world", *The Economist*, 16 April 2016, http://www.economist.com/news/business/21696941-solar-power-reshaping-energy-production-developing-world-follow-sun; Masson, op. cit. note 11.

135 Threatens quality from Masson, op. cit. note 1; Mints, op. cit. note 121; Mints, op. cit. note 123.

136 See, for example, Galen Barbose and Naïm Darghouth, *Tracking the Sun VIII: The Installed Price of Residential and Non-Residential Photovoltaic Systems in the United States* (Berkeley, CA: LBNL, August 2015), pp. 23-24, https://emp.lbl.gov/publications/tracking-sun-ix-installed-price; Lazard, op. cit. note 125; IEA-PVPS, op. cit. note 3, p. 60; Andy Colthorpe, "Japan's government confirms plans for solar tender", PV-Tech, 4 March 2016, https://www.pv-tech.org/news/japans-government-speaks-about-utility-scale-pv-tenders-explains-thinking-b.

137 Trajectories from DOE, *Revolution…Now: The Future Arrives for Five Clean Energy Technologies – 2015 Update* (Washington, DC: November 2015), http://energy.gov/sites/prod/files/2015/11/f27/Revolution-Now-11132015.pdf; competitive and cheaper than from SolarPower Europe, op. cit. note 7, pp. 5, 7, 11. In Australia, for example, the cost of solar power was well below retail power prices in capital cities as of early 2017, from Australian Climate Council, *State of Solar 2016: Globally and in Australia* (Potts Point, New South Wales: 2017), p. II, https://www.climatecouncil.org.au/uploads/4127a8c364c1f9fa8ab096b04cd93f78.pdf.

138 Eighth year based on data in this section and developments in past years from Paula Mints, "Reality check: the changing world of PV manufacturing", Renewable Energy World, 5 October 2011, http://www.renewableenergyworld.com/articles/2011/10/reality-check-the-changing-world-of-pv-manufacturing.html; Paula Mints, "The solar pricing struggle", Renewable Energy World, 28 August 2013, http://www.renewableenergyworld.com/articles/2013/08/the-solar-pricing-struggle.html; Paula Mints, "2015 top ten PV cell manufacturers", Renewable Energy World, 8 April 2016, http://www.renewableenergyworld.com/articles/2016/04/2015-top-ten-pv-cell-manufacturers.html.

139 Shares for 2016 from GTM Research, op. cit. note 122. Europe's share fell to about 6% and the US share remained at 2% in 2015, from GTM Research, *PV Pulse*, April 2016. Europe's share was around 8% in 2014, and 10% in 2013, from GTM Research, *PV Pulse*, March 2015.

140 The top 10 module manufacturers (companies that shipped assembled modules to the end-market) were JinkoSolar, Trina Solar, Canadian Solar, Hanwha Q-CELLS, JA Solar, GCL, First Solar, Yingli Green, Talesun and Risen, and they shipped just over half of all modules, from Solar Media Ltd., *PV Manufacturing & Technology Quarterly*, cited in Finlay Colville, "Top-10 solar module suppliers in 2016", PV-Tech, 31 January 2017, https://www.pv-tech.org/editors-blog/top-10-solar-module-suppliers-in-2016.

141 Solar Media Ltd., PV Manufacturing & Technology Quarterly, cited in Colville, op. cit. note 140. See also Mark Osborne, "Top 5 module manufacturers in 2016", PV-Tech, 23 November 2016, https://www.pv-tech.org/editors-blog/top-5-solar-module-manufacturers-in-2016. The top 10 cell producers in 2016 were Hanwha Q CELLS, JA Solar, Trina Solar, First Solar, JinkoSolar, Motech (China), Tongwei Solar (China), Yingli Green, Canadian Solar and Shunfeng (China), and they accounted for less than 40% of total production, from Solar Media Ltd., op. cit. this note.

142 In a race from Joe Ryan, "Solar industry braces with looming glut eroding panel prices", *Bloomberg*, 23 August 2016, https://www.bloomberg.com/news/articles/2016-08-23/solar-industry-braces-as-looming-glut-threatens-to-erode-prices. In February and March alone, expansions were announced in Asia, Europe (e.g., Netherlands, Italy), North Africa (e.g., Algeria), the Middle East (e.g., Saudi Arabia) and South America (e.g., Brazil), from Mark Osborne, "Global PV manufacturing capacity expansion announcements in March increase to 7.3GW", PV-Tech, 11 April 2016, http://www.pv-tech.org/news/global-pv-manufacturing-capacity-expansion-announcements-in-march-increase, and from Mark Osbourne, "PV manufacturing capacity expansion announcements in February reach 5.4GW", PV-Tech, 7 March 2016, https://www.pv-tech.org/news/announcements-of-pv-manufacturing-capacity-expansions-in-february-reach-5.4.

143 SolarPower Europe, op. cit. note 10, p. 8. New factories in Asia from, for example, Edgar Meza, "European Commission seeks to bar five Chinese PV manufacturers from price undertaking", *PV Magazine*, 13 October 2016, http://www.pv-magazine.com/news/details/beitrag/european-commission-seeks-to-bar-five-chinese-pv-manufacturers-from-price-undertaking_100026488/; Ian Clover, "India loses solar appeal at World Trade Organization", *PV Magazine*, 19 September 2016, http://www.pv-magazine.com/news/details/beitrag/india-loses-solar-appeal-at-world-trade-organization_100026144/; Sam Pothecary, "JA Solar announces facility expansion in Malaysia", *PV Magazine*, 6 October 2016, http://www.pv-magazine.com/news/details/beitrag/ja-solar-announces-facility-expansion-in-malaysia_100026391/; Christian Roselund, "Trina Solar begins module production in Thailand", *PV Magazine*, 29 March 2016, http://www.pv-magazine.com/news/details/beitrag/trina-solar-begins-module-production-in-thailand_100023919/; Jessica Shankleman, "JA Solar withdraws from EU minimum sale pricing agreement", *Bloomberg*, 28 September 2016, http://www.bloomberg.com/news/articles/2016-09-28/ja-solar-withdraws-from-eu-minimum-solar-pricing-agreement; Philip Blenkinsop, "EU countries oppose duty extension on Chinese solar panels: sources", *Reuters*, 26 January 2017, http://www.reuters.com/article/us-eu-china-solar-idUSKBN15A29A. Vietnam emerged as an alternative to Malaysia and Thailand from Mark Osborne, "Global PV manufacturing capacity expansion announcements in March increase to 7.3GW", PV-Tech, 11 April 2016, https://www.pv-tech.org/news/global-pv-manufacturing-capacity-expansion-announcements-in-march-increase; Mark Osborne, "GCL System adding 600MW cell capacity in Vietnam with Vina", PV-Tech, 3 January 2017, https://www.pv-tech.org/news/gcl-system-adding-600mw-cell-capacity-in-vietnam-with-vina.

144 Masson, op. cit. note 11.

145 Sam Pothacary, "First PV module manufacturing plant opened in Ghana", *PV Magazine*, 5 April 2016, https://www.pv-magazine.com/2016/04/05/first-pv-module-manufacturing-plant-opened-in-ghana_100024018/; "Ultramodern solar panel plant launched in Ghana", *News Ghana*, 2 April 2016, http://www.newsghana.com.gh/ultramodern-solar-panel-plant-launched-in-ghana/; Canadian Solar, "Canadian Solar opens Brazil's largest capacity solar module manufacturing facility", press release (Ontario: 12 December 2016), http://www.prnewswire.com/news-releases/canadian-solar-opens-brazils-largest-capacity-solar-module-manufacturing-facility-300376422.html; Ian Clover, "Commercial production begins at Solar Frontier's 150 MW CIS plant", *PV Magazine*, 1 June 2016, http://www.pv-magazine.com/news/details/beitrag/commercial-production-begins-at-solar-frontiers-150-mw-cis-plant_100024815/; Sam Pothecary, "New 50 MW module production facility operational in Kosovo", *PV Magazine*, 16 June 2016, https://www.pv-magazine.com/2016/06/16/new-50-mw-module-production-facility-operational-in-kosovo_100025007/; Mark Osborne, "OC3 adding module capacity in Germany to meet Turkish market drive", PV-Tech, 25 January 2017, https://www.pv-tech.org/news/oc3-adding-module-capacity-in-germany-to-meet-turkish-market-drive.

146 For example, Canadian Solar scaled back plans from 6.4 GW of new manufacturing capacity to 5.8 GW, from Ryan, op. cit. note 142; other companies halted plans for factories in Brazil because

of the economic slowdown there and plunging local currency, from Vanessa Dezen, "Canadian Solar investing $23 million in Brazil panel factory", Renewable Energy World, 20 June 2016, http://www.renewableenergyworld.com/articles/2016/06/canadian-solar-investing-23-million-in-brazil-panel-factory.html. Closed facilities included, for example, SunPower (United States) closed a module assembly factory in the Philippines and announced jobs cuts in order to reduce costs, from Mints, op. cit. note 21, and from Mints, op. cit. note 12. Panasonic (Japan) stopped production at a facility in February, although it had plans to reopen it for the US market, from "Panasonic to supply solar panels to Tesla", *Nikkei Asian Review*, 16 December 2016, http://asia.nikkei.com/Business/Companies/Panasonic-to-supply-solar-panels-to-Tesla; changed strategy or restructured also from, for example, Chris Martin and Brian Eckhouse, "Solar manufacturers pivot away from big U.S. utility plants", *Bloomberg*, updated 11 August 2016, http://www.bloomberg.com/news/articles/2016-08-10/solar-manufacturers-pivoting-away-from-big-u-s-utility-projects; "First Solar to cut 1,600 jobs in a 'challenging' market", *E&E News*, 18 November 2016, http://www.eenews.net/energywire/2016/11/18/stories/1060045992.

147 SolarPower Europe, "Solar cell & module production in Europe – 2016 survey", http://www.solarpowereurope.org/reports/solar-cell-module-production/, viewed 13 March 2017. Europe's manufacturing capacity fell by 3%, from 6.9 GW in 2015 to 6.7 GW in 2016, and utilisation of module factories declined from 46% in 2015 to 40% in 2016, from idem.

148 "Panasonic to supply solar panels to Tesla", op. cit. note 146; Shankleman and Martin, op. cit. note 132.

149 Julian Spector, "Dow Chemical sheds its solar shingle business", Greentech Media, 1 July 2016, https://www.greentechmedia.com/articles/read/dow-chemical-sheds-solar-shingle-business; Dow, "Powerhouse™ Shingles no longer available", http://client.dow.com/dowpowerhouse; Frank Andorka, "Dow's Powerhouse solar shingle dream finally dies", *PV Magazine*, 15 December 2016, https://pv-magazine-usa.com/2016/12/15/dows-powerhouse-solar-shingle-dream-finally-dies/. US manufacturers from, for example, Mints, op. cit. note 21; Stephen Lacey, "SunPower slashes its workforce 25%, closes production and cuts capital spend 50% in restructuring", Greentech Media, 7 December 2016, https://www.greentechmedia.com/articles/read/sunpower-slashes-its-workforce-25-closes-production-and-cuts-capital-spend; Martin and Eckhouse, op. cit. note 146; "First Solar to cut 1,600 jobs in a 'challenging' market", op. cit. note 146.

150 Paula Mints, "Trying to understand PV shipment numbers: do the math", Renewable Energy World, 22 March 2016, http://www.renewableenergyworld.com/articles/2016/03/trying-to-understanding-pv-shipment-numbers-do-the-math.html; Masson, op. cit. note 1.

151 GTM Research, op. cit. note 122.

152 ibid.

153 Even the most competitive from Masson, op. cit. note 15; lay off workers and even fail from Mints, op. cit. note 123; Mints, op. cit. note 21; Ryan, op. cit. note 142; "First Solar to cut 1,600 jobs in a 'challenging' market", op. cit. note 146; Ferris, op. cit. note 123.

154 Tokyo Shoko Research, cited in "Bankruptcy of Japanese solar companies break record in 2016 due to sluggish market", Energy Trend, 25 January 2017, http://pv.energytrend.com/news/Bankruptcy_of_Japanese_Solar_Companies_Break_Record_in_2016_Due_to_Sluggish_Market.html; also cited in Shinichi Kato, "Solar firm bankruptcy hits record high for first half of 2016", Nikkei BP, 6 September 2016, http://techon.nikkeibp.co.jp/atclen/news_en/15mk/090600812/. Poor sales performance, failed business models and capital deficiency were three major reasons cited, from idem, both sources.

155 Eric Wesoff, "The end of SunEdison: Developer now looking into liquidating its assets", Greentech Media, 18 May 2016, http://www.greentechmedia.com/articles/read/The-End-of-SunEdison-Developer-Now-Looking-Into-Liquidating-Its-Assets; Christian Roselund, "Breaking: NRG applies to acquire 2.1 GW of SunEdison solar and wind projects", *PV Magazine*, 10 August 2016, https://www.pv-magazine.com/2016/08/10/breaking-nrg-applies-to-acquire-2-1-gw-of-sunedison-solar-and-wind-projects_100025717/; Anindya Upadhyay, "SunEdison said to exit India with sale of projects to Greenko", *Bloomberg*, 9 January 2017, https://www.bloomberg.com/news/articles/2017-01-09/sunedison-said-to-exit-india-with-sale-of-projects-to-greenko.

156 IEA-PVPS, op. cit. note 3, p. 45. In addition to those in the text, examples of mergers and acquisitions include: Renewable energy project developer and operator Voltalia (France) acquired Martifer Solar, from Yamurai Zendera, "Voltalia acquires photovoltaic firm Martifer Solar", *Construction Week*, 18 October 2016, http://www.constructionweekonline.com/article-41303-voltalia-acquires-photovoltaic-firm-martifer-solar/; Daniella Ola, "ENcome acquires abakus solar", PV-Tech, 21 June 2016, http://www.pv-tech.org/news/encome-acquires-abakus-solar; two large US residential installers, Vision Solar and Zing Solar merged to form ION Solar, from Chris Crowell, "Two growing regional solar installers merge to form ION Solar", *Solar Builder Magazine*, 6 December 2016, http://solarbuildermag.com/news/two-growing-regional-solar-installers-merge-to-form-ion-solar/; Chris Crowell, "O&M news: MaxGen Energy Services acquires commercial services of Next Phase Solar from Enphase", *Solar Builder Magazine*, 11 November 2016, http://solarbuildermag.com/news/maxgen-energy-services-acquires-commercial-services-of-next-phase-solar/; Chris Crowell, "BayWa r.e. enters module business in Australia, acquiring Solarmatrix", *Solar Builder Magazine*, 6 September 2016, http://solarbuildermag.com/news/baywa-ag-enters-module-business-australia-acquiring-solarmatrix/; Chris Crowell, "Sungevity ready to go public after big merger with Easterly", *Solar Builder Magazine*, 6 July 2016, http://solarbuildermag.com/news/sungevity-ready-to-go-public-after-big-merger-with-easterly/.

157 Ralf Ossenbrink, "Ingeteam takes over Bonfiglioli's PV business", *Sun & Wind Energy*, 21 June 2016, http://www.sunwindenergy.com/photovoltaics/ingeteam-takes-over-bonfigliolis-pv-business; Bonfiglioli, "Ingeteam takes over Bonfiglioli's PV business", press release (Bilbao and Bologna: 19 June 2016), http://www.bonfiglioli.com/en/company/news-media/news/ingeteam-takes-over-bonfigliolis-pv-business/.

158 Mark Osborne, "Longi, Trina Solar and Tongwei team on 5GW mono ingot plant", PV-Tech, 4 January 2017, https://www.pv-tech.org/news/longi-trina-solar-and-tongwei-team-on-5gw-mono-ingot-plant; Liam Stoker, "WElink Energy, BSR sign £1.1 billion solar and efficient homes deal with CNBM", Solar Power Portal, 15 January 2016, http://www.solarpowerportal.co.uk/news/welink_energy_bsr_sign_1.1_billion_solar_and_efficient_homes_deal_9023.

159 Projects changed hands from, for example, "Ardian Infrastructure makes south American debut with solar plant", IPE Real Estate, 20 September 2016, https://realestate.ipe.com/news/infrastructure/ardian-infrastructure-makes-south-american-debut-with-solar-plant/10015203.fullarticle; Christian Roselund, "Southern Company acquires another 120 MW solar project in Texas", *PV Magazine*, 7 March 2016, https://www.pv-magazine.com/2016/03/07/southern-company-acquires-another-120-mw-solar-project-in-texas_100023591/; John West, "Southern Co. adds Texas solar facility to portfolio", *Atlanta Business Chronicle*, 7 July 2016, http://www.bizjournals.com/atlanta/news/2016/07/07/southern-co-adds-texas-solar-facility-to-portfolio.html; Conor Ryan, "Southern Power to acquire 102MW Henrietta Solar Project from SunPower", PV-Tech, 7 July 2016, http://www.pv-tech.org/news/southern-power-to-acquire-102mw-henrietta-solar-project-from-sunpower; Plamena Tisheva, "Cubico buys 50-MW UK solar farm from BSR", Renewables Now, 19 September 2016, http://renewables.seenews.com/news/cubico-buys-50-mw-uk-solar-farm-from-bsr-540137; "Successful sale of solar assets driving confidence in the sector", Bridge to India, 20 June 2016, http://www.bridgetoindia.com/successful-sale-of-solar-assets-driving-confidence-in-the-sector/; Southern Company, "Southern Company subsidiary acquires East Pecos Solar Facility in Texas", press release (Atlanta: 7 March 2016), http://www.prnewswire.com/news-releases/southern-company-subsidiarys-east-pecos-solar-facility-in-texas-begins-commercial-operation-300435119.html; Iris Dorbian, "Ardian buys four Solarpack solar PV plants in South America", PE Hub Network, 20 September 2016, https://www.pehub.com/2016/09/ardian-buys-four-solarpack-solar-pv-plants-in-south-america/#; United Photovoltaics Group Limited, "United PV acquired 82.4MW solar power plants in UK", press release (Hong Kong: 23 September 2016), http://unitedpvgroup.com/en/news-events/press-releases/detail/article/united-pv-acquired-824mw-solar-power-plants-in-uk; Greentech Energy Systems, "20/2016: Acquisition of the remaining 50% stake of La Castilleja solar plant completed", press release (Copenhagen: 20 December 2016), http://greentech.dk/blog/2016/12/20/202016-acquisition-of-the-remaining-50-stake-of-la-castilleja-solar-

plant-completed/; "Korea Power Company buys Colorado solar PV plant", *Power Engineering*, 29 August 2016, http://www.power-eng.com/articles/2016/08/korea-power-company-buys-colorado-solar-pv-plant.html. See also Smiti Mittal, "China's United PV secures $1.5 billion funding to acquire solar power projects", CleanTechnica, 6 January 2016, https://cleantechnica.com/2016/01/06/chinas-united-pv-secures-1-5-billion-funding-acquire-solar-power-projects/. Demand for projects won under tenders, from Masson, op. cit. note 11.

160 Michael Schmela, SolarPower Europe, "Global Market Outlook for Solar Power, 2016-2010", webinar, 7 July 2016.

161 Takashi Mochizuki, "Taiwan's Foxconn completes acquisition of Sharp", *Wall Street Journal*, 13 August 2016, https://www.wsj.com/articles/taiwans-foxconn-completes-deal-to-acquire-sharp-1470994207; Jonathan Soble, "With bet on Japan, Sharp stumbles", *New York Times*, 2 March 2016, https://www.nytimes.com/2016/03/03/business/dealbook/with-bet-on-japan-sharp-stumbles.html?_r=0; "Panasonic to supply solar panels to Tesla", *Nikkei Asian Review*, 16 December 2016, http://asia.nikkei.com/Business/Companies/Panasonic-to-supply-solar-panels-to-Tesla; Chisaki Watanabe and Dana Hull, "Tesla, Panasonic to begin solar panel production in New York", Bloomberg, 29 December 2016, https://www.bloomberg.com/news/articles/2016-12-27/tesla-panasonic-to-begin-solar-panel-production-in-new-york; Dana Hull and Chris Martin, "Tesla seals $2 billion SolarCity deal", *Bloomberg*, updated 18 November 2016, https://www.bloomberg.com/news/articles/2016-11-17/tesla-seals-2-billion-solarcity-deal-set-to-test-musk-s-vision; "Tesla completes acquisition of SolarCity", *E&E News*, 22 November 2016, http://www.eenews.net/greenwire/2016/11/22/stories/1060046152.

162 FTI Intelligence, op. cit. note 126.

163 SolarPower Europe, op. cit. note 10, p. 9. In addition, EDF signed a PPA with Southern California Edison for a 111.2 PV (AC) power plant, from Danielle Ola, "EDF buys US installer groSolar", PV-Tech, 25 April 2016, https://www.pv-tech.org/news/edf-buys-us-installer-grosolar.

164 Anindya Upadhyay, "India's Tata Power to buy $1.4bn renewables portfolio", Renewable Energy World, 14 June 2016, http://www.renewableenergyworld.com/articles/2016/06/india-s-tata-power-to-buy-1-4bn-renewables-portfolio.html; Sam Pothecary, "RWE to acquire PV and storage specialist Belectric Solar & Battery", *PV Magazine*, 29 August 2016, https://www.pv-magazine.com/2016/08/29/rwe-to-acquire-pv-and-storage-specialist-belectric-solar-battery_100025933/; Liam Stoker, "Innogy completes purchase of Belectric Solar & Battery", PV-Tech, 4 January 2017, https://www.pv-tech.org/news/innogy-completes-purchase-of-belectric-solar-battery; EDF (France) continued its move into the US market with the acquisition of Global Resource Options (groSolar), a US-based company that sells and installs residential and commercial systems, from "EDF agrees acquisition of US solar company", *PV Magazine*, 25 April 2016, https://www.pv-magazine.com/2016/04/25/edf-agrees-acquisition-of-us-solar-company_100024280/, and from Danielle Ola, "EDF buys US installer groSolar", PV-Tech, 25 April 2016, https://www.pv-tech.org/news/edf-buys-us-installer-grosolar.

165 Andy Colthorpe, "Thailand's biggest coal company mulling US$170m Japan PV investment – reports", PV-Tech, 7 April 2016, http://www.pv-tech.org/news/thailands-biggest-coal-company-could-invest-us170m-in-japan-pv-reports; Mott MacDonald, "Mott MacDonald supports major solar PV acquisition, Japan", press release (London: 26 April 2016), https://www.mottmac.com/releases/mott-macdonald-supports-major-solar-pv-acquisition-japan; Sam Pothecary, "Coal India to implement 200 MW solar project", *PV Magazine*, 30 June 2016, https://www.pv-magazine.com/2016/06/30/coal-india-to-implement-200-mw-solar-project_100025219/; PTT (Thailand), from "Foreign players descending on Japan's solar power market", *Nikkei Asian Review*, 30 April 2016, http://asia.nikkei.com/Business/Trends/Foreign-players-descending-on-Japan-s-solar-power-market; William Steel, "Wärtsilä diversifies into solar PV", Renewable Energy World, 3 May 2016, http://www.renewableenergyworld.com/articles/2016/05/wartsila-diversifies-into-solar-pv.html; Emiliano Bellini, "Eni, Sonatrach start construction on 10 MW PV plant in Algeria", PV Magazine, 20 March 2017, https://www.pv-magazine.com/2017/03/20/eni-and-sonatrach-start-construction-on-10-mw-pv-plant-in-algeria/; *MENA Solar Market Outlook for 2017*, op. cit. note 96.

166 Stine Jacobsen, "Oil firm Statoil makes first investment in solar tech", *Reuters*, 6 December 2016, http://www.reuters.com/article/us-statoil-solar-idUSKBN13V1P9.

167 See, for example, Barbara Grady, "Renewable energy's new dance partners: banks, pension funds", Green Biz, 19 July 2016, https://www.greenbiz.com/article/renewable-energy-new-dance-partners-banks-pension-funds; Solar Farms, LLC, "Solar farms generate dazzling returns for pension funds", press release (Asheville, NC: 11 January 2017), http://www.prnewswire.com/news-releases/solar-farms-generate-dazzling-returns-for-pension-funds-300389288.html; "Banks, financial institutions provide over Rs 78K crore for clean energy projects", *Economic Times*, 18 July 2016, http://economictimes.indiatimes.com/industry/energy/power/banks-financial-institutions-provide-overrs-78k-crore-for-clean-energy-projects/articleshow/53265652.cms; Maulik Vyas, "CDPQ sets up office in India: commits $150 million for renewable energy", *Economic Times*, 9 March 2016, http://economictimes.indiatimes.com/industry/energy/power/cdpq-sets-up-office-in-india-commits-150-million-forrenewable-energy/articleshow/51329123.cms; "Successful sale of solar assets driving confidence in the sector", Bridge to India, 20 June 2016, http://www.bridgetoindia.com/successful-sale-of-solar-assets-driving-confidence-in-the-sector/; Shailaja Sharma, "Piramal Enterprises, APG Asset Management commit $132 million to Essel Green Energy", LiveMint, 31 March 2016, http://www.livemint.com/Companies/NqX63R1fHIyMJ0xX8DOWvM/Piramal-Enterprises-APG-Asset-Management-commit-132-millio.html; ReNew Power, "Our Partners", https://renewpower.in/about-us/our-partners/, viewed 25 February 2016; SolarCity, "SolarCity Creates New Fund to Finance $249 Million in Solar Projects", press release (San Mateo, California: 25 February 2017), http://www.solarcity.com/newsroom/press/solarcity-creates-new-fund-finance-249-million-solar-projects; "SolarCity launches solar loan program in 14 states", Penn Energy, 3 June 2016, http://www.pennenergy.com/articles/pennenergy/2016/06/solarcity-launches-solar-power-loan-program-in-14-states.html; "SolarCity creates funds to finance over USD 347 million in solar PV projects for homeowners and small businesses, Solar Server, 29 September 2016, http://www.solarserver.com/solar-magazine/solar-news/current/2016/kw39/solarcity-creates-funds-to-finance-over-usd-347-million-in-solar-pv-projects-for-homeowners-and-small-businesses.html; Nina Chestney, "JP Morgan Asset Management acquires solar developer Sonnedix", *Reuters*, 1 September 2016, http://uk.reuters.com/article/us-jpmorgan-sonedix-solar-idUKKCN11753C.

168 Sharma, op. cit. note 167; Anindya Upadhyay, "Goldman-backed ReNew wins 522 MW of solar projects in East India", *Bloomberg*, 17 March 2016, https://www.bloomberg.com/news/articles/2016-03-17/goldman-backed-renew-wins-522mw-of-solar-projects-in-east-india. The California Public Employees' Retirement System agreed to buy up to 25% of Desert Sunlight Investment Holdings, which owns two solar power plants in southern California, from "Giant pension fund buys stake in California solar plants", *Times-Herald*, 23 March 2016, http://www.timesheraldonline.com/article/zz/20160323/NEWS/160327922.

169 Michael Allen, "Crowdfunding a renewable future", Phys Org, 12 October 2016, https://phys.org/news/2016-10-crowdfunding-renewable-future.html. Projects from, for example, "First successful SunVest (crowdfunding) solar PV system (April 2016)", SolarPVExchange, 29 April 2016, http://solarpvexchange.com/blog/2016/04/29/first-successful-sunvest-crowd-funding-solar-pv-system-april-2016/; Andrea Soh, "Crowdfunding used for solar installation at Singapore residential property (amended)", *Business Times*, 10 June 2016, http://www.businesstimes.com.sg/energy-commodities/crowdfunding-used-for-solar-installation-at-singapore-residential-property; Sarah Butler, "Marks & Spencer crowdfunds solar panels for its stores", *The Guardian* (UK), 16 June 2016, https://www.theguardian.com/business/2016/jun/16/m-and-s-crowdfunds-solar-panels-stores-marks-and-spencer. Technology innovation from, for example, GCR Staff, "Crowd funding sought for 'invisible' PV panels that mimic wood and stone", *Global Construction Review*, 11 October 2016, http://www.globalconstructionreview.com/news/crowd-funding-sought-invisible-p7v-pan7els-mim7ic/; Sam Pothecary, "Watly launched crowdfunding campaign for its offgrid power generator and water purifier", *PV Magazine*, 7 April 2016, https://www.pv-magazine.com/2016/04/07/watly-launches-crowdfunding-campaign-for-its-off-grid-power-generator-and-water-purifier_100024058/. New platforms from, for example, Andy Colthorpe, "New solar

crowdfunding platform launched in US", PV-Tech, 30 April 2016, https://www.pv-tech.org/news/new_solar_crowdfunding_investment_platform_joins_mosaic_in_us_market. For other related developments see, for example, "World premiere: crowdfunding platforms Lumo and TheSunExchange grant SolarCoins to their crowdfunders", SolarCoin, 18 October 2016, https://solarcoin.org/en/world-premiere-crowdfunding-platforms-lumo-and-thesunexchange-grant-solarcoins-to-their-crowdfunders/.

170 See, for example, SolarPower Europe, op. cit. note 10, pp. 8-9; Eric Wesoff, "SunPower breaks solar panel efficiency record, again", Greentech Media, 22 February 2016, http://www.greentechmedia.com/articles/read/SunPower-Breaks-Solar-Panel-Efficiency-Record-Again; First Solar, "First Solar achieves yet another cell conversion efficiency world record", Business Wire (Tempe, AZ: 23 February 2016), http://www.businesswire.com/news/home/20160223005315/en/l; Trina Solar, "Trina Solar announces new efficiency record of 23.5% for large-area interdigitated back contact silicon solar cell", press release (Changzhou: 26 April 2016), http://www.prnewswire.com/news-releases/trina-solar-announces-new-efficiency-record-of-235-for-large-area-interdigitated-back-contact-silicon-solar-cell-300257457.html; Erica Solomon, "How a new tandem solar cell is at the forefront on innovation", Masdar Institute, 29 May 2016, https://news.masdar.ac.ae/explore-news/stories-by-type/exploration/item/9171-how-a-new-tandem-solar-cell-is-at-the-forefront-of-solar-innovation.html; Eric Wesoff, "First Solar beats revenue, tunes guidance and nears 17% module efficiency on its lead line", Greentech Media, 4 August 2016, https://www.greentechmedia.com/articles/read/First-Solar-Beats-Revenue-Tunes-Guidance-and-Nears-17-Module-Efficiency-o; Technische Universiteit Eindhoven, "TU Eindhoven breaks world record for nanowire solar cells", press release (Eindhoven, Netherlands: 16 October 2016), https://www.tue.nl/en/university/news-and-press/news/16-10-2016-tu-eindhoven-breaks-world-record-for-nanowire-solar-cells/; Fraunhofer Institute for Solar Energy Systems (ISE), "30.2 percent efficiency – new record for silicon-based multi-junction solar cell", press release 23/16 (Freiburg: 9 November 2016), https://www.ise.fraunhofer.de/en/press-media/press-releases/2016/30-2-percent-efficiency-new-record-for-silicon-based-multi-junction-solar-cell.html. 1366 Technologies (US), which is developing a process that minimises silicon waste and could reduce production costs significantly, signed a purchase deal with Hanwha Q-Cells, from Peter Behr, "Closing in on a solar power breakthrough", *E&E News*, 21 October 2016, https://www.eenews.net/stories/1060044628; 1366 Technologies, "1366 Technologies and Hanwha Q CELLS achieve 19.6% efficiency using Direct Wafer® and Q.ANTUM cell technologies", press release (Bedford, MA: 21 December 2016), http://1366tech.com/2016/12/21/1366-technologies-hanwha-q-cells-achieve-19-6-efficiency-using-direct-wafer-q-antum-cell-technologies/. MiaSolé (United States) announced high-volume production of a new light-weight, flexible roofing product and started to ship orders, from Monica Richards/MiaSolé, "MiaSolé announces new products that revolutionize solar industry – next generation, flexible ultra-light solar technology", press release (Las Vegas, NV: 12 September 2016), http://miasole.com/2016/09/12/miasole-announces-new-products-revolutionize-solar/.

171 Roadmaps from, for example, Runyon, op. cit. note 12; Roberto Labastida, "Advanced module technologies moving onto the main stage", Renewable Energy World, 31 October 2016, http://www.renewableenergyworld.com/articles/2016/10/advanced-module-technologies-moving-onto-the-main-stage.html. See also, for example, Chris Martin, "First Solar making panels more cheaply than China's top supplier", *Bloomberg*, 14 April 2016, http://www.bloomberg.com/news/articles/2016-04-14/first-solar-making-panels-more-cheaply-than-china-s-top-supplier; "First Solar discontinues TetraSun product line, switches to Series 5 thin film", Solar Novus, 5 July 2016, http://www.solarnovus.com/first-solar-discontinues-tetrasun-product-line-switches-to-series-5-thin-film_N10110.html. Functionality and grid requirements, from Roberto Labastida, "Advanced module technologies moving onto the main stage", Renewable Energy World, 31 October 2016, http://www.renewableenergyworld.com/articles/2016/10/advanced-module-technologies-moving-onto-the-main-stage.html.

172 SolarWorld and REC Solar from Mark Osborne, "Global PV manufacturing capacity expansion announcements in March increase to 7.3GW", PV-Tech, 11 April 2016, https://www.pv-tech.org/news/global-pv-manufacturing-capacity-expansion-announcements-in-march-increase. For more on PERC-related developments, see, for example, Michael Schmela, "Why solar cell production is all about PERC: TaiyangNews publishes in-depth report on PERC cell technology", *TaiyangNews*, 8 April 2016, http://taiyangnews.info/opinion/why-solar-cell-production-is-all-about-perc/; Mark Osborne, "GCL System adding 600MW cell capacity in Vietnam with Vina", PV-Tech, 3 January 2017, http://www.pv-tech.org/news/gcl-system-adding-600mw-cell-capacity-in-vietnam-with-vina; Finlay Colville, "Hanwha restores Q-Cells to number 1 solar cell ranking in 2016", PV-Tech, 27 January 2017, https://www.pv-tech.org/news/hanwha-restores-q-cells-to-number-1-solar-cell-ranking-in-2016; Mark Osborne, "Global PV manufacturing capacity expansion announcements in March increase to 7.3GW", PV-Tech, 11 April 2016, http://www.pv-tech.org/news/global-pv-manufacturing-capacity-expansion-announcements-in-march-increase.

173 Busbars from "Trends in solar module manufacturing", The EU PVSEC Blog, 4 January 2017, http://www.photovoltaic-conference.com/press-media/blog-2017/118-blog-2017-170104.html.

174 For efficiency improvements see, for example, Monika Landgraf, "Record for perovskite/CIGS tandem solar module", Karlsruhe Institute of Technology, press release (Karlsruhe, Germany: 27 September 2016), http://www.kit.edu/kit/english/pi_2016_133_record-for-perovskite-cigs-tandem-solar-module.php; "Australia researchers set new record for perovskite solar cell efficiency", *Energy Business Review*, 5 December 2016, http://solar.energy-business-review.com/news/australia-researchers-set-new-world-efficiency-record-for-perovskite-solar-cell-051216-5687345. For stabilisation see, for example: Subham Dastidar et al., "High chloride doping levels stabilize the perovskite phase of cesium lead iodide", *Nano Letters*, vol. 15 (2016), 3563–70, http://pubs.acs.org/doi/abs/10.1021/acs.nanolett.6b00635; Ian Clover, "Oxford PV to open perovskite fab in Germany", *PV Magazine*, 11 November 2016, https://www.pv-magazine.com/2016/11/11/oxford-pv-to-open-perovskite-fab-in-germany_100026876/; Nancy Ambrosiano, "Cooling, time in the dark preserve perovskite solar power", Los Alamos National Laboratory, 17 May 2016, http://www.lanl.gov/discover/news-release-archive/2016/May/05.17-perovskite-solar-power.php; D. Koushik et al., "High-efficiency humidity-stable planar perovskite solar cells based on atomic layer architecture", *Energy and Environmental Science* (5 December 2016), http://pubs.rsc.org/en/Content/ArticleLanding/2017/EE/C6EE02687G#!divAbstract.

175 Ran Fu et al., *U.S. Solar Photovoltaic System Cost Benchmark: Q1 2016* (Golden, CO: National Renewable Energy Laboratory (NREL), September 2016), p. vi, http://www.nrel.gov/docs/fy16osti/66532.pdf.

176 See, for example, Jennifer Runyon, "Beamreach says its lightweight solar system slashes commercial solar install time by up to 80 percent", Renewable Energy World, 21 June 2016, http://www.renewableenergyworld.com/articles/2016/06/beamreach-says-its-lightweight-solar-system-slashes-commercial-solar-install-time-by-up-to-80-percent.html; "Innovations in solar plant assembly drive costs towards $1 per watt in 2017", PV Insider, 12 October 2016, http://analysis.newenergyupdate.com/pv-insider/innovations-solar-plant-assembly-drive-costs-towards-1-watt-2017.

177 Stefan Gsänger and Jean-Daniel Pitteloud, World Wind Energy Association (WWEA), personal communication with REN21, 9 March 2017; Frankfurt School-UNEP Centre and BNEF, op. cit. note 125, pp. 44-49; Ian Clover, "Wind company Suzlon enters India solar market with 210 MW project", *PV Magazine*, 13 January 2016, https://www.pv-magazine.com/2016/01/13/wind-company-suzlon-enters-india-solar-market-with-210-mw-project_100022766/. See also, for example, Karl-Erik Stromsta, "Ones to watch: wind and solar joining forces", Recharge News, 4 January 2016, http://www.rechargenews.com/wind/862372/ones-to-watch-wind-and-solar-joining-forces; Frank Jossi, "Nation's first integrated wind and solar project takes shape in Minnesota", *Midwest Energy News*, 2 March 2017, http://midwestenergynews.com/2017/03/02/nations-first-integrated-wind-and-solar-project-takes-shape-in-minnesota/; Joshua S. Hill, "Australia moves forward on three wind projects including wind/solar hybrid", CleanTechnica, 27 July 2016, https://cleantechnica.com/2016/07/27/australia-moves-forward-three-wind-projects-including-windsolar-hybrid/; Michael Place, "Engie Brasil 'analyzing' solar-wind hybrid projects", BNAmericas, 28 October 2016, https://www.bnamericas.com/en/news/electricpower/engie-brasil-analyzing-solar-wind-hybrid-projects;

Rahul Bhandari, "Solar wind hybrid power project to be set up at Rangrik", *News Himachal*, 18 May 2016, https://www.thenewshimachal.com/2016/05/solar-wind-hybrid-power-project-set-rangrik/; Anindya Upadhyay, "Hybrid solar and wind systems attract turbine makers in India", *Bloomberg*, 5 September 2016, https://www.bloomberg.com/news/articles/2016-09-05/hybrid-solar-and-wind-systems-attract-turbine-makers-in-india.

178 "US Solar market boom cuts O&M costs years ahead of forecast", PV Insider, 21 November 2016, http://analysis.pv-insider.com/us-solar-market-boom-cuts-om-costs-years-ahead-forecast; SolarPower Europe, op. cit. note 5.

179 SolarPower Europe, op. cit. note 5; Chijioke Mama, "Solar O&M in Nigeria: the challenges that lie ahead", The Solar Future, 18 January 2017, http://nigeria.thesolarfuture.com/news-source/2017/1/18/solar-om-in-nigeria-the-challenges-that-lie-ahead.

180 Ferris, op. cit. note 123; "US Solar market boom cuts O&M costs years ahead of forecast", op. cit. note 178; Jason Deign, "Rapid-cleaning robots set to cut solar energy losses, labor costs", New Energy Update, 15 March 2017, http://analysis.newenergyupdate.com/pv-insider/rapid-cleaning-robots-set-cut-solar-energy-losses-labor-costs. Robotic cleaning systems can increase system output while reducing or eliminating the need for water, and provide savings on vehicle and labour costs, from idem.

181 IEA-PVPS, op. cit. note 3, p. 52; Jason Deign, "Inverter makers focus on cutting O&M costs to increase market share", PV Insider, 23 November 2015, http://analysis.pv-insider.com/inverter-makers-focus-cutting-om-costs-increase-market-share; Anna Flávia Rochas, "Global technology suppliers raise inverter output using new materials", PV Insider, 14 September 2016, http://analysis.pv-insider.com/global-technology-suppliers-raise-inverter-output-using-new-materials.

182 Rochas, op. cit. note 181.

183 China's Huawei Solar was the largest manufacturer by shipments in 2015, from SolarPower Europe, op. cit. note 10, p. 8; IHS Technology PV Inverter Market Tracker Q2 2016, cited in John Parnell, "Huawei leads inverter market in 2015", PV-Tech, 21 July 2016, http://www.pv-tech.org/news/huawei-retains-top-spot-in-global-inverter-rankings-latest-ihs-data-shows; in 2016, Huawei Solar expanded production in Europe to meet demand in Europe and Central Asia, from Sam Pothecary, "Huawei expands operations in Europe", *PV Magazine*, 29 September 2016, http://www.pv-magazine.com/news/details/beitrag/huawei-expands-operations-in-europe_100026307/; Toshiba and Mitsubishi (both Japan), developed a joint venture to increase production capacity abroad and to target emerging markets, from Chisaki Watanabe, "Toshiba Mitsubishi looks beyond India, China for solar shipments", *Bloomberg*, 3 August 2016, https://www.bloomberg.com/news/articles/2016-08-03/toshiba-mitsubishi-looks-beyond-india-china-for-solar-shipments; fighting to maintain market share from, for example, Eric Wesoff, "Enphase's new $25M loan bets it all on next-gen microinverters and energy storage", Greentech Media, 18 July 2016, https://www.greentechmedia.com/articles/read/Enphases-New-25M-Loan-Bets-It-All-on-Next-Gen-Microinverters-and-Energy-S; Mark Osborne, "SMA Solar consolidates inverter production in Germany and China", PV-Tech, 11 August 2016, http://www.pv-tech.org/news/sma-solar-consolidates-inverter-production-in-germany-and-china; "Update 1 – SMA Solar shuts factories as pricing pressure intensifies", Reuters, 11 August 2016, http://www.reuters.com/article/sma-solar-results-redundancies-idUSL8N1AS12S.

184 Scott Moskowitz, "The global PV inverter and MLPE landscape: H2 2016", GTM Research, November 2016, https://www.greentechmedia.com/research/report/the-global-pv-inverter-and-mlpe-landscape-h2-2016.

185 GTM Research, cited in "GTM Research: Global solar photovoltaic (PV) inverter market continues to grow more concentrated as it matures", SolarServer, 12 December 2016, http://www.solarserver.com/solar-magazine/solar-news/current/2016/kw50/gtm-research-global-solar-photovoltaic-pv-inverter-market-continues-to-grow-more-concentrated-as-it-matures.html; Ian Clover, "SMA holds firm as inverter revenue leader, with Huawei topping shipment charts, says IHS Markit", *PV Magazine*, 8 May 2017, https://www.pv-magazine.com/2017/05/08/sma-holds-firm-as-inverter-revenue-leader-with-huawei-topping-shipment-charts-says-ihs-markit/.

186 "Fraunhofer ISE sets CPV module efficiency record of 43.4%", *Semiconductor Today*, 24 February 2016, http://www.semiconductor-today.com/news_items/2016/feb/fraunhoferISE_240216.shtml; Eric Wesoff, "Is time running out for CPV startup Semprius?" Greentech Media, 3 January 2017, https://www.greentechmedia.com/articles/read/Time-Running-Out-For-CPV-Startup-Semprius; IEA-PVPS, op. cit. note 3, p. 50; Fraunhofer Institute for Solar Energy Systems (ISE) and NREL, *Current Status of Concentrator Photovoltaic (CPV) Technology* (Golden, CO: December 2015), p. 7, http://www.nrel.gov/docs/fy16osti/65130.pdf; Oscar de la Rubia, Institute for Concentration Photovoltaics Systems, Spain, cited in "CPV's golden opportunity in the MENA region", Solar GCC Alliance, 11 February 2015, http://www.solargcc.com/cpvs-golden-opportunity-in-the-mena-region/.

187 Companies in the industry include: Arzon Solar (United States), formerly Amonix, from Arzon Solar "Company", http://arzonsolar.com/company/, viewed 25 February 2017; Morgan Solar (Canada), from Morgan Solar, "About Sun Simba", http://morgansolar.com/about-sun-simba/, viewed 25 February 2017, and from Morgan Solar, "Morgan Solar has reinvented solar technology", http://morgansolar.com/, viewed 25 February 2017; REhnu (United States), from http://www.rehnu.com/; Suncore (United States/China) is developing solar cells coupled to a heat exchanger to produce electricity and thermal power, from Suncore, "Solar CHP: Combined heat & power", http://suncoreus.com/products/z10-2/, viewed 25 February 2017; Solaria (United States) appears to be focused on building-integrated PV (BIPV) and high-efficiency modules for rooftop installations, with three new products launched in 2016, from Solaria, "Solaria successfully launched three solutions in 2016", http://www.solaria.com/technology-1, viewed 25 February 2017, and from Solaria, "Press releases", http://www.solaria.com/press-releases/, viewed 25 February 2017.

188 Lauren K. Ohnesorge, "Clock ticking on Durham's Semprius as it continues debt funder streak", *Triangle Business Journal*, 22 September 2016, http://www.bizjournals.com/triangle/news/2016/09/22/clock-ticking-on-durhams-semprius-as-it-continues.html; Eric Wesoff, "Is time running out for CPV startup Semprius?" Greentech Media, 3 January 2017, https://www.greentechmedia.com/articles/read/Time-Running-Out-For-CPV-Startup-Semprius. See also Semprius website, http://semprius.com/.

189 "Saint-Augustin Canada Electric (STACE) met la main sur la technologie solaire CPV de Soitec", *Plein Soleil*, 20 October 2016, http://www.plein-soleil.info/actualites/saint-augustin-canada-electricstace-met-la-main-sur-la-technologie-solaire-cpv-de-soitec/; STACE, "Saint-Augustin Canada Electric Inc.(STACE) acquires Soitec solar CPV technology", press release (Saint-Augustin, Quebec: 19 January 2017), http://www.stacelectric.com/2017/01/19/saint-augustin-canada-electric-inc-stace-acquires-soitec-solar-cpv-technology/.

190 Eric Wesoff, "Korean utility Kepco buys 30MW Alamosa CPV plant for $34M", Greentech Media, 30 August 2016, https://www.greentechmedia.com/articles/read/Korean-Utility-KEPCO-Buys-30MW-Alamosa-CPV-Plant-From-Cogentrix-For-34M.

191 IRENA and IEA PVPS, *End-of-Life Management: Solar Photovoltaic Panels* (Abu Dhabi: June 2016), http://www.irena.org/DocumentDownloads/Publications/IRENA_IEAPVPS_End-of-Life_Solar_PV_Panels_2016.pdf.

192 Ibid.

193 Andrew Spence, "Solar panel recycler leads Australia in emerging industry", Renewable Energy World, 8 July 2016, http://www.renewableenergyworld.com/articles/2016/07/solar-panel-recycler-leads-australia-in-emerging-industry.html; SEIA, "SEIA National PV Recycling Program", http://www.seia.org/seia-national-pv-recycling-program, viewed 24 February 2017; Osamu Tomioka, "Japanese companies work on ways to recycle a mountain of solar panels", *Nikkei Asian Review*, 17 November 2016, http://asia.nikkei.com/magazine/20161117-INCOMING/Tech-Science/Japanese-companies-work-on-ways-to-recycle-a-mountain-of-solar-panels.

194 European Commission, "Waste Electrical & Electronic Equipment (WEEE)", http://ec.europa.eu/environment/waste/weee/index_en.htm, viewed 24 February 2016; Sigrid Kusch, Science and Engineering for Sustainable Environmental Resources, Ulm, Germany, personal communication with REN21, April 2017.

CONCENTRATING SOLAR THERMAL POWER (CSP)

1 Data are compiled from the following primary sources: CSP Today, "Projects Tracker", http://tracker.newenergyupdate.com/tracker/projects, viewed on numerous dates leading up to 27 March 2017; US National Renewable Energy Laboratory (NREL), "Concentrating solar power projects by project name", http://www.nrel.gov/csp/solarpaces/by_project.cfm, viewed on numerous dates leading up to 27 March 2017; Renewable Energy Policy Network for the 21st Century (REN21), *Renewables 2016 Global Status Report* (Paris: 2016), pp. 67-69, http://www.ren21.net/wp-content/uploads/2016/10/REN21_GSR2016_FullReport_en_11.pdf; International Renewable Energy Agency (IRENA), *Renewable Capacity Statistics 2017* (Abu Dhabi: 2017), http://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Capacity_Statistics_2017.pdf. In some cases, information from the above sources was verified against additional country-specific sources, as cited in the rest of the endnotes for this section. Global CSP data are based on commercial facilities only; demonstration or pilot facilities are excluded. Differences between IRENA and REN21 data are due primarily to the inclusion of pilot and demonstration facilities in the IRENA report. **Figure 20** based on idem, all sources.

2 Ibid.

3 Ibid.

4 South Africa from Ibid.; Morocco as reported in REN21, op. cit. note 1, pp. 67-69.

5 Ibid.; SolarPACES, "China announces the first group of CSP demonstration projects", press release (Tabernas, Spain: 13 September 2016), http://www.solarpaces.org/press-room/news/item/116-china-announces-thefirst-group-of-csp-demonstration-projects; Catherine Wu, "China's first molten salt trough CSP loop put into operation", CSP Plaza, 13 October 2016, http://en.cspplaza.com/chinas-first-molten-salt-trough-csp-loop-put-into-operation.html; Jennifer Zhang, "Shouhang Dunhang 10MW molten salt tower CSP plant will put into operation, open to visitors on December 29th", CSP Plaza, 9 November 2016, http://en.cspplaza.com/shouhang-dunhuang-10mw-molten-salt-tower-csp-plant-will-put-into-operation-open-to-visitors-on-december-29th.html; NREL, "SunCan Dunhuang 10 MW Phase 1", 11 January 2017, https://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=6315.

6 Op. cit. note 1, all sources.

7 Ibid.

8 Ibid. **Figure 21** based on data from idem.

9 Op. cit. note 1, all sources.

10 Ibid.

11 Ibid.; NREL, "Dadri ISCC Plant", https://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=5315, viewed 23 November 2016.

12 Op. cit. note 1, all sources.

13 Op. cit. note 1, all sources.

14 Op. cit. note 1, all sources. United States from Solar Energy Industries Association (SEIA), "Solar industry data: solar industry growing at a record pace", http://www.seia.org/research-resources/solar-industry-data, viewed 20 April 2017; Spain from op. cit. note 1, all sources.

15 Op. cit. note 1, all sources. Carla Bernardo, "Khi Solar One kicks into commercial operation", ESI Africa, 8 February 2016, https://www.esi-africa.com/news/khi-solar-one-kicks-into-commercial-operation/; Carla Bernardo, "What you need to know about the Bokpoort solar plant", IOL, 14 March 2016, http://www.iol.co.za/news/south-africa/northern-cape/what-you-need-to-know-about-the-bokpoort-solar-plant-1997714.

16 Op. cit. note 1, all sources.

17 Ibid.

18 Paul Burkhardt and Mike Cohen, "Eskom has 'gone completely rogue' on green energy – IPP", Fin24, 6 December 2016, http://www.fin24.com/Economy/Eskom/eskom-has-gone-completely-rogue-on-green-energy-ipp-20161206.

19 "China to install 1.4 GW CSP capacity by 2018; South Africa backs Redstone PPA", NewEnergyUpdate, 20 September 2016, http://analysis.newenergyupdate.com/csp-today/markets/china-install-14-gw-csp-capacity-2018-south-africa-backs-redstone-ppa; Frank Haugwitz, Asia Europe Clean Energy (Solar) Advisory Co. Ltd, personal communication with REN21, April 2017; op. cit. note 1, all sources; SolarPACES, op. cit. note 5; Wu, op. cit. note 5; Zhang, op. cit. note 5; NREL, op. cit. note 5.

20 Ibid.

21 Op. cit. note 1, all sources.

22 Heba Hashem, "Global CSP capacity forecast to hit 22 GW by 2025", CSP Today, 20 September 2015, http://analysis.newenergyupdate.com/csp-today/markets/global-csp-capacity-forecast-hit-22-gw-2025; "Arab countries' energy shortage caused by distribution problems", Al-Monitor, 26 October 2014, http://www.almonitor.com/pulse/business/2014/10/httpalhayatcomopinionwalid-khadouri5144926--.html; Heba Hashem, "Influx of PV firms into China CSP set to boost funding, cut tech costs", CSP Today, 16 October 2015, http://analysis.newenergyupdate.com/csp-today/markets/influx-pv-firms-china-csp-set-boost-funding-cut-tech-costs.

23 Op. cit. note 1, all sources.

24 NREL, "Noor II", 13 March 2017, https://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=4292; NREL, "Noor III", 13 March 2017, https://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=4293.

25 NREL, "Noor I", 10 May 2016, https://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=270; op. cit. note 1, all sources.

26 NREL, "Ashalim Plot B", 22 March 2016, https://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=277.

27 Op. cit. note 1, all sources.

28 Ibid.

29 Ibid.

30 Dubai Electricity and Water Authority (DEWA), "DEWA releases RFP for 200 MW solar CSP power plant, the fourth phase of the Mohammed bin Rashid Al Maktoum Solar Park", press release (Dubai: 20 January 2017), https://www.dewa.gov.ae/en/about-dewa/news-and-media/press-and-news/latest-news/2017/01/dewa-releases-rfp-for-200mw-solar-csp.

31 Electricidad, "Planta termosolar de proyecto Cerro Dominador entraria operaciones en 2019", 14 March 2017, http://www.revistaei.cl/2017/03/14/planta-termosolar-de-proyecto-cerro-dominador-entraria-en-operaciones-en-2019/; Andrew Baker, "Abengoa restarts work on stalled Chile solar project", 14 December 2016, https://www.bnamericas.com/en/news/electricpower/abengoa-re-launches-work-on-stalled-chile-solar-project/.

32 Ibid.

33 Sener, "Agua Prieta II en Mexico", 2017, http://www.revistanoticias.sener/news/agua-prieta-ii-en-mexico/52/.

34 Ivan Shumkov, "French JV raises EUR 60m for solar thermodynamic project", 13 October 2016, https://renewablesnow.com/news/french-jv-raises-eur-60m-for-solar-thermodynamic-project-543113/.

35 Aalborg CSP, "Aalborg CSP supplies concentrated solar power system for combined heat and power generation in Denmark", 29 February 2016, http://www.aalborgcsp.com/news-events/newstitle/news/aalborg-csp-supplies-concentrated-solar-power-system-for-combined-heat-and-power-generation-in-denma/.

36 Ibid.

37 "Concentrated solar power (CSP) gets a major boost in China", HeliosCSP, 11 July 2016, http://helioscsp.com/concentrated-solar-power-csp-gets-a-major-boost-in-china/; Susan Kraemer, "SolarReserve's Shenhua deal to build 1GW of dispatchable solar day or night", CleanTechnica, 11 May 2016, https://cleantechnica.com/2016/05/11/solarreserves-shenhua-deal-build-1-gw-dispatchable-solar-day-night/; "China says 1.35 GW of CSP projects to be ready by 2018", Renewables Now, 14 September 2016, https://renewablesnow.com/news/china-says-1-35-gw-of-csp-projects-to-be-ready-by-2018-539749/; "CSP key equipment for China's concentrated solar power demonstration projects", HeliosCSP, 19 March 2017, http://helioscsp.com/csp-key-equipment-for-chinas-concentrated-solar-power-demonstration-projects/.

38 Menasol, "MENA Solar Market Outlook for 2017", presentation, Dubai, 25-26 April 2016, https://www.apricum-group.com/wp-content/uploads/2016/12/MENA-Solar-Outlook-2017.pdf;

"Localization, innovation to drive CSP in MENA: Rioglass", CSP Today, 11 May 2015, http://social.csptoday.com/markets/localization-innovation-drive-csp-mena-rioglass; Bhavtik Vallabhjee, "Build a good energy programme and the investors will come", BusinessDay, 11 March 2016, https://www.businesslive.co.za/bd/opinion/2016-03-11-build-a-good-energy-programme-and-the-investors-will-come/.

39 Tobias Buck, "Abengoa staves off insolvency with €1.17bn restructuring", *Financial Times*, 11 August 2016, https://www.ft.com/content/a4feab84-5fa8-11e6-ae3f-77baadeb1c93.

40 Ibid.

41 "Spain's Abengoa reaches agreement with creditors", *Financial Times*, 10 March 2016, https://www.ft.com/content/e6396cc5-1698-3de9-96df-44f6c236bbdc; Macarena Munoz Montijano, Luca Casiraghi and Katie Linsell, "Abengoa signs debt deal to avoid Spain's largest insolvency", *Bloomberg*, 10 March 2016, https://www.bloomberg.com/news/articles/2016-03-10/abengoa-lines-up-2-billion-financing-in-restructuring-accord.

42 Information is based on a high-level assessment and search for CSP-focused publications released during the course of 2016 addressing mergers and acquisitions within the global CSP industry.

43 Op. cit. note 1, all sources.

44 NREL, op. cit. note 11; NREL, "Noor II", op. cit. note 24; NREL, op. cit. note 25.

45 Op. cit. note 1, all sources.

46 Ibid.; Jason Deign, "Concentrating solar power isn't viable without storage, say experts", Greentech Media, 1 November 2016, https://www.greentechmedia.com/articles/read/is-csp-viable-without-storage.

47 Abengoa, "Khi Solar One near Upington achieves a technological milestone", Energyblog, 30 March 2016, http://www.energy.org.za/news/khi-solar-one-near-upington-achieves-a-technological-milestone.

48 Op. cit. note 1, all sources; Deign, op. cit. note 46.

49 NREL, *On the Path to SunShot: Advancing Concentrating Solar Power Technology, Performance, and Dispatchability* (Golden, CO: May 2016), p. 46, http://www.nrel.gov/docs/fy16osti/65688.pdf.

50 Ibid., p. 46.

51 Fred Morse, Morse Associates, Inc., United States, personal communication with REN21, April 2017; Maduna Ngobeni, "Market overview and current levels of renewable energy deployment", Stakeholder Consultation Workshop: Preparation of the Second Edition of the *State of Renewable Energy in South Africa Report*, 25 November 2016, http://www.energy.gov.za/files/renewable-energy-status-report/Market-Overview-and-Current-Levels-of-Renewable-Energy-Deployment-NERSA.pdf; Haugwitz, op. cit. note 19.

52 NREL, op. cit. note 49, p. 46; IRENA, *The Power to Change: Solar and Wind Cost Reduction Potential to 2025* (Abu Dhabi: June 2016), http://www.irena.org/DocumentDownloads/Publications/IRENA_Power_to_Change_2016.pdf.

53 Michael Irving, "Solar thermal record sees 97% conversion of sunlight into steam", *New Atlas*, 23 August 2016, http://newatlas.com/solar-thermal-record-anu/45027/; Commonwealth Scientific and Industrial Research Organisation (CSIRO), "Supercritical solar - new frontier for power generation", press release (Canberra: 3 June 2014), https://www.csiro.au/en/News/News-releases/2014/Supercritical-solar-new-frontier-for-power-generation.

54 US Department of Energy (DOE), Office of Science, "Tower of power", *ASCR Discovery*, August 2016, http://ascr-discovery.science.doe.gov/2016/08/tower-of-power/; Peter Maloney, "Researchers identify new storage tech for concentrated solar power plants", Utility Dive, 10 November 2015, http://www.utilitydive.com/news/researchers-identify-new-storage-tech-for-concentrated-solar-power-plants/408867/; European Commission (EC), "Redox materials-based structured reactors/heat exchangers for thermo-chemical heat storage systems in concentrated solar power plants", 7 November 2016, http://cordis.europa.eu/project/rcn/100980_en.html; EC, "Innovative configuration for a fully renewable hybrid CSP plant", 31 July 2016, http://cordis.europa.eu/project/rcn/108326_en.html; Mark Mehos et al., *Concentrating Solar Power Gen3 Demonstration Roadmap* (Golden, CO: NREL, January 2017), http://www.nrel.gov/docs/fy17osti/67464.pdf.

55 Irving, op. cit. note 53; CSIRO, op. cit. note 53.

56 Ibid., both references.

57 Piero de Bonis, EC, Brussels, personal communication with REN21, April 2017; EC, op. cit. note 54, both references.

58 DOE, op. cit. note 54; Maloney, op. cit. note 56; EC, op. cit. note 54, both references; Mehos et al., op. cit. note 54.

59 Luis Crespo, European Solar Thermal Electricity Association (ESTELA), Brussels, personal communication with REN21, 22 April 2017.

60 Tobias Hirsch, ed., *SolarPACES Guideline for Bankable STE Yield Assessment* (Tabernas, Spain: SolarPACES, January 2017), http://www.solarpaces.org/images/SolarPACES_Guideline_for_Bankable_STE_Yield_Assessment_-_Version_2017.pdf.

SOLAR THERMAL HEATING AND COOLING

1 Solarthermalworld.org published news about solar heating and cooling activities in 127 countries since its start in 2008, from Nigel Cotton, European Copper Institute, Brussels, Belgium, personal communication with REN21, April 2017.

2 Monika Spörk-Dür, AEE-Institute for Sustainable Technologies (AEE INTEC), Gleisdorf, Austria, personal communications with Renewable Energy Network for the 21st Century (REN21), March-May 2017; Werner Weiss, Monika Spörk-Dür and Franz Mauthner, *Solar Heat Worldwide. Markets and Contribution to the Energy Supply 2015* (Gleisdorf, Austria: International Energy Agency (IEA) Solar Heating and Cooling Programme (SHC), 2017), www.aee-intec.at/0uploads/dateien1252.pdf. **Figure 22** based on the latest market data from Australia, Austria, Brazil, China, Germany, Israel, Mexico, Turkey and the United States, which represented 87% of the cumulated installed capacity in operation in 2015. The other countries were projected according to their trend over the past two years, as per Spörk-Dür.

3 Spörk-Dür, op. cit. note 2. **Figure 23** based on idem.

4 Equivalence of 375 TWh and 221 million barrels of oil equivalent from Kyle's Converter, http://www.kylesconverter.com.

5 Weiss, Spörk-Dür and Mauthner, op. cit. note 2.

6 Data and **Figure 24** based on the latest market data available for glazed and unglazed water collectors without concentrating collectors at the time of publication for countries that together represent 94% of the world total. Data from original country sources provided in Weiss, Spörk-Dür and Mauthner, op. cit. note 2, as follows: David Ferrari, Sustainability Victoria, Melbourne, Australia; Werner Weiss, AEE INTEC, Vienna, Austria; Marcelo Mesquita, ABRASOL, São Paulo, Brazil; Hongzhi Cheng, Shandong SunVision Management Consulting, Dezhou, China; Denmark from Daniel Trier, PlanEnergi, Skørping, Denmark, and from Jan-Olof Dalenbäck, Chalmers University of Technology, Göteborg, Sweden; Richard Loyen, Enerplan, La Ciotat, France; Marco Tepper, BSW Solar, Berlin, Germany; Costas Travasaros, Greek Solar Industry Association (EBHE), Piraeus, Greece; Jaideep Malaviya, Solar Thermal Federation of India (STFI), Pune, India; Eli Shilton, Elsol, Kohar-yair, Israel; Federico Musazzi, ANIMA, the Federation of Italian Associations in the Mechanical and Engineering Industries, Milan, Italy; Kumiko Saito, Solar System Development Association (SSDA), Tokyo, Japan; Daniel Garcia, Solar Thermal Manufacturers Organisation (FAMERAC), Mexico City, Mexico; Janusz Staroscik, Association of Manufacturers and Importers of Heating Appliances (SPIUG), Warsaw, Poland; Karin Kritzinger, Centre for Renewable and Sustainable Energy Studies, University of Stellenbosch, Stellenbosch, South Africa; Pascual Polo, Spanish Solar Thermal Association (ASIT), Madrid, Spain; David Stickelberger, Swissolar, Zurich, Switzerland; Kung-Ming Chung, Energy Research Center of the National Cheng Kung University (NCKU), Tainan City, Chinese Taipei; Turkey from Kutay Ülke, Bural Heating, Kayseri, Turkey and from Krystyna Dawson, BSIRA, Berkshire, United Kingdom; Les Nelson, Solar Heating & Cooling Programs at the International Association of Plumbing and Mechanical Officials (IAPMO), Ontario, CA, United States, all personal communications with REN21, February-April 2017. The gross additions for South Africa were not available at the time of publication, so it is assumed that they remained stable from 2015 to 2016. The gross additions of Denmark for 2016 do not include the new district heating plant in Brønderslev (26,929 m^2), which consists of parabolic trough collectors. The gross additions in India refer to the calendar year 2016, whereas previous years' additions referred to the Indian fiscal year.

7 Ibid.

8 Ibid.

9 Ibid.

10 Bärbel Epp, "China: Much work needed to meet 2020 square-metre target of 0.8 billion", solarthermalworld, 30 January 2017, http://www.solarthermalworld.org/content/china-much-work-needed-meet-2020-square-metre-target-08-billion.

11 Bärbel Epp, "China: Solar process heat and space heating and cooling rack up market shares", solarthermalworld, 19 April 2017, http://www.solarthermalworld.org/content/china-solar-process-heat-and-space-heating-and-cooling-rack-market-shares.

12 Ibid.

13 Bärbel Epp, "China: Challenges and opportunities of world's largest solar thermal market", solarthermalworld, 27 June 2016, http://www.solarthermalworld.org/content/china-challenges-and-opportunities-worlds-largest-solar-thermal-market.

14 "810,000 m^2 of flat plate collectors and 720,000 m^2 of vacuum tube collectors were newly installed in the formal sector in 2016. Additionally there are around 100 small suppliers in Turkey who work without invoice, that we do not include in our numbers", from Krystyna Dawson, BSRIA, Berkshire, United Kingdom, personal communication with REN21, April 2017.

15 Ibid.

16 Ibid.

17 The informal sector is assumed to be the difference between the total market volume of 2.1 million m^2 for the year 2015 calculated by Ulke Kutay, former Ezinc Metal, today Bural Heating, Kayseri, Turkey, for GSR 2016 and the 1.5 million m^2 for the formal sector for the same year, as per Dawson, op. cit. note 14.

18 "Turkey: Over 1,000 professionals attend SolarTR 2016", solarthermalworld, 20 January 2017, http://www.solarthermalworld.org/content/turkey-over-1000-professionals-attend-solartr-2016.

19 Market figures for 2016 from Marcelo Mesquita, ABRASOL, Brazil, personal communication with REN21, April 2017.

20 Market leader Soletrol´s production figure dropped by even 24% in 2016, per Bärbel Epp, "Worldwide: Flat plate collector manufacturer ranking", solarthermalworld, 21 December 2016, http://www.solarthermalworld.org/content/worldwide-flat-plate-collector-manufacturer-ranking.

21 Mesquita, op. cit. note 19.

22 Jaideep Malaviya, "India: Collector market no longer depends on subsidies", solarthermalworld, 4 May 2017, http://www.solarthermalworld.org/content/india-collector-market-no-longer-depends-subsidies.

23 Market figures for 2016 from Jaideep Malaviya, STFI, Pune, India, personal communication with REN21, April 2017.

24 Ibid.

25 Jaideep Malaviya, "India: First solar process heat systems with CPC-Mirror vacuum tube collectors", solarthermalworld, 7 January 2017, http://www.solarthermalworld.org/content/india-first-solar-process-heat-systems-cpc-mirror-vacuum-tube-collectors.

26 Malaviya, op. cit. note 23.

27 Les Nelson, Solar Heating & Cooling Programs at the International Association of Plumbing and Mechanical Officials (IAPMO), Ontario, CA, personal communication with REN21, April 2017.

28 Op. cit. note 6.

29 Nelson, op. cit. note 27; Bärbel Epp: "USA: Commercial systems dominate Californian solar thermal market", solarthermalworld, 24 March 2017, http://www.solarthermalworld.org/content/usa-commercial-systems-dominate-californian-solar-thermal-market; Chip Bircher, SHC Alliance of the Solar Energy Industries Association (SEIA), Washington, DC, personal communication with REN21, May 2017.

30 Preliminary estimate for the EU-28 market plus Switzerland at end-2016 is based on glazed collectors only and considers the market figures from eight markets (Switzerland, France, Germany, Greece, Italy, Spain, Denmark and Poland (see endnote 6) and extrapolates this market development to all EU-28 plus Switzerland from Pedro Dias, European Solar Thermal Industry Federation (ESTIF), Brussels, Belgium, personal communication with REN21, April 2017.

31 Op. cit. note 6.

32 Bärbel Epp, "Germany: High rebates not enough to offset market decline due to cheap fossil fuels", solarthermalworld, 27 February 2017, http://www.solarthermalworld.org/content/germany-high-rebates-not-enough-offset-market-decline-due-cheap-fossil-fuels; Riccardo Battisti, "Italy: Market decline continues despite appealing incentives", solarthermalworld, 1 February 2017, http://www.solarthermalworld.org/content/italy-market-decline-continues-despite-appealing-incentives.

33 Since the beginning of 2016 the Energy Saving Ordinance, EnEV, in Germany further limits the allowed primary energy demand for heating, hot water, air conditioning and ventilation by around 25% in new builds, which can still be fulfilled by

BACK

a monovalent heat pump, per Bärbel Epp, "Germany: High rebates not enough to offset market decline due to cheap fossil fuels", solarthermalworld, 27 February 2017, http://www.solarthermalworld.org/content/germany-high-rebates-not-enough-offset-market-decline-due-cheap-fossil-fuels. The French building regulation RT2012 stipulates a minimum energy consumption level of, on average, 50 kWh per m² (primary energy) per year, including demand from space heating and cooling, ventilation, hot water and lighting, but it grants a bonus of 7.5 kWh per m² and year (primary energy) for multi-family houses so that solar thermal systems are not absolutely necessary to fulfil the standard, per Bärbel Epp, "France: Mixed feelings about 2015 industry development", solarthermalworld, 3 February 2017, http://www.solarthermalworld.org/content/france-mixed-feelings-about-2015-industry-development.

34 Janusz Starościk, SPIUG, Poland, personal communication with REN21, March 2017.

35 Preliminary estimate for the EU-28 market at end-2015 is based on glazed collectors only, Dias, op. cit. note 30.

36 Weiss, Spörk-Dür and Mauthner, op. cit. note 2,

37 Ibid. **Figure 25** based on data from idem. MENA region includes Israel, Jordan, Lebanon, Morocco, the State of Palestine and Tunisia. Latin America includes Brazil, Chile, Mexico and Uruguay. Asia includes India, Japan, the Republic of Korea, Taipei (China) and Thailand. Sub-Saharan Africa includes Botswana, Lesotho, Mauritius, Mozambique, Namibia, Nigeria, Senegal, South Africa and Zimbabwe.

38 Alejandro Diego Rosell, "Argentina: New survey confirms growth, national incentives expected soon", solarthermalworld, 11 February 2017, http://www.solarthermalworld.org/content/argentina-new-survey-confirms-growth-national-incentives-expected-soon; Bärbel Epp, "Austria: Tisun sees rising interest in solar thermal in Gulf Region", solarthermalworld, 24 January 2017, http://www.solarthermalworld.org/content/austria-tisun-sees-rising-interest-solar-thermal-gulf-region; "We have increased our exports in 2016 due to increasing demand from the residential and the commercial sector in selected Eastern and Central African countries. This demand is triggered by the solar obligation in Kenya and increasing electricity prices in neighboring countries", per Eli Silton, Elsol, Israel, personal communication with solrico, March 2017.

39 Rosell, op. cit. note 38.

40 Alejandro Diego Rosell, "Argentina: President's system order and planned energy price hikes boost solar thermal", solarthermalworld, 24 October 2014, http://www.solarthermalworld.org/content/argentina-presidents-system-order-and-planned-energy-price-hikes-boost-solar-thermal.

41 "Our sales of solar water heaters increased in 2016 due to the solar obligation which stipulates any new building like real estate, hotel or public institution with more than 100 liter of hot water per day to install a solar water heater", per Samuel Mbondo, Sunrays Solar Ltd, Nairobi, Kenya, personal communication with REN21, March 2017; Bärbel Epp, "Kenya: Financial scheme attached to solar obligation", solarthermalworld, 28 April 2015, http://www.solarthermalworld.org/content/kenya-financial-scheme-attached-solar-obligation; Bärbel Epp, "Dubai: No solar thermal system, no building permit", 4 September 2016, http://www.solarthermalworld.org/content/dubai-no-solar-thermal-system-no-building-permit.

42 Daniel Trier, PlanEnergi, Copenhagen, Denmark, personal communication with REN21, April 2017.

43 Jelica Matoricz, Aalborg CSP, Aalborg, Denmark, personal communication with REN21, April 2017.

44 Bärbel Epp, "Denmark: Solar district heating capacity nearly doubles in 2016", solarthermalworld, 25 April 2017, http://www.solarthermalworld.org/content/denmark-solar-district-heating-capacity-nearly-doubles-2016.

45 Ibid.

46 Bärbel Epp, "Denmark: New solar district heating world record", solarthermalworld, 26 January 2017, http://www.solarthermalworld.org/content/denmark-new-solar-district-heating-world-record.

47 Ibid.

48 Bärbel Epp, "Largest solar thermal installations worldwide", solarthermalworld, updated March 2017, http://www.solarthermalworld.org/installations.

49 Trier, op. cit. note 42.

50 Bärbel Epp, "Germany: First record-size solar district heating plant in 11 years", solarthermalworld, 27 September 2016, http://www.solarthermalworld.org/content/germany-first-record-size-solar-district-heating-plant-11-years; Riccardo Battisti, "Poland: Solar for more efficient district heating networks", solarthermalworld, 30 March 2017, http://www.solarthermalworld.org/content/poland-solar-more-efficient-district-heating-networks.

51 Epp, op. cit. note 50; Germany's previously largest solar thermal field, a 5.1 MW_{th} (7,100 m²) flat plate collector installation in the town of Crailsheim, came online in 2005, per Bärbel Epp, "Solar district heating in Crailsheim with seasonal borehole storage", solarthermalworld, updated March 2017, http://www.solarthermalworld.org/content/solar-district-heating-crailsheim-seasonal-borehole-storage?_ga=1.146481204.1203738618.1475610694.

52 Jan-Olof Dalenbäck, Chalmers University of Technology, Goteborg, Sweden, personal communications with REN21, February-March 2017.

53 The new district heating plant was installed in the neighbourhood of Limeil Brevannes close to Paris, per Ibid.

54 Angel Carrera, Aiguasol, Barcelona, Spain, personal communication with REN21, March 2017.

55 Dalenbäck, op. cit. note 52. Preliminary estimation of end-2016 total operation for the EU-28 market is based on glazed collectors only, from Dias, op. cit. note 30.

56 Regulations of the new subsidy programme have yet to be announced, per Epp, op. cit. note 11.

57 Bärbel Epp, "China: Much work needed to meet 2020 square-metre target of 0.8 billion", solarthermalworld, 30 January 2017, http://www.solarthermalworld.org/content/china-much-work-needed-meet-2020-square-metre-target-08-billion.

58 Epp, op. cit. note 46.

59 Bärbel Epp, "Denmark: 52,500 m² additional collector area in Vojens", solarthermalworld, updated March 2017, http://www.solarthermalworld.org/content/denmark-52500-m2-additional-collector-area-vojens.

60 Bärbel Epp, "Canada: Solar district heat meets community's entire space heating demand", solarthermalworld, 9 December 2016, http://www.solarthermalworld.org/content/canada-solar-district-heat-meets-communitys-entire-space-heating-demand.

61 Bärbel Epp and Eva Augsten, "Solar process heat: surprisingly popular", *Sun & Wind Energy*, 13 February 2017, http://www.sunwindenergy.com/content/solar-process-heat-surprisingly-popular.

62 Updated for the year 2014 with data from Deger Saygin et al., "Assessment of the technical and economic potentials of biomass use for the production of steam, chemicals and polymers", *Renewable and Sustainable Energy Reviews*, vol. 40 (December 2014), pp. 1153-67, http://www.sciencedirect.com/science/article/pii/S1364032114005668.

63 The assessment of the world market of solar heat for industrial processes (SHIP) was carried out as a survey among turnkey SHIP suppliers with the aim of publishing the *World Map of Solar Process Heat Specialists 2017*. The map includes 71 companies in 22 countries, of which 42 companies already supplied turnkey solar process heat systems and 29 companies are "market-ready" suppliers, which are listed without reference figures on the world map. The questionnaire defined turnkey as a plant planned, supplied and installed by the seller. The total number of reference plants of all companies listed on the world map (389) was checked for plausibility. Where discrepancies were found, detailed information was requested by the planners, as per Epp and Augsten, op. cit. note 61.

64 A reconciliation of the world map survey among solar process heat specialists 2017 with the Solar Heat for Industrial Processes (SHIP) database (www.ship-plants.info) revealed that 9 plants were included in the online database that were not listed on the world map, and 127 additional installations from the SHIP database were designed by 62 companies that did not participate in the world map survey. Based on this analysis, the world SHIP market included a minimum of 525 plants with an absorber and mirror area of at least 416,414 m², per Epp and Augsten,

op. cit. note 61. Assuming an average solar yield of 450 kWh per m² annually, the 416,414 m² results in 0.18 TWh annually, which corresponds to 0.001 EJ, per Bärbel Epp, solrico, Bielefeld, Germany, personal communication with REN21, March 2017.

65 SHIP database, www.ship-plants.info, viewed December 2016.

66 According to the SHIP database (www.ship-plants.info), as of March 2017, 80 plants were in the food and beverage industry, 24 plants were in the machinery industry, and 18 plants were in the textile industry. The total number of plants was 195.

67 Jaideep Malaviya: "India: Showcase in fast-growing dairy industry", solarthermalworld, 18 February 2017, http://www.solarthermalworld.org/content/india-showcase-fast-growing-dairy-industry.

68 Bärbel Epp, "South Africa: Solar green beer production creates high IRR", solarthermalworld, 14 September 2016, http://www.solarthermalworld.org/content/south-africa-solar-green-beer-production-creates-high-irr.

69 Bärbel Epp, "Denmark: Solar concentrating systems to offer wide array of uses", solarthermalworld, 20 June 2016, http://www.solarthermalworld.org/content/denmark-solar-concentrating-systems-offer-wide-array-uses.

70 Ibid.

71 Gernot Wörther, Klima- und Energiefonds, Vienna, Austria, personal communication with REN21, March 2017.

72 Bärbel Epp, "Mexico: Second solar process heat case study on copper mining", solarthermalworld, 1 December 2016, http://www.solarthermalworld.org/content/mexico-second-solar-process-heat-case-study-copper-mining.

73 Ibid.

74 Bärbel Epp, "Solar process heat in Chile: it is essential to use the ESCO model", solarthermalworld, 21 November 2016, http://www.solarthermalworld.org/content/solar-process-heat-chile-it-essential-use-esco-model.

75 Bärbel Epp, "Oman: Construction starts for world's largest solar steam power plant Miraah", solarthermalworld, 20 April 2016, http://www.solarthermalworld.org/content/oman-construction-starts-worlds-largest-solar-steam-power-plant-miraah.

76 "Miraah construction is currently ahead of schedule and under budget. We are on track to produce steam from the first greenhouse block, of 36 total, before the end of this year. Our team recently achieved over 500,000 safe working hours at site", per Katie Struble, GlassPoint Solar, Fremont, CA, personal communication with REN21, March 2017.

77 Epp and Augsten, op. cit. note 61.

78 Ibid.

79 Ibid.

80 Bärbel Epp, "Switzerland: PVT system output reaches 330 kWh_{th}/m² on top of 163 kWh_{el}/m², solarthermalworld, 29 July 2016, http://www.solarthermalworld.org/content/switzerland-pvt-system-output-reaches-330-kwhthm2-top-163-kwhelm2.

81 Daniel Mugnier, Tecsol, Perpignan, France, personal communication with REN21, March 2017.

82 Eva Augsten, "Switzerland: Borehole storage regeneration as solar thermal's ray of hope", solarthermalworld, 22 December 2106, http://www.solarthermalworld.org/content/switzerland-borehole-storage-regeneration-solar-thermals-ray-hope; Epp, op. cit. note 80; Daniel Zenhäusern, Institut für Solartechnik SPF, Rapperswil, Switzerland, personal communication with REN21, April 2017.

83 For example, one of China's largest air conditioning companies, GREE, sold hundreds of small solar cooling units, both domestically and abroad, that rely on electricity provided directly by solar PV (without grid connection) to drive a chiller, from Dai Yanjun, Shanghai Jiao Tong University (SJTU), Shanghai, China, personal communication with REN21, April 2017.

84 "3 to 5 solar thermal cooling systems in tertiary applications (public building, technical college, bank etc.) have been added in 2016 in France all in coupling cooling and domestic hot water production", per Daniel Mugnier, Tecsol, Perpignan, France, personal communication with REN21, March 2017.

85 Christian Holter, S.O.L.I.D., Graz, Austria, personal communication with REN21, April 2017.

86 "We realised two solar cooling systems for server centers in Italy last year, and two more are delivered but not commissioned yet", per Gregor Feig, Fahrenheit, Munich, Germany, personal communication with REN21, April 2017.

87 "Italy was our key sales market for solar-thermal driven chillers in 2016, but with still rather small installation numbers of 5 new commissioned systems last year. The main barrier is a lack of knowledge about the fairly good incentive policy in Italy by the national rebate programme Conto Termico 2.0", per Mario Colaiemma, Maya, Milan, Italy, personal communication with REN21, April 2017; "We have realised three solar cooling systems in 2016 (two in Italy) and shipped four more systems that will be commissioned in 2017 (two in Italy)", per Feig, op. cit. note 86.

88 Dai Yanjun, op. cit. note 83.

89 Bärbel Epp, "Jordan: Four demonstration plants for solar air conditioning commissioned", solarthermalworld, 29 March 2017, http://www.solarthermalworld.org/content/jordan-four-demonstration-plants-solar-air-conditioning-commissioned.

90 Sekem, "Promoting alternative energies: new solar station for Sekems medical center", 5 December 2016, http://www.sekem.com/en/promoting-alternative-energies-new-solar-station-for-sekems-medical-center.

91 Lucio Mesquita, Natural Resources Canada, Ottawa, Canada, personal communication with REN21, April 2017.

92 Bärbel Epp, "Nicaragua: Soft loan to fund EUR 4 million project", solarthermalworld, 14 October 2016, http://www.solarthermalworld.org/content/nicaragua-soft-loan-fund-eur-4-million-project.

93 Ibid.

94 Bärbel Epp, "Austria Solar: 'It's about faster and simpler access to solar systems'", solarthermalworld, 14 December 2016, http://www.solarthermalworld.org/content/austria-solar-its-about-faster-and-simpler-access-solar-systems.

95 Bärbel Epp, "China: Challenges and opportunities of world's largest solar thermal market", solarthermalworld, 27 June 2016, http://www.solarthermalworld.org/content/china-challenges-and-opportunities-worlds-largest-solar-thermal-market.

96 Bärbel Epp, "Germany: Vaillant establishes end-customer online platform", solarthermalworld, 15 August 2016, http://www.solarthermalworld.org/content/germany-vaillant-establishes-end-customer-online-platform; Eva Augsten, "Germany: Thermondo digitalises heating industry planning and sales", solarthermalworld, 29 May 2016, http://www.solarthermalworld.org/content/germany-thermondo-digitalises-heating-industry-planning-and-sales.

97 Alejandro Diego Rosell, "Spain: Market growth despite incentive scheme stop and go", solarthermalworld, 2 February 2016, http://www.solarthermalworld.org/content/spain-market-growth-despite-incentive-scheme-stop-and-go.

98 Rosell, op. cit. note 38.

99 Bärbel Epp, "Greece: Manufacturers exporting more each year", solarthermalworld, 18 April 2017, http://www.solarthermalworld.org/content/greece-manufacturers-exporting-more-each-year.

100 "The growing demand helped us to reduce the system investment costs from 600 EUR/m²a at the start of the subsidy scheme in 2012 to now around 450 EUR/m²a", per Rudolf Ettl, Grammer Solar, Amberg, Germany, personal communication with REN21, April 2017; Bärbel Epp, "Germany: process heat supply from vacuum tubes and air collectors on the rise", solarthermalworld, 21 April 2017, http://www.solarthermalworld.org/content/germany-process-heat-supply-vacuum-tubes-and-air-collectors-rise.

101 Epp, op. cit. note 44.

102 Ibid.

103 Bärbel Epp, "China: Arcon-Sunmark and Sunrain establish joint-venture for large projects", solarthermalworld, 10 June 2016, http://www.solarthermalworld.org/content/china-arcon-sunmark-and-sunrain-establish-joint-venture-large-projects; Bärbel Epp, "IRENA: renewable district heating and cooling roadmap to 2030", solarthermalworld, 27 April 2017, http://www.solarthermalworld.org/content/irena-renewable-district-heating-and-cooling-roadmap-2030.

104 Ibid.

105 Bärbel Epp, "Austria: New medium-temperature collectors show remarkable yield in district heating use", solarthermalworld, 2 March 2017, http://www.solarthermalworld.org/content/

austria-new-medium-temperature-collectors-show-remarkable-yield-district-heating-use.

106 Ibid.

107 Ibid.

108 Cheng Hongzhi, SunVision Management Consulting, Dezhou, China, personal communication with REN21, March 2017.

109 Bärbel Epp, "Worldwide: Flat plate collector manufacturer ranking", solarthermalworld, 21 December 2016, http://www.solarthermalworld.org/content/worldwide-flat-plate-collector-manufacturer-ranking.

110 Ibid.

111 Starościk, op. cit. note 34; "The polish solar market in 2016 was much weaker than one year ago. We produced only 60% of the gross collector area compared to 2015", per Ireneusz Jeleń, Hewalex, Czechowice-Dziedzice, Poland, personal communication with REN21, April 2017.

112 Starościk, op. cit. note 34.

113 Epp and Augsten, op. cit. note 61.

114 Ibid.

115 Ibid.

116 Ibid.

117 Bärbel Epp, "IEA SHC Task 53: Innovative solar cooling systems", solarthermalworld, 28 February 2017, http://www.solarthermalworld.org/content/iea-shc-task-53-innovative-solar-cooling-systems.

118 Ibid.

119 Bärbel Epp, "IEA SHC: New PVT system enhancement research", solarthermalworld, 20 December 2016, http://www.solarthermalworld.org/content/iea-shc-new-pvt-system-enhancement-research; the German company PA-ID has installed around 8,000 2Power panels at almost 500 project sites, from Bärbel Epp, "Germany: 2Power PVT modules supply power and heat from same roof space", solarthermalworld, 2 September 2016, http://www.solarthermalworld.org/content/germany-2power-pvt-modules-supply-power-and-heat-same-roof-space.

120 Zenhäusern, op. cit. note 82.

121 Ibid.

WIND POWER

1 The wind industry added 54,642 MW for a total of 486,790 MW, from Global Wind Energy Council (GWEC), *Global Wind Report – Annual Market Update 2016* (Brussels: April 2017), http://www.gwec.net/strong-outlook-for-wind-power/; 54,846.2 MW was added for a total of 486,661 MW, from World Wind Energy Association (WWEA), *WWEA Annual Report 2016* (Bonn: May 2017), http://www.wwindea.org/; 55,492 MW was added for a total of 488,123 MW, from FTI Consulting, *Global Wind Market Update – Demand & Supply 2016, Part Two – Demand Side Analysis* (London: March 2017), p. 47, http://www.fti-intelligencestore.com/index.php?route=download/main&download_id=151; and 54,166 MW was added (connected capacity) for a total of 486.7 GW, from EurObserv'ER, *Wind Energy Barometer* (Paris: February 2017), pp. 2, 4, https://www.eurobserv-er.org/wind-energy-barometer-2017/.

2 GWEC, op. cit. note 1; FTI Intelligence, "Vestas returns to no. 1 spot in global wind turbine supplier ranking in 2016", press release (London: 20 February 2017). **Figure 26** based on historical data from GWEC, op. cit. note 1; data for 2016 from sources in this section. Note that additions reported in this section are generally gross additions; the net increase in total capacity can be lower, reflecting decommissioning. However, relatively few of the countries that installed wind power capacity during the year decommissioned previously existing capacity.

3 Figure of 90 countries from Shruti Shukla, GWEC, personal communication with Renewable Energy Policy Network for the 21st Century (REN21), 13 April 2017; 29 countries from GWEC, op. cit. note 1, p. 5. Countries with more than 1 GW included 17 countries in Europe, 5 in Asia-Pacific, 6 in the Americas and 1 in Africa (South Africa), from idem (both sources). Note that 113 countries/regions had some wind capacity in operation as of end-2016, per WWEA, op. cit. note 1.

4 FTI Intelligence, op. cit. note 2.

5 GWEC, op. cit. note 1; WWEA, op. cit. note 1.

6 GWEC, op. cit. note 1. **Figure 27** based on country-specific data and sources provided throughout this section.

7 New markets from Steve Sawyer, cited in GWEC, "Wind power chalks up more strong numbers", press release (Brussels: 10 February 2017), http://www.gwec.net/wind-power-chalks-up-more-strong-numbers/; Bolivia added the 24 MW Phase II of its Qollpana wind farm, for a year-end total of 27 MW, from Empresa Nacional de Electricidad, "Inauguran parquet eólico Qollpana Fase II consolidando la energía eólica en Bolivia", press release (Cochabamba: 9 September 2016), http://www.ende.bo/noticia/noticia/54; Georgia inaugurated its first wind farm (20.7 MW), from Plamena Tisheva, "Georgia inaugurates 1st wind farm", Renewables Now, 7 October 2016, https://renewables.seenews.com/news/georgia-inaugurates-1st-wind-farm-542474.

8 Denmark had an estimated 927 watts per person, followed by Sweden (669.6 W), Germany (617.7 W), Ireland (613.1 W) and Portugal (509.5 W). The Caribbean island of Bonaire had 620.4 W per person, all from WWEA, op. cit. note 1. The top EU countries per inhabitant were Denmark (918.5 kW per 1,000 inhabitants), Sweden (661.8), Germany (608.7), Ireland (585.2) and Portugal (509.5), from EurObserv'ER, op. cit. note 1, p. 7.

9 GWEC, op. cit. note 1.

10 GWEC, op. cit. note 1; WWEA, "Worldwide wind market booming like never before: wind capacity over 392 gigawatt", press release (Bonn: 9 September 2015), http://www.wwindea.org/hyr2015/.

11 GWEC, op. cit. note 1; Steve Sawyer, GWEC, personal communication with REN21, 14 January 2016; Tom Randall, "Wind and solar are crushing fossil fuels", *Bloomberg*, 6 April 2017, https://www.bloomberg.com/news/articles/2016-04-06/wind-and-solar-are-crushing-fossil-fuels; WindEurope, "Wind energy is competitive", 21 March 2016, https://windeurope.org/policy/topics/economics/; Katie Fehrenbacher, "Wind now competes with fossil fuels. Solar almost does", *Fortune*, 6 October 2015, http://fortune.com/2015/10/06/wind-cheap-coal-gas/.

12 China added 23,369 MW for a total of 168,730 MW, from Shi Pengfei, Chinese Wind Energy Association (CWEA), personal communication with REN21, 21 March 2017; China added 23,370 MW for a total of 168,732 MW, from GWEC, op. cit. note 1; China added 23,328 MW for a total of 168,690 MW, from EurObserv'ER, op. cit. note 1, p. 3; and added 23,369 MW for a total of 168,730 MW, from FTI Consulting, op. cit. note 1, p. 51.

13 GWEC, op. cit. note 7; GWEC, op. cit. note 1.

14 EurObserv'ER, op. cit. note 1, p. 5.

15 Based on additions of 19,300 MW for total of 148,640 MW in operation, from China National Energy Board, cited in Dazhong Xiao, China National Energy Administration (CNEA), "2016 wind power and grid operation", 26 January 2017, www.nea.gov.cn/2017-01/26/c_136014615.htm (using Google Translate); total installed capacity increased from 151 GW in 2015 to 165 GW, from China Electricity Council, cited in CNEA, provided by Shi, op. cit. note 12. Differences in statistics result, at least in part, from differences in what is counted and when. Note that most of the capacity added in 2016 was feeding the grid by year's end. The difference in statistics among Chinese organisations and agencies is explained by the fact that they count different things: installed capacity refers to capacity that is constructed and usually has wires carrying electricity from the turbines to a substation; capacity qualifies as grid-connected (i.e., included in China Electricity Council statistics) once certification is granted and operators begin receiving the FIT premium payment, which can take weeks or even months. It is no longer the case that thousands of turbines stand idle awaiting connection in China because projects must be permitted in order to start construction; however, there is still often a several month lag from when turbines are wire-connected to the substation until the process of certification and payment of FIT premium is complete. Steve Sawyer, GWEC, personal communication with REN21, 3 March 2017.

16 Additions of Yunnan (3.25 GW), Hebei (1.66 GW) and Jiangsu (1.49 GW) from China National Energy Board, cited in Xiao, op. cit. note 15.

17 The top three provinces (Inner Mongolia, Xinjiang, and Gansu), all far from population centres, had approximately 40% of China's total wind power capacity at end-2016, based on data from China National Energy Board, cited in Xiao, op. cit. note 15; first time from GWEC, op. cit. note 1, pp. 37-38. New regulations include provincial targets for renewable shares of electricity consumption and an early warning system to prevent investment in areas with high risk of curtailment, based on information provided by Shi Pengfei, CWEA, personal communication with REN21, 30 March 2017, and by Frank Haugwitz, Asia Europe Clean Energy (Solar) Advisory Company, Ltd, personal communication with REN21, 30 March 2017. Deployment in the Central and Eastern regions, over that in the three Northern regions, is prioritised in the 13th Five-Year Plan, and the northern regions have the next five years to solve their curtailment problems, from GWEC, op. cit. note 1, pp. 37-38.

18 Nuclear power from Shi, op. cit. note 17. New regulations from, for example, Julie Zhu, "Solar power's time to shine in China", Finance Asia, 14 June 2016, http://www.financeasia.com/News/426847,solar-powers-time-toshine-in-china.aspx; Max Dupuy and Xuan Wang, "China's string of new policies addressing renewable energy curtailment: an update", Regulatory Assistance Project, 8 April 2016, http://www.raponline.org/featuredwork/chinas-string-of-new-policies-addressing-renewable-energy-curtailment-an; "China ban on new coal power eases clean energy waste, WRI says", *Bloomberg*, 29 April 2016, http://www.bloomberg.com/news/articles/2016-04-29/china-ban-on-new-coal-power-eases-clean-energy-waste-wri-says; FTI Consulting, op. cit. note 1, p. 23. Major challenges and reasons from the following sources: Sawyer, op. cit. note 15; Feifei Shen, Iain Wilson and Ben Sharples, "China's idled wind farms portend trouble with renewables", Renewable Energy World, 29 June 2016, http://www.renewableenergyworld.com/articles/2016/06/china-s-idled-wind-farms-portend-trouble-in-renewables.html; Kathy Chen and David Stanway, "China pushes for mandatory integration of renewable power", *Reuters*, 28 March 2016, http://www.reuters.com/article/us-china-power-renewables-idUSKCN0WU0RF; Coco Liu, "Facing grid constraints, China puts a chill on new wind energy projects", Inside Climate News, 28 March 2016, https://insideclimatenews.org/news/28032016/china-wind-energy-projects-suspends-clean-energy-climate-change.

19 National curtailment data from CNEA and China Electricity Council, provided by Shi, op. cit. note 12. The highest rates of curtailment were seen in Gansu (43%), Xinjiang (38%), Jilin (30%) and Inner Mongolia (21%), from China National Energy Board, cited in Xiao, op. cit. note 15.

20 Wind generation and share of output from China National Energy Board, cited in Xiao, op. cit. note 15. This was up from 186.3 TWh

and 3.3% in 2015, from China National Energy Board, cited by CNEA, "2015 Wind Power Industry Development", 2 February 2016, www.nea.gov.cn/2016-02/02/c_135066586.htm (using Google Translate). China's wind power generation in 2012 was 100 TWh, accounting for 2% of annual electricity output, from GWEC, op. cit. note 1, p. 13.

21 India added approximately 3,612 MW of wind power capacity in 2016 for a year-end total of 28,700.44 MW, based on Government of India, Ministry of Power, Central Electricity Authority, *All India Installed Capacity, Monthly Report January 2017* (New Delhi: 2017), Table: "All India Installed Capacity (in MW) of Power Stations (As on 31.01.2017) (Utilities)", http://www.cea.nic.in/reports/monthly/installedcapacity/2017/installed_capacity-01.pdf, and on 25,088.19 MW at the end of 2015, from Government of India, Ministry of New and Renewable Resources (MNRE), "Physical progress (achievements): programme/ scheme wise physical progress in 2015-16 (up to the month of December, 2015)", www.mnre.gov.in/mission-and-vision-2/achievements, viewed 1 February 2016.

22 FTI Consulting, op. cit. note 1, p. 21. India's Generation Based Incentive was set to expire and the higher Accelerated Depreciation for wind power was set to be halved (to 40%) in the first quarter of 2017, from idem.

23 Turkey added 1,387.75 MW for a total of 6,106.05 MW, from Turkish Wind Energy Association, *Turkish Wind Energy Statistics Report* (Ankara: January 2017), pp. 4, 5, http://www.tureb.com.tr/files/tureb_sayfa/duyurular/2017_duyurular/subat/turkiye_ruzgar_enerjisi_istatistik_raporu_ocak_2017.pdf; Turkey added 1,387 MW in 2016 for a total of 6,081 MW, from WindEurope, *Wind in Power 2016 European Statistics* (Brussels: 9 February 2017), p. 9, https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Statistics-2016.pdf; added 1,387 MW for a total of 6,081 MW, from GWEC, op. cit. note 1; added 1,382.8 MW for a total of 6,101.1 MW, from FTI Consulting, op. cit. note 1, p. 50.

24 Pakistan added 282 MW for a total of 591 MW, followed by the Republic of Korea (201 MW, for a total of 1,031 MW) and Japan (196 MW; 3,234 MW), from GWEC, op. cit. note 1; Pakistan added 373 MW for a total of 709 MW, followed by Republic of Korea (201 MW; 1,006 MW) and Japan (196 MW; 3,223 MW), from FTI Consulting, op. cit. note 1, pp. 51, 54; Pakistan added 335 MW for a total of 591 MW, followed by the Republic of Korea (198 MW; 1,031 MW) and Japan (196 MW; 3,234 MW), from WWEA, op. cit. note 1.

25 Indonesia's Sidrap wind plant will have 75 MW of capacity, from "Financial close for Indonesia's first utility-scale wind project", *Windpower Monthly*, 7 February 2017, http://www.windpowermonthly.com/article/1423494/financial-close-indonesias-first-utility-scale-wind-project; "VN green energy gets strong tail wind", Vietnam Net, 3 December 2016, http://english.vietnamnet.vn/fms/science-it/167956/vn-green-energy-gets-strong-tail-wind.html.

26 The United States added 8,203 MW for a total of 82,143 MW (accounting for decommissioning), from American Wind Energy Association (AWEA), *AWEA U.S. Wind Industry Annual Market Report Year Ending 2016* (Washington, DC: April 2017). Rankings based on data in this section. The United States added a net of 8,738.1 MW in 2016 for a total of 81,311.5 MW, from US Energy Information Administration (EIA), *Electric Power Monthly with Data for December 2016* (Washington, DC: February 2017), Table 6.1, p. 134, https://www.eia.gov/electricity/monthly/current_year/february2017.pdf; wind power generated 226.485 TWh of electricity in 2016, from EIA, idem, Table 1.1.A, p. 16, https://www.eia.gov/electricity/monthly/current_year/february2017.pdf. Note that EIA data do not include facilities smaller than 1 MW and do not include off-grid capacity.

27 One-fourth of gross additions and ranking third are based on 8,203 MW of wind power added, from AWEA, op. cit. note 26; on 14,762 MW of solar PV added, from GTM Research, personal communication with REN21, 2 May 2017, and from GTM Research, cited in US Solar Energy Industries Association, "Solar Market Insight Report 2016 Year in Review – Key Figures", http://www.seia.org/research-resources/solar-market-insight-report-2016-year-review; and on gross additions of capacity from hydropower (321.2 MW), municipal solid waste (39.6 MW), natural gas (9,137.2 MW), nuclear (643.9 MW) and other (23.4 MW), from EIA, op. cit. note 26. Note that EIA data omit plants with a total generator nameplate capacity below 1 MW. Ranking second after solar PV for net capacity additions based on above additions for wind power and solar PV, and on net capacity additions from hydropower (321.2 MW), bio-power (-15.5 MW), geothermal power (-30 MW), natural gas (7,532.2 MW), coal (-9,659 MW), petroleum and other gases (-435.6 MW), nuclear (643.9 MW) and other (23.4 MW), from EIA, op. cit. note 26.

28 Texas added 2.611 MW, followed by Oklahoma (1,462 MW), Iowa (707 MW), Kansas (687 MW) and North Dakota (603 MW), and the top states for total capacity were Texas (20, 321 MW), Iowa (6,917 MW) and Oklahoma (6,645 MW), from AWEA, "U.S. Wind Industry Fourth Quarter 2016 Market Update" (Washington, DC: 26 January 2017), http://awea.files.cms-plus.com/FileDownloads/pdfs/4Q2016%20AWEA%20Market%20Report%20Public%20Version.pdf.

29 AWEA, op. cit. note 28.

30 Hannah Hunt, AWEA, personal communication with REN21, 31 March 2017. Going beyond state mandates (Renewable Portfolio Standards) includes utilities in, for example, Colorado and Alabama, from David Labrador, "U.S. wind power demand: corporations take the lead", CleanTechnica, 23 February 2016, https://cleantechnica.com/2016/02/23/us-wind-power-demand-corporations-take-the-lead/; Iowa from Lauren Tyler, "MidAmerican Energy files request for 2 GW wind farm in Iowa", *North American Windpower*, 15 April 2016, http://nawindpower.com/midamerican-energy-files-request-for-2-gw-wind-farm-in-iowa.

31 Hunt, op. cit. note 30; AWEA, op. cit. note 28.

32 AWEA, op. cit. note 28.

33 Canada added 702 MW for a total of 11,898 MW, from Canadian Wind Energy Association (CanWEA), "Installed capacity", http://canwea.ca/wind-energy/installed-capacity/, viewed 17 February 2017. For comparison, in 2015 Canada added 1,506 MW for a total of 11,205 MW, from CanWEA, "Wind energy continues rapid growth in Canada in 2015", press release (Ottawa: 12 January 2016), http://canwea.ca/wind-energy-continues-rapid-growth-in-canada-in-2015/. Added 702 MW for a total of 11,870 MW, from FTI Consulting, op. cit. note 1, p. 52, and added 702 MW for a total of 11,900 MW, from GWEC, op. cit. note 1.

34 CanWEA, "Powering Canada's Future" (Ottawa: December 2016), http://canwea.ca/wp-content/uploads/2017/01/Canada-Current-Installed-Capacity_e.pdf; largest source of new generation from CanWEA, "Wind energy in Canada", http://canwea.ca/wind-energy/installed-capacity/, viewed 25 March 2017.

35 Ontario added 413 MW (for a total of 4,781 MW), followed by Québec (added 249 MW for a total of 3,510); additions from "Canadian wind grows by 700MW", Renews Biz, 1 February 2017, http://renews.biz/105753/canadian-wind-grows-by-700mw/; year-end totals from CanWEA, "Installed capacity", op. cit. note 33; Prince Edward Island, from Diane Bailey, "Canada island plans to increase wind by a third", *Windpower Monthly*, 21 March 2017, http://www.windpowermonthly.com/article/1428024/canada-island-plansincrease-wind-third.

36 The EU installed 12,490 MW (10,923 MW onshore and 1,567 MW offshore) for a cumulative year-end total of 153.7 GW (141.1 GW onshore and 12.6 GW offshore), from WindEurope, op. cit. note 23; similar data from GWEC, op. cit. note 1. The EU added 12,068.1 MW in 2016 for a year-end total of 153,640.5 MW, from EurObserv'ER, op. cit. note 1, p. 6. About 482 MW of wind power capacity was decommissioned in the EU during 2016, from Steve Sawyer, GWEC, personal communication with REN21, 30 April 2017.

37 WindEurope, op. cit. note 23; shares of onshore and offshore based on data from GWEC, op. cit. note 1, p. 16.

38 Based on data from WindEurope, op. cit. note 23, p. 12. The EU added an estimated 3,358 MW of new fossil capacity in 2016 (including 3,115 MW of natural gas and 243 MW of coal), but the region decommissioned about 12,449 MW of fossil capacity (including 7,267 MW of coal, 2,256 MW of natural gas and 2,197 MW of fuel oil). Between 2005 and 2016, wind power's share of total EU power capacity increased from 6% to 16.7%, all from idem.

39 WindEurope, op. cit. note 23, p. 7.

40 GWEC, *Global Wind Energy Outlook 2016* (Brussels: 2016), http://files.gwec.net/register?file=/files/GlobalWindEnergyOutlook2016; Feng Zhao, FTI Consulting, personal communication with REN21, 12 April 2017; GWEC, op. cit. note 1, p. 42.

41 WindEurope, *Making Transition Work* (Brussels: September 2016),

BACK

https://windeurope.org/wp-content/uploads/files/about-wind/reports/WindEurope-Making-transition-work.pdf. See also WindEurope, op. cit. note 23, p. 9.

42 WindEurope, "Europe adds 12.5 GW of new wind capacity in 2016 with record €27.5bn in new investments", press release (Brussels: 9 February 2017), https://windeurope.org/newsroom/press-releases/europe-adds-12-5-gw-of-new-wind-capacity-in-2016-with-record-27-5bn-euro-in-new-investments/.

43 Based on data from WindEurope, op. cit. note 23, p. 9. The top two markets accounted for over 56%, and France added 1,561 MW for a total of 12,065 MW, the Netherlands added 887 MW for a total of 4,328 MW, the United Kingdom added 736 MW for a total of 14,542 MW, and Poland added 682 MW for a total of 5,782 MW, from idem, and similar numbers from GWEC, op. cit. note 1, p. 15. The Netherlands added a net of 815 MW (215 MW onshore and 600 MW offshore) for a year-end total of 4,206 MW, from Centraal Bureau voor de Statistiek, "Hernieuwbare elektriciteit; productie en vermogen", 28 February 2017, http://statline.cbs.nl/Statweb/publication/?DM=SLNL&PA=82610NED&D1=7&D2=2-4&D3=25-26&HDR=T,G2&STB=G1&VW=T. The United Kingdom added 1,404 MW for a total of 15,696 MW, based on preliminary data from UK Department for Business, Energy & Industrial Strategy, *National Statistics, Energy Trends Section 6: Renewables,* updated 30 March 2017, Table 6.1 "Renewable electricity capacity and generation", p. 69, https://www.gov.uk/government/statistics/energy-trends-section-6-renewables. See text and other endnotes for Germany data.

44 The decline in the EU during 2016 was due mainly to lower installations in Poland and the United Kingdom, from Zhao, op. cit. note 40.

45 Germany ended 2016 with 49,534 MW of grid-connected capacity, up from 44,541 GW at the end of 2015, from Bundesministerium für Wirtschaft und Energie (BMWi), *Zeitreihen zur Entwicklung der erneuerbaren Energien in Deutschland, unter Verwendung von Daten der Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat) (Stand: Februar 2017)*, p. 7, http://www.erneuerbare-energien.de/EE/Redaktion/DE/Downloads/zeitreihen-zur-entwicklung-der-erneuerbaren-energien-in-deutschland-1990-2016.pdf. Germany added 4,642 MW (including 695 MW offshore) for a year-end total of 50,001 MW; during the year, 386 turbines (385.6 MW) were decommissioned and replaced by 271 turbines (785 MW), all from C. Ender, "Wind energy use in Germany: status 31.12.2016", *DEWI Magazin*, March 2017, pp. 56-65, http://www.dewi.de/dewi_res/fileadmin/pdf/publications/Magazin_50/DM_50_lowres.pdf. Germany added 5,443 MW (accounting for 44% of the market) for a total of 50,019 MW, from WindEurope, op. cit. note 23, pp. 7, 9. Considering decommissioned capacity, Germany's capacity increased by a net of 4,259.17 MW onshore and 818 MW offshore; an additional 122.7 MW was installed but not yet grid connected, from Deutsche WindGuard, *Status of Land-Based Wind Energy Development in Germany 2016* (Varel, Germany: 2017), http://www.windguard.com/_Resources/Persistent/85b5b9813fa5a3cc27e03ed089a7dba68783a939/Factsheet-Status-Land-Based-Wind-Energy-Development-Germany-2016.pdf, and from Deutsche WindGuard, *Status of Offshore Wind Energy Development in Germany 2016* (Varel, Germany: 2017), http://www.windguard.com/_Resources/Persistent/2c1d303ec32d879a801beb803e39a5ed4e460102/Factsheet-Status-Offshore-Wind-Energy-Development-Year-2016.pdf. Germany added 5,443 MW for a total of 50,018 MW, from GWEC, op. cit. note 1, added 5,443 MW for a total of 50,019 MW, from EurObserv'ER, op. cit. note 1, p. 6, and added 5,443 MW for a total of 49,840 MW from FTI Consulting, op. cit. note 1, p. 50.

46 FTI Consulting, op. cit. note 1, p. 50; Aloys Nghiem, WindEurope, personal communication with REN21, 10 April 2017; GWEC, op. cit. note 1, p. 46. Onshore installations in particular were triggered by quarterly reductions in the FIT and the looming shift to Germany's the auction system, starting in 2017, from Ender, op. cit. note 45, pp. 56-65. Gross electricity generation from wind power in Germany was 79.8 TWh in 2016 (up less than 1% over 2015), from BMWi, "Energiedaten – Gesamtausgabe", as of 30 January 2017, published 27 February 2017, https://www.bmwi.de/Redaktion/DE/Artikel/Energie/energiedaten-gesamtausgabe.html.

47 Gross installations were France (installed 1,561 MW for a total of 12,065 MW), the Netherlands (887 MW; 4,328 MW), Finland (570 MW; 1,539 MW), Ireland (384 MW; 2,830 MW) and Lithuania (178 MW; 493 MW), from WindEurope, op. cit. note 23, pp. 7, 9, and same numbers for France, the Netherlands and Ireland, from GWEC, op. cit. note 1, p. 15; same numbers for the Netherlands, Finland and Ireland, but France added 1,772 MW for total of 12,065 MW, and Lithuania added 69 MW for a total of 493 MW, from WWEA, op. cit. note 1. France added 1,346 MW for a total of 11,670 MW; the Netherlands added 788.5 MW for a total of 4,179.5 MW; Finland added 570 MW for a total of 1,533 MW; Ireland added 324.7 MW for a total of 2,764.7 MW; Lithuania added 71 MW for a total of 509 MW, from EurObserv'ER, op. cit. note 1, p. 6. France added 1,561 MW for a total of 11,930 MW, followed by the Netherlands (887 MW; 4,255 MW), Finland (570 MW; 1,527 MW), Ireland (384 MW; 2,867 MW) and Lithuania (178 MW; 604 MW), from FTI Consulting, op. cit. note 1, p. 50. The Netherlands added a net of 815 MW (215 MW onshore and 600 MW offshore) for a year-end total of 4,206 MW, from Centraal Bureau voor de Statistiek, op. cit. note 43. France had 11,670 MW in operation as end 2016, per RTE Réseau de transport d'électricité, *Bilan Électrique Français 2016: Synthèse presse* (Paris: 2016), p. 5, http://www.rtefrance.com/sites/default/files/2016_bilan_electrique_synthese.pdf.

48 WindEurope, op. cit. note 23, pp. 7, 9.

49 Estimated output was 300 TWh, from WindEurope, op. cit. note 23, p. 7; and estimated output was 302.7 TWh, from EurObserv'ER, op. cit. note 1, p. 8.

50 Russia ended 2016 with 15 MW of capacity, from WindEurope, op. cit. note 23, p. 9; first auction from WWEA, *Perspectives of the Wind Energy Market in Russia* (Bonn: forthcoming, 2017).

51 GWEC, op. cit. note 1, pp. 15, 18. Note that numbers of countries and regional data include Mexico but do not include numbers and capacity data for several island countries and territories in the Caribbean region that also had wind energy capacity in operation at end-2016. See WWEA, op. cit. note 1.

52 FTI Consulting, op. cit. note 1, p. 47. Brazil's additions in 2016 were down 27.1% relative to 2015, from EurObserv'ER, op. cit. note 1, p. 4.

53 EurObserv'ER, op. cit. note 1, p. 3; Steve Sawyer, GWEC, personal communication with REN21, 6 September 2016. Note that more than 500 MW of contracted wind projects were cancelled during 2016, from FTI Consulting, op. cit. note 1, p. 28. Projects also have been cancelled in Brazil due to the low price level of the auctions, from Jean Daniel Pitteloud, WWEA, Bonn, personal communication with REN21, 27 April 2017.

54 Brazil added 2,014 MW for a total of 10,740 MW, from Associação Brasileira de Energia Eólica (ABEEólica), "Dados Mensais", January 2017, pp. 4, 6, http://www.abeeolica.org.br/wp-content/uploads/2017/01/Dados-Mensais-ABEEolica-01.2017-1.pdf; from GWEC, op. cit. note 1; and from EurObserv'ER, op. cit. note 1, p. 3. Brazil added 2,014 MW for a total of 10,696 MW, from FTI Consulting, op. cit. note 1, p. 53, and added 2,085 MW for a total of 10,800 MW, from WWEA, op. cit. note 1. Brazil had 10,123.9 MW at end-2016 from Agência Nacional de Energia Elétrica (ANEEL), "Informações gerenciais", December 2016, http://www.aneel.gov.br/informacoes-gerenciais. Commissioned but not all grid connected, from GWEC, op. cit. note 1, p. 16. Lack of transmission lines and slow pace of construction from Lucas Morais, "Lack of transmission capacity to curb Brazil's wind expansion – report", Renewables Now, 7 October 2016, https://renewables.seenews.com/news/lack-of-transmission-capacity-to-curb-brazils-wind-expansion-report-542486; Sawyer, op. cit. note 53.

55 National Electrical System Operator of Brazil (ONS), "Geração de energia", http://www.ons.org.br/historico/geracao_energia.aspx, viewed 19 March 2017.

56 GWEC, op. cit. note 1, p. 30; Steve Sawyer, GWEC Newsletter, January 2017. Six turbine manufacturers, with annual production capacity of more than 3 GW, were already seeing idled capacity in early 2017, from FTI Consulting, op. cit. note 1, p. 28. Facilities were established to satisfy local content laws, but there is limited if any opportunity for export because the turbines produced in Brazil are not priced competitively, and as of early 2017 there was concern about potential for future demand due to the cancelled auction, from Sawyer op. cit. note 53. Industry suffering due to lack of auctions also from Camila Ramos, Clean Energy Latin America (CELA), Brazil, personal communication with REN21, 30 November 2016.

57 Chile added 513 MW for a total of 1,424 MW, followed by Mexico (454 MW; 3,527 MW), Uruguay (365 MW; 1,210 MW), Peru (93 MW; 241 MW), the Dominican Republic (50 MW; 135 MW) and

Costa Rica (20 MW; 298 MW), from GWEC, op. cit. note 1. Chile added 513 MW for a total of 1,523 MW, followed by Mexico (454 MW; 3,549 MW) and Uruguay (365 MW; 1,146 MW), from FTI Consulting, op. cit. note 1, p. 53. Chile added 491 MW for a total of 1,424 MW, followed by Mexico (426 MW; 3,709 MW, Uruguay (354 MW; 1,210 MW) and Peru (97 MW; 245 MW), from WWEA, op. cit. note 1. Uruguay added 354.7 MW for a total of 1,211.5 MW, from Uruguay Secretary of Energy, Ministry of Industry, Energy and Mining, personal communication with REN21, 20 March 2017.

58 GWEC, op. cit. note 1, p. 15.

59 GWEC, op. cit. note 7.

60 Approximately 0.4 GW (only in South Africa) was added in Africa during 2016, from GWEC, op. cit. note 1. By contrast, nearly 1 GW was added across Africa in 2014, from GWEC, *Global Wind Report 2014: Annual Market Update* (Brussels: April 2015), p. 8, http://www.gwec.net/wp-content/uploads/2015/03/GWEC_Global_Wind_2014_Report_LR.pdf; and approximately 836 MW was added on the continent in 2015, from GWEC, *Global Wind Report: Annual Market Update 2015* (Brussels: April 2016), p. 17, http://www.gwec.net/wp-content/uploads/vip/GWEC-Global-Wind-2015-Report_April-2016_19_04.pdf. South Africa added 418 MW in 2016 for a total of 1,471 MW, from GWEC, op. cit. note 1, and from WWEA, op. cit. note 1. Note that Egypt added 174 MW for a year-end total of 842 MW, and Morocco added 100 MW for a total of 896 MW, with additions provided by original equipment manufacturers (OEMs), from Zhao, op. cit. note 40, and from FTI Consulting, op. cit. note 1, p. 55.

61 GWEC, op. cit. note 7; GWEC, op. cit. note 1; Kenya also from Daniel Cusick, "How a huge wind farm in Kenya could transform Africa's energy landscape", *E&E News*, 11 October 2016, http://www.eenews.net/climatewire/2016/10/11/stories/1060044075.

62 Largest investment and expected completion from Lake Turkana Wind Power, "Overview", http://ltwp.co.ke/project-overview/, viewed 21 March 2017; largest in Africa from African Development Bank Group, "Lake Turkana Wind Power Project: the largest wind farm project in Africa", https://www.afdb.org/en/projects-and-operations/selected-projects/lake-turkana-wind-power-project-the-largest-wind-farm-project-in-africa/, viewed 21 March 2017; approximately 15% from Lake Turkana Wind Power, "Project Overview", http://ltwp.co.ke/, viewed 18 May 2017. The project was completed and soon to be commissioned as of late April 2017, per GWEC, op. cit. note 1. The project is expected to generate electricity for more than 1 million homes, from Antony Kiganda, "Kenya's Lake Turkana Wind Power project nears completion", Asoko Insight, 29 November 2016, https://asokoinsight.com/news/kenyas-lake-turkana-wind-power-project-nears-completion.

63 Australia added 140 MW for a total of 4,327 MW, from GWEC, op. cit. note 1; added 140 MW for total of 4,325 MW, from FTI Consulting, op. cit. note 1, p. 54; and added 140 MW for a total of 4,326 MW, from WWEA, op. cit. note 1. The Pacific Islands added 1 MW of capacity for a year-end total of 23 MW, from FTI Consulting, op. cit. note 1, p. 54.

64 The Kuwait project was reported by the OEM of turbines installed, from Zhao, op. cit. note 40, and from FTI Consulting, op. cit. note 1, p. 55. For other news of this project, see, for example, Nada Bedir, "Fostering renewable energy deployment in Kuwait – special report", *Kuwait Times*, 4 April 2016, http://news.kuwaittimes.net/website/fostering-renewable-energy-deployment-kuwait/;"Kuwait Al-Shagaya solar and wind project to be completed soon", Voice of Renewables, 18 May 2016, http://voiceofrenewables.com/solar/kuwait-al-shagaya-solar-and-wind-project-to-be-completed-soon/; and Elecnor, "Wind power Shagaya", http://www.elecnor.es/Common/pdf/galerias_descargas-en/02-renewables/12-wind-power/Referencia-Shagaya-(Kuwait)-EN.pdf?_ga=1.99237917.2025466108.1492180197, viewed 17 April 2017. Saudi Arabia from FTI Consulting, op. cit. note 1, p. 18; from Jan Dodd, "Saudi Arabia announces 400MW tender", *Windpower Monthly*, 3 February 2017, http://www.windpowermonthly.com/article/1423109/saudiarabia-announces-400mw-tender; and from Reem Shamseddine, "Saudi Aramco, GE to launch Saudi Arabia's first wind turbine next month", *Reuters*, 18 December 2016, http://ca.reuters.com/article/businessNews/idCAKBN1470PM.

65 Figure of 2,219 MW connected to grids for total of 14,384 MW from GWEC, op. cit. note 1, p. 59. A little more than 2 GW of capacity was grid-connected for a total of 14,160 MW, from EurObserv'ER, op. cit. note 1, p. 4; 1,985 MW was added (including 1,326 MW in Europe, 629 MW in Asia-Pacific and 30 MW in North America), for a total of 14,061 MW, from FTI Consulting, op. cit. note 1, p. 48. Globally 24 turbines (totalling 9 MW) were decommissioned, from FTI Consulting, op. cit. note 1, p. 48; decommissioned turbines included 5 MW in Germany, 2 MW in Portugal (a 2 MW floating turbine) and 2 MW in the Netherlands (four 500 kW turbines), from WindEurope, *The European Offshore Wind Industry – Key Trends and Statistics 2016* (Brussels: January 2017), https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Offshore-Statistics-2016.pdf.

66 Based on 1,558 MW added in Europe and a total of 12,631 MW at year's end, from GWEC, op. cit. note 1, p. 59. Gross additions in Europe were 1,567 MW and net additions were 1,558 MW, for a regional total of 12,631, from WindEurope, op. cit. note 65. Europe accounted for 87.6% of offshore wind capacity at year's end, followed by Asia-Pacific with 12.1% and North America, from FTI Consulting, op. cit. note 1, p. 48. **Figure 28** based on data from GWEC, *Global Wind Report: Annual Market Update 2015*, op. cit. note 60, pp. 50-51; GWEC, op. cit. note 1; Shi Pengfei, CWEA, personal communication with REN21, April 2010 and March 2017; FTI Consulting, op. cit. note 1, p. 60; WindEurope, op. cit. note 65, p. 17; AWEA, "First US offshore wind farm unlocks vast new ocean energy resource", press release (Block Island, RI: 12 December 2016), http://www.awea.org/MediaCenter/pressreleasev2.aspx?ItemNumber=9627.

67 Germany brought 813 MW (net) online, followed by the Netherlands (691 MW) and the United Kingdom (56 MW), and at year's end, work was ongoing on 4.8 GW of projects in Belgium, Germany, the Netherlands and the United Kingdom, all from WindEurope, op. cit. note 65. Germany added a net of 853 MW, from BMWi, op. cit. note 45, p. 7; Germany added 818 MW, bringing total offshore capacity to 4,108.3 MW, and dismantled its first offshore turbine (5 MW prototype); 122.7 MW was erected during the year but not grid connected, from B. Neddermann, "Offshore wind energy capacity in Germany reaches 4,108 megawatts", *DEWI Magazin*, March 2017, pp. 66-69, http://www.dewi.de/dewi_res/fileadmin/pdf/publications/Magazin_50/DM_50_lowres.pdf. The Netherlands added a net of 600 MW offshore, from Centraal Bureau voor de Statistiek, op. cit. note 43. Countries with projects under construction included Belgium, Finland, Germany, the Netherlands and the United Kingdom, from idem. Driver from Christian Schwägerl, "For European wind industry, offshore projects are booming", *Yale e360*, 20 October 2016, http://e360.yale.edu/feature/european_offshore_wind_industry_booming/3046/. Finland started construction of its first offshore wind farm, the 40 MW Tahkoluoto project, expected to be the first designed for icy conditions, from William Steel, "Developers optimistic about Finland's offshore wind market", Renewable Energy World, 16 June 2016, http://www.renewableenergyworld.com/articles/2016/06/developers-optimistic-about-finland-s-offshore-wind-market.html. No capacity was brought online off the coasts of the United Kingdom in 2016, with only the Netherlands (744 MW) and Germany (582 MW) adding capacity, from FTI Consulting, op. cit. note 1, p. 48.

68 China added 592.2 MW near shore (all previously existing projects were in intertidal areas) for a total of 1,627 MW, from GWEC, op. cit. note 1, pp. 39, 61, and from GWEC, op. cit. note 7; China added 592 MW for a total of 1,613 MW from FTI Consulting, op. cit. note 1, p. 48.

69 "China can expect a surge in offshore wind farms, Goldwind says", *Bloomberg*, 11 January 2017, https://www.bloomberg.com/news/articles/2017-01-11/china-can-expect-a-surge-in-offshore-wind-farms-goldwind-says. Note that the 13th Five-Year Plan for Wind Power Development includes a target of 5 GW in operation by 2020, from Shi, op. cit. note 17.

70 Republic of Korea from Shaun Campbell, "Strong growth pushes wind close to 500GW", *Windpower Monthly*, 1 March 2017, http://www.windpowermonthly.com/article/1425161/strong-growth-pushes-wind-close-500gw; United States from AWEA, op. cit. note 66; Alex Kuffner, "Wind farm off Block Island operating at full capacity after repair", *Providence Journal*, 6 February 2017, http://www.providencejournal.com/news/20170206/wind-farm-off-block-island-operating-at-full-capacity-after-repair; Japan anchored a 7 MW floating turbine in 2015 that began official operation in 2016, from Yoshinori Ueda, Japan Wind Power Association, personal communication with GWEC, 30 April 2017; a 7 MW turbine was installed in May 2016 and anchored in July, with official operation estimated to be in 2017, from idem; see also

Fukushima Floating Offshore Wind Farm Demonstration Project, "The installation of 'Fukushima Hamakaze' in the testing area", 1 August 2016, http://www.fukushima-forward.jp/english/news_release/news160801.html. All three, including floating turbine in Japan, from FTI Consulting, op. cit. note 1, p. 48, and from GWEC, op. cit. note 1, pp. 62-63. In addition, a near-shore/intertidal wind project in Vietnam (the 99.2 MW Bac Lieu wind farm) came online in stages from 2013-2015, GWEC, op. cit. note 1, p. 65; it is not included in the offshore data because it is a few metres offshore and dry much of the time, per Sawyer, op. cit. note 36.

71 Barriers to offshore wind power in the United States include vast open land with good onshore wind resources, from US Department of Energy (DOE), Energy Efficiency and Renewable Energy (EERE), *Wind Technologies Market Report 2015* (Washington, DC: August 2016), p. 10, https://emp.lbl.gov/sites/all/files/2015-windtechreport.final_.pdf, and from Chris Martin, "Largest US offshore wind farm planned in New York waters", Renewable Energy World, 20 July 2016, http://www.renewableenergyworld.com/articles/2016/07/largest-us-offshore-wind-farm-planned-in-new-york-waters.html. Also, note that offshore wind in the United States is competing in a market with relatively lower electricity prices than in Europe, from Steve Sawyer, GWEC, personal communication with REN21, 20 September 2016. As of August 2016, 23 offshore projects totalling more than 16 GW were in various stages of development, including the Block Island project, which came online in late 2016, from DOE, EERE, op. cit. this note, p. vi. According to AWEA, by late 2016, 13 offshore projects totalling 6 GW were in various stages of development in 10 states, off the Atlantic and Pacific coasts and in the Great Lakes, from Nancy Sopko, "American offshore wind power is here", AWEA, 22 August 2016, http://www.aweablog.org/american-offshore-wind-power/, and from Greg Alvarez, "Top six wind power trends of 2016", AWEA, 22 December 2016, http://www.aweablog.org/top-six-wind-power-trends-2016/. Drivers for offshore wind in the country include proximity of good offshore resources to population centres, from DOE, EERE, op. cit. this note, p. 10; as well as favourable policies in some eastern states, from Brian Dumaine, "Wind power takes to the seas", *Fortune*, 14 March 2017, http://fortune.com/2017/03/14/offshore-wind-power-deepwater-de-shaw/.

72 At year's end, the UK had 5,156 MW, followed by Germany (4,108 MW), Denmark (1,271 MW), the Netherlands (1,118 MW) and Belgium (712 MW), from WindEurope, op. cit. note 65. Germany's offshore capacity was 4,150 MW, from BMWi, op. cit. note 45, p. 7. China added 592 MW for a total of 1,627 MW, from GWEC, op. cit. note 1, and from "China can expect a surge in offshore wind farms, Goldwind says", *Bloomberg*, 11 January 2017, https://www.bloomberg.com/news/articles/2017-01-11/china-can-expect-a-surge-in-offshore-wind-farms-goldwind-says.

73 FTI Consulting, *Global Wind Market Update – Demand & Supply 2015 – Wind Farm Owner-Operators* (London: 2016), p. 2; GWEC, op. cit. note 1.

74 GWEC, op. cit. note 1, pp. 8-11. For example, Whirlpool installed its own wind turbines at two additional factories in Ohio, from David Weston, "Whirlpool installs turbine plants", *Windpower Monthly*, 25 May 2016, http://www.windpowermonthly.com/article/1396377/whirlpool-install-turbines-plants; Nestlé signed a wind deal to meet half of its UK and Ireland power needs from a Scottish wind farm, from "Nestlé signs Sanquhar wind farm deal", *BBC News*, 22 June 2016, http://www.bbc.com/news/uk-scotland-south-scotland-36586926; IKEA purchased its second wind farm in Alberta, Canada, from Amanda Stephenson, "IKEA buys second Alberta wind farm", *Calgary Sun*, 26 January 2017, http://www.calgarysun.com/2017/01/26/ikea-buys-second-alberta-wind-farm; see also Greg Alvarez, "Corporate America wants wind power", AWEA Blog, 17 November 2016, http://www.aweablog.org/corporate-america-wants-wind-power/.

75 US figure from Hunt, op. cit. note 30; Europe from FTI Intelligence, op. cit. note 2; see also GWEC, op. cit. note 1, pp. 8-11.

76 In Sweden and Norway, demand from insurance companies, furniture stores and others has exceeded expectations and targets, from Jesper Starn, "Sweden sees red over Google and IKEA's green goals", *Bloomberg*, 8 February 2017, https://www.bloomberg.com/news/articles/2017-02-09/google-ikea-nordic-wind-power-crush-comes-too-soon-for-sweden.

77 See, for example, Samantha Turnbull, "Australia's first community-owned renewable energy retailer Enova to open its doors in Byron Bay", *ABC News Australia*, 4 January 2016, http://www.abc.net.au/news/2016-01-05/australia-first-community-owned-energy-retailer-enova/7068420; Energy4All Limited, "Delivering community-owned green power", http://www.energy4all.co.uk/, viewed 29 April 2017; Community Windpower website, http://www.communitywindpower.co.uk/, viewed 29 April 2017; Windustry, "Community wind", http://www.windustry.org/community-wind, viewed 29 April 2017.

78 Spain and Ontario from Stefan Gsänger and Jean-Daniel Pitteloud, WWEA, Bonn, personal communication with REN21, 9 March 2017; Spain also from Eòlica Popular (EOLPOP) website, http://www.viuredelaire.cat/, viewed 12 April 2017; Ontario project achieved commercial operation in late 2016, from Oxford Community Energy Co-operative, "Oxford Community Energy Co-op", http://www.oxford-cec.ca/, viewed 18 May 2017; Australia from Michael Slezak, "Renewables roadshow: How Daylesford's windfarm took back the power", *The Guardian* (UK), 14 March 2017, https://www.theguardian.com/environment/2017/mar/15/renewables-roadshow-community-owned-windfarm-daylesford-hepburn-australia.

79 Institute for Sustainable Energy Policies (ISEP), "Community power growing in Japan and world-wide", *REN21 Newsletter*, March 2017. ISEP uses the same definition of community power as the WWEA: "Community power" is defined as having at least two of the following criteria: local stakeholders (individuals or a group) own the majority or all of the project; control over voting rests with the community-based organisation, made up of local stakeholders; the majority of social and environmental benefits are distributed locally, per WWEA, "WWEA defines community power", 23 May 2011, http://www.wwindea.org/communitypowerdefinition/.

80 Gsänger and Pitteloud, op. cit. note 78. This is occurring in the EU, for example, from Giorgio Corbetta, European Wind Energy Association (EWEA), personal communication with REN21, 30 March 2016. See, for example, Sara Knight, "Analysis: Citizen ownership at risk from new system", *Windpower Monthly*, 25 August 2015, http://www.windpowermonthly.com/article/1361449/analysis-citizen-ownership-risk-new-system; WWEA, "Study: Community wind threatened by discriminating policies", press release (Bonn: 22 March 2016), http://www.wwindea.org/study-community-wind-threatened-by-discriminating-policies/; Carlo Schick, Stefan Gsänger and Jan Dobertin, *Headwind and Tailwind for Community Power* (Bonn: WWEA, February 2016), http://www.wwindea.org/study-community-wind-threatened-by-discriminating-policies/.

81 WWEA, *Small Wind World Report 2016* (Bonn: March 2016), Summary, http://www.wwindea.org/small-wind-world-market-back-on-track-again/; RenewableUK, *Small and Medium Wind UK Market Report* (London: March 2015), http://www.renewableuk.com/news/304391/Small-and-Medium-Wind-UK-Market-Report-2015.htm; displace diesel from Navigant Research, "Small and medium wind power", http://www.navigantresearch.com/research/small-and-medium-wind-power, viewed 12 February 2014; Navigant Research, "Worldwide small & medium wind power installations are expected to total more than 3.2 gigawatts from 2014 through 2023", press release (Boulder, CO: 5 January 2015), https://www.navigantresearch.com/newsroom/worldwide-small-medium-wind-power-installations-are-expected-to-total-more-than-3-2-gigawatts-from-2014-through-2023. Off-grid applications continued to play an important role in remote areas of developing countries, per WWEA, op. cit. this note. In China there are increasing numbers of wind/solar PV hybrid systems in rural areas, from Chinese Wind Energy Equipment Association (CWEEA), "The development of Chinese small wind generators", *WWEA Wind Bulletin*, no. 2 (September 2016), pp. 6-7, http://www.wwindea.org/wwea-bulletin-issue-2-2016-small-wind-special/.

82 Preliminary data from WWEA, *Small Wind World Report 2017* (Bonn: forthcoming June 2017), Summary, http://small-wind.org/wp-content/uploads/2014/12/SWWR2017-SUMMARY.pdf.

83 Preliminary data from WWEA, op. cit. note 82. Global small wind capacity at end-2015 is estimated at roughly 1.3 GW, based on surveys of international government and industry publications, from Alice C. Orrell et al., *2015 Distributed Wind Market Report* (Richland, WA: Pacific Northwest National Laboratory, August 2016), prepared for DOE, p. ii, https://energy.gov/sites/prod/files/2016/08/f33/2015-Distributed-Wind-Market-Report-08162016_0.pdf. This was up from an estimated 810 MW at the end of 2014, 678 MW in 2012, and 755 MW in 2013, from Alice C. Orrell and Nikolas F. Foster with Scott L. Morris,

2014 Distributed Wind Market Report (Washington, DC: DOE, EERE), August 2015), pp. 15-16, https://energy.gov/eere/wind/downloads/2014-distributed-wind-market-report.

84 Data for China and the United States are preliminary, from WWEA, op. cit. note 82. UK data were not available at time of publication.

85 Preliminary data from WWEA, op. cit. note 82. Italy had an estimated 83 MW by January 2017, from Jean Daniel Pitteloud, WWEA, Bonn, personal communication with REN21, 27 April 2017.

86 Navigant Research, "Global annual installed capacity of small and medium wind turbines is expected to exceed 446 MW in 2026", press release (Boulder, CO: March 2017), https://www.navigantresearch.com/newsroom/global-annual-installed-capacity-of-small-and-medium-wind-turbines-is-expected-to-exceed-446-mw-in-2026; Pitteloud, op. cit. note 85.

87 China from Orrell et al., 2015 *Distributed Wind Market Report*, op. cit. note 83, p. 11. The UK market fell from 28.5 MW in 2014 to close to 12 MW in 2015; Italy's 2015 market fell to 10.8 MW, down 32% compared to 2014, from idem, p. 11. In 2015, the United States deployed 4.3 MW of small-scale wind turbines, or 1,695 units, and saw over USD 21 million in investment; this was up slightly over 2014, when 3.7 MW was added (1,600 units) at USD 20 million, but down from 2013, when 5.6 MW was installed (2,700 units) and USD 36 million invested, from idem, p. i.

88 Gsänger and Pitteloud, op. cit. note 78; Navigant Research, op. cit. note 86.

89 Market size (based on billion Euro market) from GWEC, cited in Jennifer Runyon, "Making the most energy from the wind", *Renewable Energy World*, May/June 2015, pp. 32-37. Repowering began in Denmark and Germany, due to a combination of incentives and a large number of ageing turbines. It is driven by technology improvements and the desire to increase output while improving grid compliance and reducing noise and bird mortality, from International Energy Agency (IEA), *Technology Roadmap – Wind Energy, 2013 Edition* (Paris: 2013), p. 10, and from James Lawson, "Repowering gives new life to old wind sites", Renewable Energy World, 17 June 2013, http://www.renewableenergyworld.com/rea/news/article/2013/06/repowering-gives-new-life-to-old-wind-sites. Ultimately, repowering, where it happens, is driven by the economics of the project, and relevance of other factors depends on whether the government puts incentives in place in relation to them, from Steve Sawyer, GWEC, personal communication with REN21, 13 April 2015.

90 Runyon, op. cit. note 89; Zuzana Dobrotkava, World Bank, Washington, DC, personal communication with REN21, 28 January 2016.

91 An estimated 606 turbines totalling 485 MW, and significant increase over 2015, from FTI Consulting, *Global Wind Market Update – Demand & Supply 2016, Part One – Supply Side Analysis* (London: 2016), p. 24, http://www.fti-intelligencestore.com/index.php?route=download/main&download_id=147; plus 115 turbines totalling 48 MW in the United States, from AWEA, op. cit. note 26.

92 Germany data from Bundesnetzagentur, provided by Peter Bickel, Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW), personal communication with REN21, April 2017. All except Germany and United States from FTI Consulting, op. cit. note 91, p. 24. Denmark dismantled 58 MW/179 units; Finland 42 MW/18 units; Canada 12 MW/57 units; the United Kingdom 3 MW/5 units; the Netherlands 2 MW/4 units; Sweden 2 MW/6 units; Japan 1 MW/1 unit, all from idem. The United States decommissioned 48 MW/115 units, from AWEA, op. cit. note 26. Germany dismantled 336 units (366 MW) from FTI Consulting, op. cit. note 91.

93 MAKE, cited in Betsy Lillian, "To repower or to retrofit: how does the PTC affect wind owners' decisions?" *North American Windpower*, 8 December 2016, http://nawindpower.com/to-repower-or-retrofit-how-does-the-ptc-affect-wind-owners-decisions. Note also plans to dismantle 83 MW of turbines in Altamont Pass to reduce impacts on birds, from Ros Davidson, "Dismantling under way at Altamont Pass", *Windpower Monthly*, 11 March 2016, http://www.windpowermonthly.com/article/1386985/dismantling-altamont-pass.

94 Share of demand in text and **Figure 29** based on data from the following: **Denmark** (37.6%) share of total electricity consumption, from Energinet.dk, cited in David Weston, "Danish wind share falls in 2016", *Windpower Monthly*, 13 January 2017, http://www.windpowermonthly.com/article/1420900/danish-wind-share-falls-2016. Ireland (27%), Cyprus (19.7%), Spain (19%), Romania (12.5%), Sweden (11.4%), Lithuania (10.6%), Austria (10.4%) and EU (10.4%) all wind penetration rates, from WindEurope, op. cit. note 23, p. 21. WindEurope estimates represent the average of penetration rates captured hourly from ENTSO-E and corrected with data from national TSOs and BEIS, although data were not available for all European countries. In **Spain**, wind power accounted for 18.4% of annual generation, from Red Eléctrica de España, "Estructura de generación anual nacional 2016", 8 March 2017, http://www.ree.es/es/. Portugal (24%) from João Gomes, Associação Portuguesa de Energias Renováveis, personal communication with REN21, April 2017. **Uruguay** (22.8%) from Uruguay Secretary of Energy, Ministry of Industry, Energy and Mining, *Balance Energético Preliminar 2016* (Montevideo: 2017), http://www.dne.gub.uy/web/energia/-/balance-energetico-nacion-1. Wind power accounted for 21.6% of electricity production and 22.8% of electricity consumption in Uruguay, based on data from idem. **Germany** (13%) share of gross electricity consumption, from BMWi, op. cit. note 45, pp. 41-42. Wind power's share of Germany's gross electricity consumption was 10.9% onshore and 2.1% offshore (for total of 13%) in 2016, down from 11.9% onshore and 1.4% offshore (for total of 13.3%), from idem. Wind power accounted for 14.3% of electricity generation (net generation of power plants for public power supply) in Germany during 2016, from Fraunhofer ISE, "Electricity generation in Germany in 2016", updated 12 March 2017, https://www.energy-charts.de/energy_pie.htm. **United Kingdom** (11.1%) share of electricity supplied based on 37,505 GWh (onshore 21,094 GWh and offshore 16,411 GWh) of wind power generation from UK Department for Business, Energy & Industrial Strategy, *National Statistics*, op. cit. note 43, p. 69, and on total UK generation of 338.580 TWh and total supplied was 336.89 TWh, from UK Department for Business, Energy & Industrial Strategy, *National Statistics, Energy Trends Section 5: Electricity*, p. 57, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/604090/Electricity.pdf. **Costa Rica** (10.5%) of electricity demand based on wind generated 1,147,291.27 MWh of electricity during 2016; total electricity production was 10,781,699.03 MWh, and total national electricity demand was 10,932,084.16 MWh. So wind represented 10.5% of total national demand and over 10.6% of national generation, from Instituto Costarricense de Electricidad, *Generación y Demanda Informe Annual Centro Nacional de Control de Energía, 2016* (San José: March 2017), p. 4, https://appcenter.grupoice.com/CenceWeb/AccesoArchivos?pmod=1&pcat=3&ptip=3008&pcod=8. Wind power capacity in the **EU** generated almost 300 TWh during 2016, from GWEC, op. cit. note 1, p. 16.

95 In addition to countries noted above and in Figure 29, countries meeting 5% or more of their annual demand with wind power included Australia, Italy, the United States, Brazil, Belgium, Canada, Poland, Estonia, Turkey, Greece and the Netherlands. Based on data from WindEurope, op. cit. note 23, p. 21; GWEC, op. cit. note 1; CanWEA, "Installed capacity", op. cit. note 33. National Electrical System Operator of Brazil (ONS), "Geração de energia", http://www.ons.org.br/historico/geracao_energia.aspx, viewed 19 March 2017; EIA, op. cit. note 26, Tables 1.3.B and 1.14.B.

96 Over 5.5% based on generation at utility-scale facilities in all economic sectors by wind power and total US power capacity, from EIA, op. cit. note 26, Tables 1.3.B and 1.14.B. Wind power accounted for more than 5% of generation in 20 states, more than 10% in 14 states (up by 2 over 2015), more than 15% in 9 states (up from 8 in 2015) and more than 20% in 5 states (up from 3 in 2015), namely Iowa (36.6%), Kansas (29.6%), South Dakota (30.3%), Oklahoma (25.1%) and North Dakota (21.5%), all from idem.

97 The potential share of wind energy in the net energy consumption of Germany's federal states was 87.8% in Schleswig-Holstein, followed by Mecklenburg-Vorpommern (86.4%), Brandenburg (64.1%), Sachsen-Anhalt (62.7%), Niedersachsen (32.5%) and Thüringen (20.1%), all from Ender, op. cit. note 45, pp. 62, 64. Note that data are not based on actual production (not yet available) but on potential annual yield assuming a normal (100%) wind year, based on average load factors calculated for wind turbines of different power classes for each federal state and on assumption that all wind turbines

reported by year's end contribute to a full annual energy yield. In addition, downtimes due to maintenance, repair, curtailment, etc. are not taken into account, from idem, p. 64.

98 Share of 4% based on global wind power capacity installed at end-2016; on average capacity factors of 22.83% onshore and 36.15% offshore, based on capacity and generation data for 2015, from IEA, *Renewable Energy Medium-Term Market Report 2016* (Paris: 2016), pp. 131 and 163; and on estimated total global electricity generation of 24,756 TWh in 2016. Electricity generation in 2016 based on the following: 24,098 TWh in 2015 from BP, Statistical *Review of World Energy 2016* (London: 2016), and an estimated 2.73% growth in global electricity generation for 2016. For further details, see endnote for Figure 4 in Global Overview chapter. Wind's share was 5%, per WWEA, *WWEA Annual Report 2016* (Bonn: May 2017), http://www.wwindea.org/.

99 Gsänger and Pitteloud, op. cit. note 78; GWEC, op. cit. note 1.

100 See, for example, GE, "GE announces record onshore wind orders for 2016", press release (Paris: 7 February 2017), http://www.genewsroom.com/press-releases/ge-announces-record-onshore-wind-orders-2016-283565, and Vestas, "Vestas Wind Systems A/S: Vestas Annual Report 2016", news wire (Aarhus, Denmark: 8 February 2017), http://www.finanznachrichten.de/nachrichten-2017-02/39871581-vestas-wind-systems-a-s-vestas-annualreport-2016-252.htm. Order intakes increased 17% from 2015 (8,943 MW) to 2016 (10,494 MW), and revenue increased by EUR 1.8 billion to EUR 10.7 billion, from Vestas, op. cit. this note.

101 Turbines are becoming cheaper and their yield is improving, with capacity factors increasing from about 20% in around 2000 to above 30%, and as high as 50% in some locations, from Jessica Shankleman, "Green energy boom picks up speed even as investment stagnates", *Bloomberg*, 11 October 2016, https://www.bloomberg.com/news/articles/2016-10-12/green-energy-boom-picks-up-speed-even-as-investment-stagnates. Competition with natural gas and solar PV, from Eric Lantz, US National Renewable Energy Laboratory (NREL), cited in Jennifer Runyon, "Wind outlook 2017: a solid year despite pockets of global unrest", *Renewable Energy World*, January/February 2017, pp. 20-23.

102 Steve Sawyer, GWEC, personal communication with REN21, 29 October 2015; Bloomberg New Energy Finance (BNEF), "Wind and solar boost cost-competitiveness versus fossil fuels", press release (London and New York: 6 October 2015), http://about.bnef.com/press-releases/wind-solar-boost-cost-competitiveness-versus-fossil-fuels/.

103 DOE, EERE, op. cit. note 71, p. ix; Schwägerl, op. cit. note 67; Frankfurt School-UNEP Collaborating Centre for Climate & Sustainable Energy Finance and BNEF, *Global Trends in Renewable Energy Investment 2017* (Frankfurt: April 2017), p. 17, http://fs-unep-centre.org/sites/default/files/publications/globaltrendsinrenewableenergyinvestment2017.pdf. BNEF estimates that the central LCOE of onshore wind power declined 18% in one year, to USD 68 per MWh in the second half of 2016, and offshore wind was down 28% to USD 126 per MWh in the same time frame.

104 Chile from FTI Consulting, op. cit. note 1, p. 29; India from "India's first wind power auction to upend traditional business model", Bridge to India, February 2017, http://www.bridgetoindia.com/indias-first-wind-power-auction-upend-traditional-business-model/; Mexico and Morocco from Zhao, op. cit. note 40; offshore in Europe from GWEC, op. cit. note 7.

105 Jess Shankleman and Brian Parkin, "Wind power blows through nuclear, coal as costs drop at sea", *Bloomberg*, 8 March 2017, https://www.bloomberg.com/news/articles/2017-03-09/wind-power-blows-through-nuclear-coal-as-costs-plunge-at-sea; GWEC, op. cit. note 1. Brazil, Mexico, Turkey, and parts of Australia, China and the United States from Sawyer, op. cit. note 102, and from Sawyer, op. cit. note 11; Morocco from Steve Sawyer, GWEC, personal communication with REN21, 14 April 2017; Canada from CanWEA, "Wind energy continues rapid growth…", op. cit. note 33; South Africa from GWEC, "Wind energy has saved South Africa R1.8 billion more than it cost for first half of 2015 – and it's cash positive for Eskom", undated, http://www.gwec.net/wind-energy-has-saved-south-africa-r1-8-billion-more-than-it-cost-for-first-half-of-2015-and-its-cash-positive-for-eskom/, and from Joanne Calitz, Crescent Mushwana and Tobias Bischhof-Niemz, "Financial benefits of renewables in Africa in 2015", CSIR Energy Centre, 14 August 2015, http://www.csir.co.za/media_releases/docs/Financial%20benefits%20of%20Wind%20and%20PV%202015.pdf; Chile from "Review of 2016 – part two", *Windpower Monthly*, 31 December 2016, http://www.windpowermonthly.com/article/1419212/review-2016-part-two, and from Tom Azzopardi, "Wind wins again in Chile", *Windpower Monthly*, 18 August 2016, http://www.windpowermonthly.com/article/1406103/wind-wins-again-chile; Europe (Spain) based on Michael McGovern, "Wind was Spain's cheapest power", *Windpower Monthly*, 4 January 2016, http://www.windpowermonthly.com/article/1378082/wind-spains-cheapest-power; onshore wind costs competitive with coal and gas-fired generation in many countries from BNEF, cited in Plamena Tisheva, "Offshore wind costs falling fast – BNEF", Renewables Now, 1 November 2016, https://renewables.seenews.com/news/offshore-wind-costs-falling-fast-bnef-545227, and from Frankfurt School-UNEP Centre and BNEF, op. cit. note 103, p. 19.

106 Frankfurt School-UNEP Centre and BNEF, op. cit. note 103, p. 19.

107 GWEC, op. cit. note 1. Lack of transmission is the biggest long-term barrier for wind energy development in the United States, from Rob Gramlich, AWEA, cited in David A. Lieb, "Renewable energy efforts stymied by transmission roadblocks", *Associated Press*, 22 December 2015, https://apnews.com/0462fcffedd749c2a7e0e729be79d681/renewable-energy-efforts-stymied-transmission-roadblocks. In Brazil, lack of sufficient transmission lines in areas with the greatest wind power potential is a key barrier to development, and Mexico faces transmission-related challenges, from GWEC, *Global Wind Report: Annual Market Update 2015*, op. cit. note 60, pp. 31, 59. For China, see relevant market text and sources. Lack of public acceptance from Fatih Birol, Executive Director, IEA, Foreword in GWEC, *Global Wind Report: Annual Market Update 2015*, op. cit. note 60, p. 7, and in Mexico, among indigenous populations and within natural reserves in particular, from Emilio Soberón, Mexico Low Emission Development Program, US Agency for International Development, personal communication with REN21, April 2017.

108 The amount of electricity curtailed during the year was almost equivalent to that produced from all new installations in 2016, and curtailment consumed the profits that wind farm operators have gained from falling turbine prices, per GWEC, op. cit. note 1, p. 38.

109 China, the EU and the United States from IEA, *World Energy Outlook 2015* (Paris: 2015), p. 346; India had annual turbine production capacity of about 10 GW in early 2017, from FTI Consulting, op. cit. note 1, p. 21. In addition, Brazil has 3-3.5 GW of manufacturing capacity, from Zhao, op. cit. note 40.

110 110 FTI Intelligence, op. cit. note 2; FTI Consulting, op. cit. note 91, pp. 6, 10.

111 Ibid., both references.

112 Ibid., both references. Siemens fell out of the top five for the first time since 2012, and Nordex returned to the top 10 thanks to its acquisition of Acciona, from idem. BNEF published a similar ranking of top companies, with Vestas in the lead followed by GE, Goldwind, Gamesa, Enercon, Nordex, Guodian, Siemens, Ming Yang and Envision, from BNEF, cited in David Weston, "Siemens-Gamesa merger to create a 'big-four' of OEMs", *Windpower Monthly*, 22 February 2017, http://www.windpowermonthly.com/article/1425082/siemens-gamesa-merger-create-big-four-oems; MAKE Consulting also put Vestas in the lead, followed by GE, Goldwind, Gamesa, Siemens, Enercon, Nordex, United Power, Mingyang and Envision, from Joshua S. Hill, "Vestas strengthens grip on top wind turbine manufacturer spot in 2016", CleanTechnica, 3 April 2017, https://cleantechnica.com/2017/04/03/vestas-strengthens-grip-top-wind-turbine-manufacturer-spot-2016/. **Figure 30** based on data from FTI Consulting, op. cit. note 91, pp. 6, 10.

113 FTI Intelligence, op. cit. note 2; FTI Consulting, op. cit. note 91, pp. 6, 10.

114 FTI Consulting, op. cit. note 91, p. 12.

115 Based on data from Ibid., p. 10. Note that the top 15 accounted for over 88% of the total market (based on volumes of MW installed by vendors who sell turbines with rated capacities of at least 200 kW per unit). Also, there were 49 such wind turbine manufacturers producing turbines in 2016. All from idem, pp. 6, 10.

116 Zhao, op. cit. note 40; FTI Consulting, *Global Wind Supply Chain Update 2015* (London: January 2015), Executive Summary, http://www.fticonsulting.com/~/media/Files/us-files/intelligence/intelligence-events/global-wind-supply-chain-update-2015-fti-ppt-final.pdf.

117 "AWEA: Wind power now America's largest renewable energy

resource", 25x'25, Weekly REsource, 10 February 2017; Celeste Wanner, "What's the state of American wind power manufacturing?" AWEA Blog, 30 November 2016, http://www.aweablog.org/whats-state-american-wind-power-manufacturing/. In addition, GRI Renewable Industries opened a new tower facility, from idem.

118 David Weston, "Siemens opens UK blade site", *Windpower Monthly*, 1 December 2016, http://www.windpowermonthly.com/article/1417425/siemens-opens-uk-blade-site; Ivan Shumkov, "Siemens starts building Cuxhaven offshore wind nacelle factory", Renewables Now, 13 June 2016, https://renewablesnow.com/news/siemens-starts-building-cuxhaven-offshore-wind-nacelle-factory-528541/.

119 Siemens, "Siemens to build rotor blade factory for wind turbines in Morocco", press release (Hamburg: 10 March 2016), https://www.siemens.com/press/en/pressrelease/?press=/en/pressrelease/2016/windpower-renewables/pr2016030214wpen.htm&content[]=WP.

120 Senvion acquired Kenersys' (Germany) Indian factory and product portfolio, from David Weston and Sara Knight, "Senvion announces job cuts to secure 'competitiveness'", *Windpower Monthly*, 13 March 2017, http://www.windpowermonthly.com/article/1427097/senvion-announces-job-cuts-secure-competitiveness; David Weston, "Innogy opens Ireland office", *Windpower Monthly*, 27 January 2017, http://www.windpowermonthly.com/article/1422366/innogy-opens-ireland-office; "Dong opens Taiwan base", Renews Biz, 16 November 2016, http://renews.biz/104935/dong-opens-taiwan-base/.

121 FTI Intelligence, op. cit. note 2.

122 Aloys Nghiem, WindEurope, personal communication with REN21, 28 February 2017; Nordex and Acciona Windpower, "Nordex and Acciona Windpower join forces to create a major player in the wind industry", press release (Hamburg: 4 October 2015), http://www.nordex-online.com/en/news-press/news-detail.html?tx_ttnews%5Btt_news%5D=2671&tx_ttnews%5BbackPid%5D=1&cHash=4e2718b412.

123 Jose Elías Rodríguez, "Siemens, Gamesa to form world's largest wind farm business", *Reuters*, 17 June 2016, http://in.reuters.com/article/gamesa-m-a-siemens-idINKCN0Z30OI; "Review of 2016 – part one", *Windpower Monthly*, 23 December 2016, http://www.windpowermonthly.com/article/1419176/review-2016-part-one. The new company had 70 GW of wind capacity in operation, from idem.

124 "Review of 2016 – part two", op. cit. note 105; "Spain's Gamesa buys half of Adwen from Areva for 60 million euros", *Reuters*, 15 September 2016, http://www.reuters.com/article/us-gamesa-m-a-adwen-idUSKCN11L0CN.

125 GE from Rick Clough, "GE agrees to buy blade maker LM WindPower for $1.65 billion", Renewable Energy World, 11 October 2016, http://www.renewableenergyworld.com/articles/2016/10/ge-agrees-to-buy-blade-maker-lm-wind-power-for-1-65-billion.html, and from "Review of 2016 – part two", op. cit. note 105; Senvion from FTI Intelligence, op. cit. note 2; Nordex, "Nordex Group acquires SSP Technology A/S", press release (Hamburg: 1 February 2017), http://www.nordex-online.com/index.php?id=53&L=2&tx_ttnews; Vestas from "Review of 2016 – part one", op. cit. note 123, and from Michelle Froese, "Vestas completes acquisition of Availon", *Windpower Engineering & Development*, 2 March 2016, http://www.windpowerengineering.com/policy/business-issues/mergers-acquisitions/vestas-completes-acquisition-availon/. Another example is blade maintenance specialist GEV (UK), which expanded into the United States to chase the growing O&M market there, from "GEV goes west with US office", Renews Biz, 16 May 2016, http://renews.biz/102683/gev-goes-west-with-us-office/.

126 State-owned Chinese companies from FTI Intelligence, op. cit. note 2. For example, Goldwind acquired another project in the United States (in Texas) as part of a five-year strategy to capitalise on the extension of the US production tax credit, from Goldwind, "Goldwind Americas signs 160 MW Texas deal with RES", press release (Chicago: 17 May 2016), http://www.goldwindamericas.com/goldwind-americas-signs-160-mw-texas-deal-res. EDF from Francois De Beaupuy, "EDF buys 80% stake of UPC AWM to enter Chinese wind market", *Bloomberg*, 12 July 2016, http://www.bloomberg.com/news/articles/2016-07-12/edf-buys-80-stake-of-upc-awm-to-enter-chinese-wind-market.

127 FTI Intelligence, op. cit. note 2.

128 Gsänger and Pitteloud, op. cit. note 78; Ian Clover, "Wind company Suzlon enters India solar market with 210 MW project", *PV Magazine*, 13 January 2016, https://www.pv-magazine.com/2016/01/13/wind-company-suzlon-enters-india-solar-market-with-210-mw-project_100022766/; generation profile from Frankfurt School-UNEP Centre and BNEF, op. cit. note 103, p. 45. Also see, for example, Karl-Erik Stromsta, "Ones to watch: wind and solar joining forces", Recharge News, 4 January 2016, http://www.rechargenews.com/wind/862372/ones-to-watch-wind-and-solar-joining-forces; Frank Jossi, "Nation's first integrated wind and solar project takes shape in Minnesota", *Midwest Energy News*, 2 March 2017, http://midwestenergynews.com/2017/03/02/nations-first-integrated-wind-and-solar-project-takes-shape-in-minnesota/; Kennedy Energy Park, "50MW wind, solar and storage hybrid facility approved", 27 July 2016, http://kennedyenergypark.com.au/news/50mw-wind-solar-and-storage-hybrid-facility-approved; Joshua S. Hill, "Australia moves forward on three wind projects including wind/solar hybrid", CleanTechnica, 27 July 2016, https://cleantechnica.com/2016/07/27/australia-moves-forward-three-wind-projects-including-windsolar-hybrid/; Michael Place, "Engie Brasil 'analyzing' solar-wind hybrid projects", BNAmericas, 28 October 2016, https://www.bnamericas.com/en/news/electricpower/engie-brasil-analyzing-solar-wind-hybrid-projects; Rahul Bhandari, "Solar wind hybrid power project to be set up at Rangrik", *News Himachal*, 18 May 2016, https://www.thenewshimachal.com/2016/05/solar-wind-hybrid-power-project-set-rangrik/. Suzlon and Gamesa, and boost reliability and resource sharing, from Anindya Upadhyay, "Hybrid solar and wind systems attract turbine makers in India", *Bloomberg*, 5 September 2016, https://www.bloomberg.com/news/articles/2016-09-05/hybrid-solar-and-wind-systems-attract-turbine-makers-in-india. For more on hybrid systems, see Frankfurt School-UNEP Centre and BNEF, op. cit. note 103, pp. 44-49.

129 See, for example, "Vattenfall wind farms to use BMW energy storage", *Electric Light & Power*, 16 March 2017, http://www.elp.com/articles/2017/03/vattenfall-wind-farms-to-use-bmw-energy-storage.html; Betsy Lillian, "Flywheel energy storage system addresses wind power volatility", *North American Windpower*, 26 September 2016, http://nawindpower.com/flywheel-energy-storage-system-addresses-wind-power-volatility; Naturspeicher, "Der Naturstromspeicher – unsere unweltfreundlich gross-Batterie", http://www.naturspeicher.de/de/naturstromspeicher.php, viewed 28 April 2017. See also GE Renewable Energy, "Shifting the winds in your favor with energy storage", https://www.gerenewableenergy.com/wind-energy/technology/integrated-energy-storage-for-wind-turbines.html, viewed 28 April 2017.

130 "Gamesa makes offgrid foray", Renews Biz, 10 May 2016, http://renews.biz/102614/gamesa-makes-offgrid-foray/.

131 Susan Kraemer, "Scandinavian offshore wind nixed due to Russian threat", Renewable Energy World, 26 January 2017, http://www.renewableenergyworld.com/articles/2017/01/scandinavian-offshore-wind-nixed-due-to-russian-threat.html; Terry Macalister, "Shell creates green energy division to invest in wind power", *The Guardian* (UK), 15 May 2016, https://www.theguardian.com/business/2016/may/15/shell-creates-green-energy-division-to-invest-in-wind-power; Mikael Holter, "Statoil buys half of $1.4 billion EON German wind project", Renewable Energy World, 25 April 2016, http://www.renewableenergyworld.com/articles/2016/04/statoil-buys-half-of-1-4-billion-eon-german-wind-project.html; Keystone Engineering from Anne-Marie Walters, "Energy from offshore: engineering firm transitions expertise from offshore oil to offshore wind", Renewable Energy World, 22 July 2016, http://www.renewableenergyworld.com/articles/2016/07/energy-from-offshore-engineering-firm-transitions-expertise-from-offshore-oil-to-offshore-wind.html; Jess Shankleman and Brian Parkin, "Wind power blows through nuclear, coal as costs drop at sea", *Bloomberg*, 8 March 2017, https://www.bloomberg.com/news/articles/2017-03-09/wind-power-blows-through-nuclear-coal-as-costs-plunge-at-sea; Jess Shankleman, "Big oil replaces rigs with wind turbines", *Bloomberg*, updated 23 March 2017, https://www.bloomberg.com/news/articles/2017-03-23/oil-majors-take-a-plunge-in-industry-that-may-hurt-fossil-fuel. Shell has continued to own wind farms in the United States and one offshore plant in the Netherlands since an earlier foray into the wind power industry; now the company is returning because of the low price of oil,

from Steve Sawyer, GWEC, personal communication with REN21, April 2017.

132 Barry O'Halloran, "Gaelectric sells wind farms to China General Nuclear Power", *Irish Times*, 7 December 2016, http://www.irishtimes.com/business/energy-and-resources/gaelectric-sells-wind-farms-to-china-general-nuclear-power-1.2897059. Rosatom from FTI Consulting, op. cit. note 1, p. 18.

133 Ray Pelosi, "The next generation in wind power technology", *Renewable Energy World*, March/April 2016, pp. 26-30; Jan Behrendt Ibsoe, "Editorial", *DEWI Magazin*, March 2017, pp. 3-4, http://www.dewi.de/dewi_res/fileadmin/pdf/publications/Magazin_50/DM_50_lowres.pdf. Also, optimise and grid codes from Tildy Bayar, "Wind turbine manufacturers consider new drivetrain in technology", Renewable Energy World, 16 September 2015, http://www.renewableenergyworld.com/articles/print/volume-18/issue-9/features/wind/wind-turbine-manufacturers-consider-new-drivetrain-technology.

134 Sawyer, op. cit. note 15; Vestas, "The windiest place on earth", YouTube video, 9 March 2017, https://www.youtube.com/watch?v=pYsaQflII8U; Vestas, "The true pioneer of wind industry – emerging markets", https://www.vestas.com/en/about/pioneering%20the%20industry#!, viewed 21 March 2017.

135 "Noise tails off for Siemens", Renews Biz, 27 September 2016, http://renews.biz/104328/noise-tails-off-forsiemens/; Eize de Vries, "Exclusive: Vestas tests four-rotor concept turbine", *Windpower Monthly*, 20 April 2016, http://www.windpowermonthly.com/article/1391775/exclusive-vestas-tests-four-rotor-concept-turbine; David Weston, "First power from Vestas four-rotor concept", *Windpower Monthly*, 4 July 2016, http://www.windpowermonthly.com/article/1401013/first-power-vestas-four-rotor-concept.

136 FTI Intelligence, op. cit. note 2.

137 GE, "GE Renewable Energy introduces new suite of digital wind farm apps", press release (New Orleans: 24 May 2016), http://www.genewsroom.com/press-releases/ge-renewable-energy-introduces-new-suite-digital-wind-farm-apps-282970; Vestas and Envision, from FTI Intelligence, op. cit. note 2; Goldwind, "Goldwind announces new GW3S Smart Wind Turbine", press release (Beijing: 15 November 2016), http://www.prnewswire.com/news-releases/goldwind-announces-new-gw3s-smart-wind-turbine-300362605.html.

138 Runyon, op. cit. note 101, pp. 20-23; DOE, EERE op. cit. note 71, p. vii; FTI Consulting, *Global Wind Market Update – Demand & Supply 2015 – Technology Overview* (London: 2016).

139 Significantly higher capacity factors from DOE EERE, op. cit. note 71, p. viii; new opportunities from IEA, op. cit. note 109, p. 346. In the United States, rotor diameters, turbine nameplate capacity and hub height have increased significantly over the years; the average capacity factor in 2015 of projects built in 2014 reached 41.2%, compared to an average 31.2% among projects built during the period 2004-2011, from DOE, EERE, op. cit. note 71, p. viii. Hub heights and rotor diameters have been increasing in Germany as well, from Deutsche WindGuard, *Status of Land-Based Wind Energy Development in Germany 2016*, op. cit. note 45.

140 Data from Associação Brasileira de Energia Eólica (ABEEólica), "Dados mensais", February 2017, http://www.abeeolica.org.br/wp-content/uploads/2017/02/Dados-Mensais-ABEEolica-02.2017.pdf, and provided by Camila Ramos, CELA, Brazil, personal communication with REN21, 27 April 2017. In the United States, wind turbines built during 2014 and 2015 achieved capacity factors greater than 40% in 2016, from John Hensley, "Top 11 wind energy trends of 2016", AWEA Blog, 19 April 2017, http://www.aweablog.org/top-11-wind-energy-trends-2016.

141 Enercon launched its 4.2 MW E141 model with diameter of 141 metres, from EurObserv'ER, op. cit. note 1, p. 13; GE, "GE expands onshore wind portfolio with North American version of new 3.4 MW wind turbines", press release (New Orleans: 23 May 2016), https://www.genewsroom.com/press-releases/ge-expands-onshore-wind-portfolio-north-american-version-new-34-mw-wind-turbines; Nordex released two versions (low-wind and moderate-wind) of a new 3.6 MW turbine, from David Weston, "Nordex unveils 3.6MW turbine", *Windpower Monthly*, 3 August 2016, http://www.windpowermonthly.com/article/1404432/nordex-unveils-36mw-turbine, and from Nordex, "Nordex: N117/3600 and N131/3600 produce up to 12% higher yield at sites with moderate and light winds", press release (Hamburg: 3 August 2016), http://www.nordex-online.com/index.php?id=53&L=2&tx_ttnews; Senvion, "Senvion announces its highest yield turbine for North America", press release (Denver/New Orleans: 23 May 2016), https://www.senvion.com/global/en/newsroom/press-releases/detail/senvion-announces-its-highest-yield-turbine-for-north-america-6/; Senvion, "Senvion unveils turbine with 3.6 megawatt power upgrade for sites with medium wind speeds", press release (Hamburg: 27 September 2016), https://www.senvion.com/global/en/newsroom/press-releases/detail/senvion-unveils-turbine-with-36-megawatt-power-upgrade-for-sites-with-medium-wind-speeds/; MHI Vestas was developing its 8 MW V164 model with diameter of 164 metres, and Siemens was selling its 7 MW SWT 7.0 with diameter of 154 metres for offshore use, from EurObserv'ER, op. cit. note 1, p. 13; Siemens also unveiled an 8 MW turbine for offshore use, from Joshua S. Hill, "Siemens unveils new 8 MW offshore wind turbine", CleanTechnica, 6 July 2016, https://cleantechnica.com/2016/07/06/siemens-unveils-new-8-mw-offshore-wind-turbine/.

142 FTI Intelligence, op. cit. note 2. See, for example, Vestas, "Products", https://www.vestas.com/en/products/turbines, viewed 20 March 2017; GE, op. cit. note 141.

143 Average turbine size delivered to market (considering vendors who sold turbines with rated capacities of at least 200 kW per unit), from FTI Consulting, op. cit. note 91, p. 26. In 2014, the average size delivered to market was 1,981 kW, from Feng Zhao et al., *Global Wind Market Update – Demand & Supply 2014* (London: FTI Consulting LLP, March 2015), p. xiii. Average size delivered to market (based on measured rated capacity) was 1,926 kW in 2013, from Navigant Research, *World Market Update 2013: International Wind Energy Development. Forecast 2014-2018* (Copenhagen: March 2014), Executive Summary.

144 FTI Consulting, op. cit. note 91, p. 27. Averages were 2,800 MW in "other", which included the Middle East and CIS countries; 2,666 MW in Europe; 2,284 MW in Latin America; 2,106 MW in North America; 1,966 MW in Asia-Pacific, and 1,979 MW in Africa, from idem. The average capacity of turbines installed in Germany in 2016 increased to 2.848 MW onshore and 5.244 MW offshore, from Deutsche WindGuard, *Status of Land-Based Wind Energy Development in Germany 2016*, op. cit. note 45, and from Deutsche WindGuard, *Status of Offshore Wind Energy Development in Germany 2016*, op. cit. note 45. The average capacity of turbines (onshore and offshore) installed in Germany was 3.0306 MW, from Ender, op. cit. note 45, p. 58. Sweden, Finland and Austria exceeded the 3 MW threshold in 2016, from Nghiem, op. cit. note 46.

145 FTI Consulting, op. cit. note 91, p. 28. Their share was 62.6%, from idem.

146 Brent Cheshire, "Offshore wind playing a lead role in UK green energy transformation", Renewable Energy World, 13 October 2015, http://www.renewableenergyworld.com/articles/2015/10/offshore-wind-playing-a-lead-role-in-the-u-k-s-green-energy-transformation.html. European offshore wind farm size increased another 12% in 2016, relative to 2015, to 380 MW; in 2006, the average project size was 46.3 MW, all from WindEurope, op. cit. note 65.

147 WindEurope, op. cit. note 65, pp. 15, 27. The average size of turbines installed offshore in Germany during 2016 was 5,244 kW, up 27% over 2015 (4,318 kW), from Deutsche WindGuard, *Status of Offshore Wind Energy Development in Germany 2016*, op. cit. note 45. Second half of 2016 from Nghiem, op. cit. note 122.

148 On the market or nearly commercial from Runyon, op. cit. note 101, pp. 20-23; grid connected from WindEurope, op. cit. note 65, from William Steel, "First commercial power achieved from MHI Vestas' Mammoth 8-MW Turbines", Renewable Energy World, 20 December 2016, http://www.renewableenergyworld.com/articles/2016/12/first-commercial-power-achieved-from-mhi-vestas-mammoth-8-mw-turbines.html, and from MHI Vestas Offshore Wind, "First V16408.0 turbine installed at Burbo Bank Extension", press release (Aarhus, Denmark: 8 September 2016), http://www.mhivestasoffshore.com/first-v164-8-0-mw-turbine-installed-burbo-bank-extension-2/.

149 MHI Vestas Offshore Wind, "World's most powerful wind turbine once again smashes 24 hour power generation record as 9 MW wind turbine is launched", press release (Aarhus, Denmark: 26 January 2017), http://www.mhivestasoffshore.com/new-24-hour-record/.

150 Giorgio Corbetta, EWEA, personal communication with REN21,

20 March 2015; Steve Sawyer, Foreword in Shruti Shukla, Paul Reynolds and Felicity Jones, *Offshore Wind Policy and Market Assessment: A Global Outlook* (New Delhi: GWEC, December 2014), p. 4, http://www.gwec.net/wp-content/uploads/2015/02/FOWIND_offshore_wind_policy_and_market_assessment_15-02-02_LowRes.pdf.

151 FTI Consulting, op. cit. note 91, pp. 7, 22.

152 WindEurope, op. cit. note 65, p. 22.

153 Daniel Cusik, "Offshore wind is almost a go, but challenges remain", *E&E News*, 31 May 2016, http://www.eenews.net/climatewire/2016/05/31/stories/1060038068.

154 WindEurope, op. cit. note 65. The distance from shore and water depth of projects under construction in Europe during 2016 averaged 44 kilometres (up from 43.4 kilometres in 2015) and 29 metres (up from 27.2 metres), respectively, and the average size of projects under construction increased by 12% over 2015, to 380 MW, from idem, p. 15.

155 Data are based on number of individual foundations installed in 2016, from WindEurope, op. cit. note 65, p. 13.

156 Jennifer Delony, "Foundation first: Designing offshore wind turbine substructures for maximum cost reduction", Renewable Energy World, 21 December 2016, http://www.renewableenergyworld.com/articles/print/volume-19/issue-10/features/wind/foundation-first-designing-offshore-wind-turbine-substructures-for-maximum-cost-reduction.html.

157 Several companies are working on floating turbines and projects. For example, GE and naval shipbuilding company DCNS (France) are collaborating to develop floating wind farms, from Mark Egan, "Ship shape: this floating offshore wind farm could be the future of renewable energy", GE Reports, 30 August 2016, http://www.gereports.com/ship-shape-this-floating-offshore-wind-farm-could-be-the-future-of-renewable-energy/; Joshua S. Hill, "GE labels floating offshore wind turbines the renewable energy of the future", CleanTechnica, 1 September 2016, https://cleantechnica.com/2016/09/01/ge-labels-floating-offshore-wind-turbines-renewable-energy-future/; Swedish floating wind technology firm SeaTwirl AB plans to develop a full-scale 1 MW vertical axis wind turbine, from Tsvetomira Tsanova, "Swedish IPO to support vertical axis floating wind tech", Renewables Now, 28 November 2016, https://renewablesnow.com/news/swedish-ipo-to-support-vertical-axis-floating-wind-tech-548618/; DCNS (France) and New England Aqua Ventus (United States) announced plans for a 12 MW pilot floating project off the US state of Maine, from Mariyana Yaneva, "French DCNS joins floating offshore wind project in USA", Renewables Now, 6 June 2016, http://renewables.seenews.com/news/french-dcns-joins-floating-offshore-wind-project-in-usa-527718.

158 Ueda, op. cit. note 70; Fukushima Floating Offshore Wind Farm Demonstration Project, "The installation of 'Fukushima Hamakaze' in the testing area", 1 August 2016, http://www.fukushima-forward.jp/english/news_release/news160801.html; "Fukushima floating offshore wind power project", *GWEC Newsletter*, March 2016; Geert de Clercq, "Quadran, Eolfi-CGN wind French floating offshore tenders", *Reuters*, 25 July 2016, http://www.reuters.com/article/france-windpower-offshore-idUSL8N1AB2NE; William Steel, "France gears up for floating wind", Renewable Energy World, 23 November 2016, http://www.renewableenergyworld.com/articles/2016/11/france-gears-up-for-floating-wind.html; Jennifer Johnson, "France awards two floating wind farm tenders", Energy Digital, 25 July 2016, http://www.energydigital.com/renewableenergy/4195/France-awards-two-floating-wind-farm-tenders.

159 Chisaki Watanabe, "Japan expanding floating wind farm amid intensifying global race", *Bloomberg*, 24 August 2016, http://www.bloomberg.com/news/articles/2016-08-24/japan-expanding-floating-wind-farm-amid-intensifying-global-race; Statoil, "Our offshore wind projects", https://www.statoil.com/en/what-we-do/new-energy-solutions/our-offshore-wind-projects.html, viewed 20 March 2017; Diane Cardwell, "Offshore wind farms see promise in platforms that float", *New York Times*, 29 September 2016, http://www.nytimes.com/2016/09/30/business/energy-environment/offshore-wind-farms-see-promise-in-platforms-that-f.html; Jess Shankleman, "Race to build offshore wind farms that float on sea gathers pace", *Bloomberg*, 17 March 2017, https://www.bloomberg.com/news/articles/2017-03-17/race-to-build-offshore-wind-farms-that-float-on-sea-gathers-pace.

160 DONG Energy, "World's first radar for offshore wind power now delivers data", press release (Fredericia, Denmark: 21 September 2016), http://www.dongenergy.com/en/media/newsroom/news/articles/first-data-BEACon-radar; Sawyer, op. cit. note 15.

161 William Steel, "Siemens celebrates topping out ceremony at new wind turbine factory in Cuxhaven, Germany", Renewable Energy World, 19 December 2016, http://www.renewableenergyworld.com/articles/2016/12/siemens-celebrates-topping-out-ceremony-at-new-wind-turbine-factory-in-cuxhaven-germany.html. In early 2017, Siemens started construction of a transport ship for towers and blades, from idem.

162 Faster than expected, from Tisheva, op. cit. note 105; Susan Kraemer, "How DONG Energy bid offshore wind at just 8 cents", Renewable Energy World, 14 September 2016, http://www.renewableenergyworld.com/articles/2016/09/how-dong-energy-bid-offshore-wind-at-just-8-cents.html; Ibsoe, op. cit. note 133, pp. 3-4. The LCOE for offshore wind energy declined to approximately USD 0.06 per kWh for Horns Rev, Borssele 3&4 and Kriegers Flak tenders in Europe during 2016. This new LCOE level not only reduced the price of offshore wind energy by 50%, it also put the technology on the point of the price curve that was not forecasted to be reached before 2020-21, from Ibsoe, op. cit. note 133, pp. 3-4. Drivers from EurObserv'ER, op. cit. note 1, p. 13; GWEC, op. cit. note 1, p. 59; Kraemer, op. cit. note 162; increased competition from Catapult, *Cost Reduction Monitoring Framework 2016*, Executive Summary (Glasgow: January 2017), prepared for UK Offshore Wind Programme Board, https://s3-eu-west-1.amazonaws.com/media.ore.catapult/wp-content/uploads/2017/01/24082709/CRMF-2016-Summary-Report-Print-Version.pdf; technical improvements from "Siemens aims for € 0.08/kWh", Renews Biz, 22 June 2016, http://renews.biz/103138/siemens-aims-for-008kwh/. Some developers are achieving lower costs of capital by using project finance with high (up to 80%) debt ratios, from International Renewable Energy Agency (IRENA), *Innovation Outlook: Offshore Wind* (Abu Dhabi: October 2016), p. 54, http://www.irena.org/DocumentDownloads/Publications/IRENA_Innovation_Outlook_Offshore_Wind_2016.pdf.

163 "Offshore wind can match coal, gas for value by 2025-RWE, E.ON, GE, others", *Reuters*, 6 June 2016, http://af.reuters.com/article/energyOilNews/idAFL8N18Y16U?sp=true. The countries included France, Germany and Sweden, and the companies included RWE, E.On, Siemens (all Germany), Statoil (Norway), Vattenfall (Sweden) and GE (United States), from idem.

164 Nghiem, op. cit. note 122; GWEC, op. cit. note 1, p. 59; Schwägerl, op. cit. note 67; "Review of 2016 – part two", op. cit. note 105. Note that these bids excluded grid connection costs (estimated at around EUR 14 per MWh) and the projects are relatively close to shore, from FTI Consulting, op. cit. note 1, p. 32. The Dutch tender for Borssele 1 & 2 in June 2016 came in at EUR 72 per MWh, followed by a Danish nearshore tender in September, at EUR 64 per MW; in November, another Danish tender, at Krieger's Flak, saw a winning bid of EUR 49.9 per MWh, followed by another Dutch tender in December for Borssele 3 & 4, which came in at EUR 54.5 per MWh, all from GWEC, op. cit. note 1, p. 59.

165 Catapult, op. cit. note 162.

166 Orrell et al., 2015 *Distributed Wind Market Report*, op. cit. note 83, pp. i, 22-23, 25. Capacity-weighted average installed costs of 1.6 MW of new small-scale turbines sold in the United States in 2015 was USD 5,760 per kW, down from USD 6,230 per kW in 2014 (based on 2.8 MW of sales) and USD 6,940 per kWh in 2013 (based on 5 MW of sales). The estimated capacity-weighted average capacity factor in 2015 was 32% (based on a sample size of 3.6 MW from 66 projects in 12 US states), up from 25% in 2013-2014 (based on 19.MW in 120 projects across 15 US states), all from idem.

167 Orrell et al., *2015 Distributed Wind Market Report*, op. cit. note 83, p. 18. See, for example, Michelle Froese, "Leasing options for small wind energy", Windpower Engineering & Development, 3 March 2016, http://www.windpowerengineering.com/policy/financing/leasing-options-small-wind-power/; Polaris, "Leasing", http://www.polarisamerica.com/wind-basics/financial/leasing/, viewed 31 March 2016; Navigant Research, "Market Data: small and medium wind turbines: demand drivers, market trends and challenges, and global market forecasts", 2017, http://www.navigantresearch.com/research/market-data-small-and-medium-wind-turbines, viewed 17 March 2017.

168 United Wind, "United Wind closes $8M in Series B funding", press release (Brooklyn, NY: 7 March 2016), http://unitedwind.com/category/press-releases/; Northern Power Systems from

Orrell et al., *2015 Distributed Wind Market Report*, op. cit. note 83, p. 18.

169 Orrell et al., *2015 Distributed Wind Market Report*, op. cit. note 83, p. 18.

170 Based on data for 2014 and 2015 (more recent data not available), from WWEA, op. cit. note 81, Summary. In the United Kingdom there were about 15 small and medium (up to 225 kW) wind turbine manufacturers as of late 2014 or early 2015, from RenewableUK, op. cit. note 81, p. 19.

171 CWEEA, op. cit. note 81, pp. 6-7, http://www.wwindea.org/wwea-bulletin-issue-2-2016-small-wind-special/; Orrell et al., 2015 Distributed Wind Market Report, op. cit. note 83, p. ii; Navigant Research, op. cit. note 167. In the United States, 31 companies reported sales in 2012, 16 companies in 2013, 11 in 2014, and 10 (eight domestic manufacturers and two importers) in 2015; in addition, foreign manufacturers have lost interest in the United States due to the expiration of important federal incentives, all from Orrell et al., *2015 Distributed Wind Market Report*, op. cit. note 83, p. ii.

172 "Endurance Wind UK goes bust", Renews Biz, 1 December 2016, http://renews.biz/105114/endurance-wind-ukgoes-bust/; UK sales accounted for up to 90% of the company's revenue, from idem.

173 Orrell et al., *2015 Distributed Wind Market Report*, op. cit. note 83, pp. I, 8, 9.

174 CWEEA, op. cit. note 81, pp. 6-7.

175 **Sidebar 2** and **Table 2** from the following sources: all data come from IRENA's Renewable Cost Database of 15,000 utility-scale renewable power generation projects and 1 million small-scale solar PV systems. A real weighted average cost of capital of 7.5% is assumed for the OECD and China, and 10% for all other countries. For details of the other underlying assumptions and the project-level data for installed costs, capacity factors and LCOE, see IRENA, *Renewable Power Generation Costs in 2016* (Abu Dhabi: 2017), www.irena.org/costs. For solar PV's rapid decline, see IRENA, *The Power to Change: Solar and Wind Cost Reduction Potential to 2025* (Abu Dhabi: 2017), http://www.irena.org/DocumentDownloads/Publications/IRENA_Power_to_Change_2016.pdf.

DISTRIBUTED RENEWABLE ENERGY FOR ENERGY ACCESS

1 Cost savings from PwC Global Power & Utilities, *Electricity Beyond the Grid: Accelerating Access to Sustainable Power for All* (May 2016), p. 6, https://www.pwc.com/gx/en/energy-utilities-mining/pdf/electricity-beyond-grid.pdf; fuel and prices from International Finance Corporation (IFC), *Off-Grid Solar Market Trends Report 2016* (Washington, DC: February 2016), p. 6, http://www.energynet.co.uk/webfm_send/1690; modularity, flexibility and construction times from Andrew Meyer, "Why a distributed energy grid is a better energy grid", Swell Energy, 20 May 2016, https://www.swellenergy.com/blog/2016/05/20/why-a-distributed-energy-grid-is-a-better-energy-grid; learning curves and rates of improvement from Kartikeya Singh, "Business innovation and diffusion of off-grid solar technologies in India", *Energy for Sustainable Development*, vol. 30 (2016), pp. 1-13; reliability and resilience from Siddharth Suryanarayanan and Elias Kyriakides, "Microgrids: an emerging technology to enhance power system reliability", IEEE Smart Grid Newsletter Compendium, *Smart Grid*: *The Next Decade*, March 2012, http://resourcecenter.smartgrid.ieee.org/sg/product/publications/SGNL0057; improved health from World Health Organization, "Household Air Pollution and Health", fact sheet (Geneva: February 2016), http://www.who.int/mediacentre/factsheets/fs292/en/, and from Narasimha D. Rao, Anjana Agarwal and Davida Wood, *Impacts of Small-scale Electricity Systems: A Study of Rural Communities in India and Nepal* (Washington, DC: World Resources Institute, 2016), pp. 38-39, http://www.wri.org/sites/default/files/Impacts_of_Small-Scale_Electricity_Systems.pdf; climate change from Ottmar Edenhofer et al., eds., "IPCC 2011 Summary for Policymakers", in *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation* (Cambridge, UK: Cambridge University Press, 2011), p. 65, https://www.ipcc.ch/pdf/special-reports/srren/SRREN_FD_SPM_final.pdf; deforestation and environment from Global Alliance for Clean Cookstoves (GACC), "Fighting deforestation with cleaner cookstoves and fuels", 2 November 2016, http://cleancookstoves.org/about/news/11-02-2016-fighting-forest-degradation-with-cleaner-cookstoves-and-fuels.html; women's empowerment from Yongping Zhai, "4 ways to empower Asian women through energy access," Asian Development Bank (ADB), 12 January 2016, https://blogs.adb.org/blog/4-ways-empower-asian-women-through-energy-access, and from Katherine Lucey, "Women's energy entrepreneurship: empowering women and scaling access to energy", Solar Sister, 24 March 2016, https://www.solarsister.org/blog/womens-energy-entrepreneurship-empowering-women-and-scaling-access-toenergy; poverty reduction from Msolo Onditi, Irene Garcia and Anna Leidreiter, *100% Renewable Energy and Poverty Reduction in Tanzania* (Hamburg, Germany: World Future Council, April 2016), p. 7, https://www.worldfuturecouncil.org/file/2016/04/WFC_2016_100RE_and_poverty_reduction_in_Tanzania.pdf, and from Upendra Shrestha, "Knowledge for resilient livelihoods – Bidhya's story", Practical Action, 27 April 2016, http://practicalaction.org/blog/2016/04/.

2 Most recent data are from 2014. International Energy Agency (IEA), "Chapter 2 Extract: Energy Access", in *World Energy Outlook 2016* (Paris: 2016), pp. 92-93, http://www.worldenergyoutlook.org/media/weowebsite/energymodel/documentation/WEO2016_Chapter02_acces.pdf.

3 IEA, World Energy Outlook 2016 Biomass database, http://www.worldenergyoutlook.org/resources/energydevelopment/energyaccessdatabase/, viewed 8 March 2017.

4 Data from IEA, *World Energy Outlook 2016* (Paris: 2016). **Figure 31** from IEA, World Energy Outlook 2016 Electricity Access database, http://www.worldenergyoutlook.org/resources/energydevelopment/energyaccessdatabase/, viewed 8 March 2017; **Figure 32** from IEA, op. cit. note 3.

5 IEA, World Energy Outlook 2016 Electricity Access database, op. cit. note 4, viewed 8 March 2017.

6 Millennium Resource Strategies Limited, *Implementing Renewable Energy Initiatives in Africa* (Abidjan, Côte d'Ivoire: October 2015), p. 4, https://www.icafrica.org/fileadmin/documents/2015/Annual_Meeting/ICA_Plenary_-_Background_Paper__FINAL_2_.pdf.

7 Electrification rate from IEA, World Energy Outlook 2016 Electricity Access database, op. cit. note 4, viewed 8 March 2017; power system size from Anton Eberhard et al., *Independent Power Projects in Sub-Saharan Africa – Lessons from Five Key Countries* (Washington, DC: World Bank, 2016), p. 11, https://openknowledge.worldbank.org/bitstream/handle/10986/23970/9781464808005.pdf.

8 IFC, *Sub-Saharan Africa (SSA) Power Sector Strategy* (Washington, DC: October 2016), p. 6, http://www.minambiente.it/sites/default/files/archivio/allegati/sviluppo_sostenibile/SSA_Power_strategy.pdf.

9 IEA, op. cit. note 3.

10 IEA, World Energy Outlook 2016 Electricity Access database, op. cit. note 3, viewed 16 February 2017.

11 IEA, op. cit. note 3.

12 Ibid.

13 Ibid.

14 Ibid.

15 IEA, World Energy Outlook 2016 Electricity Access database, op. cit. note 4, viewed 8 March 2017.

16 Ibid.; IEA, op. cit. note 3; Elisa Portale and Joeri de Wit, *Tracking Progress Toward Providing Sustainable Energy for All in Middle East and North Africa* (Washington, DC: World Bank, 2014), https://openknowledge.worldbank.org/bitstream/handle/10986/20251/908890BRI0Box300note0series02014031.pdf?sequence=5; IFC, op. cit. note 8.

17 IEA, World Energy Outlook 2016 Electricity Access database, op. cit. note 4.

18 IEA, op. cit. note 3.

19 IFC, op. cit. note 8.

20 Independent Evaluation Group of the World Bank, *Reliable and Affordable Off-Grid Electricity Services for the Poor: Lessons from World Bank Group Experience* (Washington, DC: November 2016), p. 5, http://ieg.worldbankgroup.org/Data/reports/lp_off-grid_electricity_1116.pdf.

21 Bloomberg New Energy Finance (BNEF) and Lighting Global, *Off-grid Solar Market Trends Report* (London: February 2016), p. 1, https://data.bloomberglp.com/bnef/sites/4/2016/03/20160303_BNEF_WorldBankIFC_Off-GridSolarReport_.pdf.

22 Lighting Global and Global Off-Grid Lighting Association (GOGLA), *Global Off-Grid Solar Market Report: Semi-Annual Sales and Impact Data, January-June 2016* (Utrecht, The Netherlands: October 2016), p. 8, https://www.gogla.org/sites/default/files/documenten/final_sales-and-impact-report_h22016_full_public.pdf; GOGLA, *Global Off-Grid Solar Market Report: Semi-Annual Sales and Impact Data, July-December 2016* (Utrecht, The Netherlands: May 2017), pp. 8-9, https://www.gogla.org/sites/default/files/recource_docs/final_sales-and-impact-report_h22016_full_public.pdf.

23 GOGLA, Global Off-Grid Solar Market Report: Semi-Annual Sales and Impact Data, July-December 2016 (Utrecht, The Netherlands, 2017), https://www.gogla.org/sites/default/files/recource_docs/final_sales-and-impact-report_h22016_full_public.pdf; BNEF, "Off-Grid Solar Market Trends Report 2016", 23 February 2017, https://about.bnef.com/blog/off-grid-solar-market-trends-report-2016/.

24 Ibid.

25 BNEF and Lighting Global, op. cit. note 21. **Figure 33** from GOGLA, op. cit. note 23.

26 GOGLA, op. cit. note 23.

27 International Renewable Energy Agency (IRENA), "International off-grid renewable energy conference highlights changing energy access narrative", 10 January 2016, https://irenanewsroom.org/2016/10/01/international-off-grid-renewable-energy-conference-highlights-changing-energy-access-narrative/.

28 Lighting Global and GOGLA, op. cit. note 22, both sources.

29 Ibid.

30 Ibid., p. 14. GOGLA, op. cit. note 23.

31 BNEF and Lighting Global, op. cit. note 21, pp. 14-18.

32 Ibid.; Lighting Global and GOGLA, op. cit. note 22, p. 21. GOGLA, op. cit. note 23.

33 Alternative Energy Tutorials, "Pico solar systems", http://www.alternative-energy-tutorials.com/energyarticles/pico-solar-systems.html, updated January 2017.

34 In 2016, the 1.2 billion people living without access to the power grid spent about USD 27 billion annually on lighting and mobile phone charging with kerosene, candles, battery torches or other fossil fuel-powered stopgap (improvised substitutes) technologies, for which pico-solar technologies offer a substitute. BNEF and Lighting Global, op. cit. note 21.

35 Ibid.

36 Ibid; GOGLA, op. cit. note 23.

37 IFC, op. cit. note 8, p. 33. GOGLA, op. cit. note 23.

38 BNEF and Lighting Global, op. cit. note 21.

39 Ibid.

40 Alliance for Rural Electrification, *Rural Electrification with Renewable Energy* (Brussels: 2011), p. 10, https://www.ruralelec.org/sites/default/files/are_technological_publication_0.pdf.

41 IRENA, *Off-Grid Renewable Energy Systems: Status and Methodological Issues* (Abu Dhabi: 2015), p. 25, http://www.irena.org/DocumentDownloads/Publications/IRENA_Off-grid_Renewable_Systems_WP_2015.pdf.

42 BNEF and Lighting Global, op. cit. note 21, p. 9.

43 BNEF, *How Can Pay-As-You-Go Solar Be Financed?* (London: 7 October 2016), p. 1, https://data.bloomberglp.com/bnef/sites/4/2016/10/BNEF_WP_2016_10_07-Pay-as-you-go-solar.pdf.

44 IRENA, *Solar PV in Africa: Costs and Markets* (Abu Dhabi: September 2016), p. 9, https://www.irena.org/DocumentDownloads/Publications/IRENA_Solar_PV_Costs_Africa_2016.pdf.

45 Preliminary data from World Wind Energy Association, *Small Wind World Report 2017* (Bonn: forthcoming June 2017), Summary, http://www.wwindea.org/.

46 Netherlands Development Organisation (SNV), "Biogas", http://www.snv.org/sector/energy/topic/biogas, viewed 16 February 2017.

47 "Advances in microhydro technology make home power affordable", *Electrical Contractor*, December 2009, http://www.ecmag.com/section/miscellaneous/advances-microhydro-technology-make-home-power-affordable.

48 Pushkar Manandhar, Nepal Resident Mission, ADB, "Mini-grid Development in Nepal: Approaches, Key Challenges and Requirements", presentation, 9 June 2016, slide 2, https://d2oc0ihd6a5bt.cloudfront.net/wp-content/uploads/sites/837/2016/04/4-Pushkar-Manandhar.pdf.

49 Michael Harris, "ADB financing could add up to 1,000 micro-hydropower plants in Pakistan's Khyber Pakhtunkhwa", HydroWorld, 5 December 2016, http://www.hydroworld.com/articles/2016/12/adb-financing-could-add-up-to-1-000-micro-hydropower-plants-in-pakistan-s-khyber-pakhtunkhwa.html. The northern part of the country already has 24 MW installed, per Abdur Reyman Cheema, "Hurry up with the micro hydro", *The Third Pole*, 19 July 2016, https://www.thethirdpole.net/2016/07/19/hurry-up-with-the-micro-hydro/.

50 Global Lighting and Energy Access Partnership (LEAP), *The State of the Off-Grid Appliance Market* (Washington, DC: 2016); Lighting Global and GOGLA, op. cit. note 22.

51 **Sidebar 3** from the following sources: economics of energy access from Shonali Pachauri, Diana Ürge-Vorsatz and Michael LaBelle, "Synergies between energy efficiency and energy access policies and strategies", *Global Policy*, vol. 3, iss. 2 (2012), pp. 187-97, http://onlinelibrary.wiley.com/doi/10.1111/j.1758-5899.2011.00165.x/abstract; 50-85% less energy from Stewart Craine, Evan Mills and Justin Guay, *Clean Energy Services for All: Financing Universal Electrification* (San Francisco, CA: The Sierra Club, 2014), p. 2, https://www.sierraclub.org/sites/www.sierraclub.org/files/0747_Clean_Energy_Services_Report_03_web.pdf, and from World Bank, *EA+EE: Enhancing the World Bank's Energy Access Investments Through Energy Efficiency* (Washington, DC: 2015), p. 23, http://documents.worldbank.org/curated/en/875391468186565552/pdf/98193-WP-P151483-Box391505B-PUBLIC-World-Bank-EA-EE-Enhancing-WBs-Energy-Access-Investments-Through-Energy-Efficiency-FINAL-25-June-2015.pdf; energy efficiency enabling DRE systems to deliver services from Energy and Environment Partnership, *Energy Efficiency in EEP S&EA* (Pretoria, South Africa: 2016), http://eepafrica.org/wp-content/uploads/EE_Overview.pdf; most economical option from IRENA, *Accelerating Off-grid Renewable Energy, International Off-grid Renewable Energy Conference 2014: Key Findings and Recommendations* (Abu Dhabi: 2014), http://www.irena.org/documentdownloads/publications/iorec/iorec_2014_key_findings.pdf; Bangladesh from S. M. Najmul Hoque and Barun Kumar Das, "Analysis of cost, energy and CO2 emission of solar home systems in Bangladesh", *International Journal of Renewable Energy Research*, vol. 3, no. 2 (2013), https://www.researchgate.net/publication/271079170_Analysis_of_Cost_Energy_and_CO2_Emission_of_Solar_Home_Systems_in_Bangladesh; LED technologies from Amol Phadke et al., *Powering a Home with Just 25 Watts of Solar PV: Super-Efficient Appliances Can Enable Expanded Energy Access Using Off-Grid Solar Power Systems* (Berkeley, CA: Lawrence Berkeley National Laboratory, 2015), p. 4, http://www.cleanenergyministerial.org/Portals/2/pdfs/GlobalLEAP-PoweringAHome.pdf; LED sales from GOGLA, *Global Off-Grid Solar Market Report* (Utrecht, The Netherlands: June 2016), p. 8, https://www.gogla.org/sites/default/files/recource_docs/global_off-grid_solar_market_report_jan-june_2016_public.pdf; activities taken too late from Pachauri, Ürge-Vorsatz and LaBelle, op. cit. this note; largest numbers at least cost from World Bank, op. cit. this note; lack of expertise and information from Global LEAP, op. cit. note 50; the increased expert focus included an expert panel held at the Energy Efficiency Global Forum in Washington, DC in 2016 and a series of reports and webinars that have elevated the discussion on these topics, from The White House, *Catalyzing Global Markets for Off-grid Energy Access* (Washington, DC: November 2016), http://sun-connect-news.org/fileadmin/DATEIEN/Dateien/New/catalyzing_global_markets_for_off-grid_energy_access_final_cover.pdf, from Clean Energy Solutions Center, "Energy Efficiency for Energy Access: Appliance Efficiency in Resource-Constrained Settings", webinar, 17 February 2016, https://cleanenergysolutions.org/training/energy-efficiency-energy-access-appliance-efficiency-resource-constrained-settings, and from IEA, *Energy Efficiency Market Report 2016* (Paris: 2016), https://www.iea.org/eemr16/files/medium-term-energy-efficiency-2016_WEB.PDF; investor interest from US Department of Energy, "FACT SHEET: Obama Administration Announces New Financing for Renewable Energy Projects and Actions to Spur Innovation and Promote Energy Access Globally" (Washington, DC: 14 November 2016), https://www.energy.gov/articles/fact-sheet-obama-administration-announces-new-financing-renewable-energy-projects-and; Global LEAP, "The Global LEAP Awards", http://globalleap.org/awards, viewed 14 February 2017; Rockefeller Foundation, "Smart Power for Rural Development", https://www.rockefellerfoundation.org/our-work/initiatives/smart-power-for-rural-development/, viewed 14 February 2017; Overseas Development Institute, GOGLA, Practical Action and SolarAid, *Accelerating Access to Electricity in Africa with Off-grid Solar* (London: 2016), https://www.odi.org/publications/10200-accelerating-access-electricity-africa-off-grid-solar.

52 IRENA, *Innovation Outlook: Renewable Mini-grids. Summary for Policy Makers* (Abu Dhabi: 2016), http://www.irena.org/DocumentDownloads/Publications/IRENA_Innovation_Outlook_Minigrids_Summary_2016.pdf.

53 **Figure 34** from IRENA, *Innovation Outlook: Renewable Mini-grids* (Abu Dhabi: 2016), p. 18, http://www.irena.org/DocumentDownloads/Publications/IRENA_Innovation_Outlook_Minigrids_2016.pdf.

54 Ernesto Macías Galan, Solarwatt, Dresden, Germany, personal communication with REN21, 30 January 2017.

55 BNEF, *Q1 Off-Grid and Mini-grid Market Outlook* (London: 18 January 2017), p. 10, https://data.bloomberglp.com/bnef/sites/14/2017/01/BNEF-2017-01-05-Q1-2017-Off-grid-and-Mini-grid-Market-Outlook.pdf.

56 Solarplaza, "Fluidic Energy signs agreement for mini-grid electricity project to help 100 African villages", Unlocking Solar Capital Africa, 2 April 2016, http://www.unlockingsolarcapital.com/newssource/2016/4/2/fluidic-energy-signs-agreement-for-mini-grid-electricity-project-to-help-100-african-villages.

57 "Kenya: AFD provides 33 million euros to add renewable power in Kenya Power mini grids", AllAfrica, 2 August 2016, http://allafrica.com/stories/201608030668.html.

58 Energy4impact, "JUMEME launches its first solar powered mini-grid on the Lake Victoria island of Ukara, Tanzania", 5 April 2016, https://www.energy4impact.org/news/jumeme-launches-its-first-solar-powered-mini-grid-lake-victoria-island-ukara-tanzania.

59 "156 households connected to solar grid in Pench buffer", *Times of India*, 29 December 2016, http://timesofindia.indiatimes.com/city/nagpur/156-households-connected-to-solar-grid-in-Penchbuffer/articleshow/56226412.cms.

60 **Figure 35** from World Future Council, *Beyond Fire: How to Achieve Sustainable Cooking* (Hamburg, Germany: October 2016), p. 41, https://www.worldfuturecouncil.org/file/2016/10/WFC_BeyondFire_web-version.pdf.

61 Sneha Gautam et al., "Probe-based measurements of moisture in dung fuel for emissions measurements", *Energy for Sustainable Development*, vol. 35 (2016), pp. 1-6, https://doi.org/10.1016/j.esd.2016.09.003.

62 World Future Council, op. cit. note 60, p. 7.

63 Cecilia Flately, GACC, Washington, DC, personal communication with REN21, 29 December 2016.

64 **Figure 36** from Ibid.

65 Caitlyn Hughes, Solar Cookers International, Sacramento, CA, personal communication with REN21, 22 November 2016.

66 Ibid.

67 **Figure 37** from Felix Ter Heegde, SNV, The Hague, The Netherlands, personal communication with REN21, 9 January 2017.

68 Ter Heegde, op. cit. note 67..

69 Ibid.

70 ibid.

71 Ibid.

72 "Gamesa makes offgrid foray", reNEWS, 10 May 2016, http://renews.biz/102614/gamesa-makes-offgrid-foray/.

73 The project is managed by the Malian Agency for Development of Rural Electricity (AMADER). PwC Global Power & Utilities, op. cit. note 1.

74 The California-based company has offices in Nairobi and Manila and received early backing from First Solar. Powerhive, "Powerhive completes $20M financing round to support development of off-grid energy access solutions in emerging markets", 25 January 2016, http://www.powerhive.com/877/.

75 Sustainable Energy for All (SEforALL), *Scaling Up Finance for Sustainable Energy Investments – Report of the SE4All Advisory Board's Finance Committee – 2015* (Washington, DC: 2015), p. 10, http://www.se4all.org/sites/default/files/SE4All-Advisory-Board-Finance-Committee-Report.pdf.

76 IEA, "Financing energy access", http://www.worldenergyoutlook.org/resources/energydevelopment/energyforallfinancingaccessforthepoor, viewed 23 February 2017.

77 Ibid. **Figure 38** from Oil Change International, Shift the Subsidies database, http://shiftthesubsidies.org/.

78 Neha Rai, Sarah Best and Marek Soanes, *Unlocking Climate Finance for Decentralised Energy Access*, IIED Working Paper (London: International Institute for Environment and Development, June 2016), p. 7, http://pubs.iied.org/pdfs/16621IIED.pdf.

79 World Bank, "How solar is changing the climate game", 10 November 2016, http://www.worldbank.org/en/news/feature/2016/11/10/how-solar-is-changing-the-climate-game.

80 This fund includes USD 325 million for Pakistan's off-grid micro-hydro projects. "ADB offers $325m loan to Pakistan to install clean energy sources", *Energy Business Review*, 28 November 2016, http://www.energy-business-review.com/news/adb-approves-325m-funding-to-help-improve-clean-energy-access-in-pakistan-281116-5680962.

81 African Development Bank (AfDB), "SEFA grants US $1 million to promote green mini-grids in Niger", 2 August 2016, https://www.afdb.org/en/news-and-events/sefa-grants-us-1-million-to-promote-green-mini-grids-in-niger-15990/.

82 Deutsche Bank, "Green Climate Fund approves Deutsche Bank proposal for sustainable energy for Africa", press release (Frankfurt: 17 October 2016), https://www.db.com/newsroom_news/2016/medien/-en-11718.htm.

83 Deutsche Bank, "Deutsche Bank submits Sustainable Energy for Africa proposal to Green Climate Fund", press release (Frankfurt: 28 September 2016), https://www.db.com/newsroom_news/2016/medien/deutsche-bank-submits-sustainable-energy-for-africa-proposal-to-green-climate-fund-en-11700.htm.

84 Green Climate Fund, "KawiSafi Ventures Fund in East Africa", 20 December 2016, http://www.greenclimate.fund/-/kawisafi-ventures-fund-in-east-africa.

85 Ibid.

86 Amount of UGX 15.5 million converted on 31 December 2016 using exchange rate from http://www.oanda.com/currency/converter/. The programme is run under the United Nations Capital Development Fund. "Sweden gives poor Ugandans Shs15.5 billion for clean cooking stoves", *The Ugandan*, 7 November 2016, http://theugandan.com.ug/sweden-gives-poor-ugandans-shs15-5-billion-for-clean-cooking-stoves/.

87 In 2015, USD 158 million was raised. **Figure 39** from BNEF, op. cit. note 55, p. 10.

88 "Largest ever investment in off-grid solar: Lumos Global raises $90 million", PR Newswire, 1 December 2016, http://www.prnewswire.com/news-releases/largest-ever-investment-in-off-grid-solar-lumos-global-raises-90-million-300371350.html.

89 "d.light secures $7.5 million from developing world markets, raising total of $30 million this year for off-grid solar", PR Newswire, 31 October 2016, http://www.prnewswire.com/news-releases/dlight-secures-75-million-from-developing-world-markets-raising-total-of-30-million-this-year-for-off-grid-solar-300353841.html.

90 "BBOXX pursues its ambitious growth with successful $20 million fund raising", PR Newswire, 30 August 2016, http://www.prnewswire.com/news-releases/bboxx-pursues-its-ambitious-growth-with-successful-20-million-fund-raising-591708211.html; Mobisol, "IFC and FMO invest in Mobisol", 12 December 2016, http://www.plugintheworld.com/mobisol/2016/12/12/ifc-and-fmo-invest-in-mobisol/; Wedaeli Chibelushi, "Off Grid Electric secures $18 million in funding from Helios and responsAbility", *African Business Review*, 3 August 2016, http://www.africanbusinessreview.co.za/finance/2433/Off-Grid-Electric-secures-18-Million-in-funding-from-Helios-and-responsibility.

91 Katherine Tweed, "PowerMundo pushes to scale up off-grid solar in Peru", Greentech Media, 5 December 2016, https://www.greentechmedia.com/articles/read/powermundo-pushes-to-scale-up-off-grid-solar-in-peru.

92 BNEF, op. cit. note 55, p. 10.

93 Maina Waruru, "Kenya to install solar mini-grids to power remote north", Renewable Energy World, 10 August 2016, http://www.renewableenergyworld.com/articles/2016/08/kenya-to-install-23-solar-mini-grids-to-power-remote-north.html.

94 Africa Global Funds, "PowerGen Renewable Energy receives $4.5m in a Series A investment round", 21 December 2016, https://www.africaglobalfunds.com/news/private-equity/deals/powergen-renewable-energy-receives-45m-in-a-series-a-investment-round/.

95 "Fluidic Energy receives $20 million investment from Asia Climate Partners to expand renewable energy access in Southeast Asia", PR Newswire, 28 November 2016, http://www.prnewswire.com/news-releases/fluidic-energy-receives-20-million-investment-from-asia-climate-partners-to-expand-renewable-energy-access-in-southeast-asia-300368822.html.

96 Kevin Mwanza, "Total invests In Africa-focused solar startups Off Grid Electric and Powerhive", AFK Insider, 3 February 2016, http://afkinsider.com/118728/total-invests-africa-focused-solar-startups-off-grid-electricpowerhive/#sthash.XhIcyPyl.s3tSIRz6.dpuf.

97 **Figure 40** from GACC, *2016 Progress Report. Clean Cooking: Key to Achieving Global Development and Climate Goals* (Washington, DC: 2016), p. 10, http://cleancookstoves.org/reports/GACC_AR_2016_FlowPaper2/#page=10.

98 World Bank Energy Sector Management Assistance Program, "ESMAP brings innovation to increase adoption of cleaner, more efficient cookstoves in households across Uganda", 4 July 2016, https://www.esmap.org/node/57099.

99 GACC, "Envirofit and Biolite selected to receive first funding from Clean Cooking Working Capital Fund", 10 August 2016, http://cleancookstoves.org/about/news/08-10-2016-envirofit-and-biolite-selected-to-receive-first-funding-from-clean-cooking-working-capital-fund.html.

100 Davinia Cogan and Simon Collings, *Crowd Power: Mapping the Market for Energy Access* (London: GVEP International, May 2016), p. 1, https://www.energy4impact.org/fr/file/1697/download?token=CLBAAi7Q.

101 Ariane Delalande and Charlotte Geoffray, "Awango by Total: solutions to improve access to energy", Crowdsourcing Week, 24 November 2016, http://crowdsourcingweek.com/session/awango-by-total-solutions-to-improve-access-to-energy/.

102 Indiegogo, "Global Alliance for Clean Cookstoves", https://www.indiegogo.com/partners/cookstoves, viewed 22 November 2016.

103 Macías Galan, op. cit. note 54.

104 Samson Tolessa, Deputy Director, GIZ ECO, Ethiopia, "Emerging Diffusion and Business Models for Stand-Alone PV", presentation at Organization of Africa Electrification Initiative Practitioner Workshop, Dakar, Senegal, 14-16 November 2011, http://siteresources.worldbank.org/EXTAFRREGTOPENERGY/Resources/717305-1327690230600/8397692-1327691237767/Emerging_Diffusion_and_Business_Models_for_Stand-Alone_PV_imp.pdf.

105 The Foundation set an ambitious target to reach 1,000 villages within the first three years of the initiative. See Kyle Muther, *Smart Power for Rural Development Creating a Sustainable Market Solution to Energy Poverty* (Shared Value Initiative, undated), p. 1, http://www.sun-connect-news.org/fileadmin/DATEIEN/Dateien/New/Smart_Power_Case_Final.pdf and SEforALL, *Strategic Framework for Results 2016-21* (Washington, DC: June 2016), http://www.se4all.org/sites/default/files/2016_EUSEW_LR.pdf.

106 Virginia Wiseman, "January 2016 Sustainable Energy Finance Update", International Institute for Sustainable Development, 2 February 2016, http://sdg.iisd.org/news/january-2016-sustainable-energy-finance-update/?rdr=energy-l.iisd.org.

107 BNEF, op. cit. note 43.

108 M-KOPA Solar, "Company overview", http://solar.m-kopa.com/about/company-overview/, viewed 23 February 2017.

109 This PAYG is backed by Nigeria's Bank of Industry. End-users pay less than USD 10 per month for enough electricity to power LED light bulbs, a television and a fan as well as to charge mobile phones. Yomi Kazeem, "Light up Naija: a pay-as-you-go solar solution could kickstart renewable energy adoption in Nigeria", Quartz Africa, 21 June 2016, http://qz.com/711138/a-pay-as-you-go-solar-solution-could-kickstart-renewable-energy-adoption-innigeria/.

110 Jennifer Runyon, "Pay-as-you-go solar companies spread light across Africa", Renewable Energy World, 16 June 2016, http://www.renewableenergyworld.com/articles/2016/06/pay-as-you-go-solar-companies-spread-light-across-africa.html.

111 Energy and Environment Partnership, *Commercialising Solar Home Systems Distribution in Myanmar Through Innovative Pay-As-You-Go Solutions* (Yangon, Myanmar: undated), http://eepmekong.org/index.php/resources/fact-sheets/5th-call-for-proposals/253-commericialising-solar-home-systems-distribution-in-myanmar-through-innovative-pay-as-you-go-solutions/file.

112 GSMA, *Mobile for Development Utilities: Unlocking Access to Utility Services: The Transformational Value of Mobile* (London: July 2016), p. 20, http://www.gsma.com/mobilefordevelopment/wpcontent/uploads/2016/07/Mobile-for-Development-Utilities-Annual-Report.pdf.

113 Arc Finance, "Renewable Energy Microfinance and Microenterprise Program (REMMP) benefits 1 million people with clean energy!" 28 May 2016, http://arcfinance.org/arc-in-the-news/renewable-energy-microfinance-and-microenterprise-program-remmp-benefits-1-million-people-with-clean-energy/.

114 "Sierra Leone News: First household solar pilot kits launched in Sierra Leone", Awako, 5 December 2016, http://awoko.org/2016/12/06/sierra-leone-news-first-household-solar-pilot-kits-launched-in-sierra-leone/.

115 Kavya Devarapalli, "Can microfinance boost solar energy in India?" Ecoideaz, http://www.ecoideaz.com/expertcorner/microfinance-for-solar-energy, viewed 23 February 2017.

116 Arc Finance, op. cit. note 113.

117 Ibid.

118 GACC, *Consumer Finance Models for Clean Cookstoves: Global Mapping* (Washington, DC: September 2015), https://cleancookstoves.org/binary-data/RESOURCE/file/000/000/421-1.pdf.

119 Lennart Båge, "Microfinance: a lifeline for poor rural people", International Fund for Agricultural Development, February 2008, https://www.ifad.org/who/president/archive/tags/1651524.

120 United Nations Development Programme (UNDP), *Achieving Sustainable Energy for All in the Asia-Pacific* (Bangkok: UNDP-Asia Pacific Research Center, August 2013), p. 112, http://www.asiapacific.undp.org/content/rbap/en/home/library/climate-and-disaster-resilience/APRC-EE-2013-SE4ALL.html; Izael P. Da Silva, "The four barriers for the diffusion of solar energy technologies in Africa: trends in Kenya", Sun-Connect News, 22 August 2016, http://www.sun-connect-news.org/market/details/the-four-barriers-for-the-diffusion-of-solar-energy-technologies-in-africa-trends-in-kenya/.

121 William Brent, "Policy, not finance, biggest obstacle to scaling decentralized renewable energy: Energy Access Summit", Renewable Energy World, 13 June 2016, http://www.renewableenergyworld.com/articles/2016/06/policy-not-finance-biggest-obstacle-to-scaling-decentralized-renewable-energy-energy-access-summit.html.

122 Johanna Diecker, Susie Wheeldon and Andrew Scott, *Accelerating Access to Electricity in Africa with Off-grid Solar Policies to Expand the Market for Solar Household Solutions* (London: Overseas Development Institute, January 2016), p. 6, https://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/10231.pdf.

123 Brent, op. cit. note 121.

124 BNEF, op. cit. note 55.

125 "Rwanda: renewable energy project to connect 77,000 rural homes", AllAfrica, 30 August 2016, http://allafrica.com/stories/201608300032.html.

126 Smiti, "India plans 10 GW renewable energy capacity through micro, mini grids", Planetsave, 5 June 2016, http://planetsave.com/2016/06/05/india-plans-10-gw-renewable-energy-capacity-micro-mini-grids/; China National Renewable Energy Center, *China Renewable Energy Outlook 2016* (Beijing: 2016), pp. 37-38, http://www.ea-energianalyse.dk/reports/1473_REO2016.pdf.

127 Andre E. Susanto, "Indonesia's new rural electrification regulation", PV-Tech, 8 December 2016, https://www.pv-tech.org/guest-blog/indonesias-new-rural-electrification-regulation.

128 DNA India, "Maharashtra approves solar energy policy, offers incentives for power generation", 26 January 2016, http://www.dnaindia.com/money/report-maharashtra-approves-solar-energy-policy-offers-incentives-forpower-generation-2170350; Uttar Pradesh New & Renewable Energy Development Agency, *Mini Grid Policy Uttar Pradesh 2016* (Lucknow, India: 2016), pp. 1-8, http://upneda.org.in/sites/default/files/all/section/Mini%20Grid%20Policy%202016.pdf.

129 "NERC to finalise mini-grid regulations", ESI Africa, 4 October 2016, https://www.esi-africa.com/news/nerc-to-finalise-mini-grid-regulations/.

130 Nico Yoga Permana, "Permen ESDM No. 19 Tahun 2016 Tentang Pembelian Tenaga Listrik dari PLTS Fotovoltaik oleh PT. PLN", 2 August 2016, http://ebtke.esdm.go.id/post/2016/08/02/1300/permen.esdm.no.19.tahun.2016.tentang.pembelian.tenaga.listrik.dari.plts.fotovoltaik.oleh.pt.pln.

131 Rural areas in which projects are built include the Argentine provinces of Catamarca, Chaco, Entre Ríos, La Pampa, Neuquen and Salta. Mirco Sieg, "Argentina tenders 6,500 off-grid photovoltaic systems", *PV Magazine*, 14 July 2016, https://www.pv-magazine.com/2016/07/14/argentina-tenders-6500-off-grid-photovoltaic-systems_100025410/.

132 Empresa de Pesquisa Energética, "Portaria No. 104, de 23 de março de 2016", 23 March 2016, http://www.epe.gov.br/leiloes/Documents/prt2016104mme.pdf; Climatescope 2016, "Brazil 10th Reserve Auction – 23 September 2016", http://global-climatescope.org/en/policies/#/policy/4896, viewed 14 February 2017.

133 Susie Wheeldon, "News release: Sierra Leone reports progress with 'Energy Revolution' campaign", Power for All, 28 October 2016, http://www.powerforall.org/blog/2016/10/28/news-release-sierra-leone-reports-progress-with-energy-revolution-campaign.

134 GACC, "Report: More than 53 million clean and/or efficient cookstoves and fuels distributed from 2010-2015", 6 December 2016, http://cleancookstoves.org/about/news/12-06-2016-report-more-than-53-million-clean-and-or-efficient-cookstoves-and-fuels-distributed-from-2010-2015.html.

135 Madhya Pradesh Urja Vikas Nigam Limited, "Madhya Pradesh Policy for Decentralized Renewable Energy Systems, 2016", http://www.mprenewable.nic.in/Decentralized%20RE%20Policy%20in%20English%2024.09.2016.pdf.

136 Arne Jacobsen, Technical Lead, Lighting Global Quality Assurance, "Quality Assurance for Off-Grid Solar Products: An Emerging International Framework", presentation, 11 May 2016, https://cleanenergysolutions.org/sites/default/files/documents/ajacobson-lg-qa-unf-iec-webinar-may11-2016.pdf.

137 International Electrotechnical Commission, "Facilitating rural electrification in developing and newly industrialized countries", 17 August 2016, http://blog.iec.ch/2016/08/facilitating-rural-electrification-in-developing-and-newly-industrialized-countries/.

138 United Nations, "Sustainable Development Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all", https://sustainabledevelopment.un.org/sdg7, viewed 23 February 2017; United Nations, *Report of the Secretary-General, Progress Towards the Sustainable Development Goals* (New York: 2016), http://www.un.org/ga/search/view_doc.asp?symbol=E/2016/75&Lang=E.

139 SEforALL, "Building partnerships", http://www.se4all.org/our-partners, viewed 23 February 2017.

140 Work is under way and/or has been finalised on 36 Action Agendas to lay out a nationally tailored approach to deliver SEforALL objective(s) and on 26 Investment Prospectuses to identify pipelines of investment projects and programmes. SEforALL, op. cit. note 105.

141 Ibid.

142 Christoph Henrich, UNDP, personal communication with REN21, 8 February 2017.

143 SEforALL, op. cit. note 139.

144 EnDev, *Annual Planning 2017 Energising Development – Phase 2* (Eschborn, Germany: October 2016), p. 7, http://endev.info/images/e/e2/EnDev_Annual_Planning_for_2017.pdf.

145 US Agency for International Development (USAID), "Power Africa announces more than $1 billion in new commitments at the US Africa Business Forum", press release (Washington, DC: 21 September 2016), https://www.usaid.gov/news-information/press-releases/sep-21-2016-power-africa-announces-more-1-billion-new-commitments-us-africa..

146 Ibid.

147 USAID, "USAID announces $4 million to solar start-ups for African off-grid energy", press release (Washington, DC: 24 January 2017), https://www.usaid.gov/news-information/press-releases/oct-14-2016-usaid-announces-4-million-solar-start-ups-african-grid-energy.

148 Virunga Power, "Providing a jolt of support to power the minigrid market", 9 June 2016, http://virungapower.com/news/2016/6/9/providing-a-jolt-of-support-to-power-the-minigrid-market.

149 GACC, "About", http://cleancookstoves.org/about/, viewed 16 February 2017.

150 GACC, "Research and evaluation", http://cleancookstoves.org/research-and-evaluation/, viewed 16 February 2017.

151 GACC, op. cit. note 97.

152 Global Policy Watch, "AfDB president launches `New Deal on Energy in Africa'", 28 January 2016, https://www.globalpolicywatch.com/2016/01/afdb-president-launches-new-deal-on-energy-in-africa/.

153 AfDB, "AfDB launches a Green Mini-Grid Help Desk to support project developers deliver energy access in rural areas", 10 June 2016, https://www.afdb.org/en/news-and-events/afdb-launches-a-green-mini-grid-help-desk-to-support-project-developers-deliver-energy-access-in-rural-areas-16197/.

154 World Bank, "Mini grids: bringing low-cost, timely electricity to the rural poor", 7 July 2016, http://www.worldbank.org/en/news/feature/2016/07/07/mini-grids-bringing-low-cost-timely-electricity-to-the-rural-poor.

155 Benjamin K. Sovacool, Morgan Bazilian and Michael Toman, "Paradigms and poverty in global energy policy: research needs for achieving universal energy access," *Environmental Research Letters*, vol. 11, no. 6 (June 2016), pp. 1-6, http://iopscience.iop.org/article/10.1088/1748-9326/11/6/064014/meta.

156 PwC Global Power & Utilities, op. cit. note 1.

INVESTMENT FLOWS

1 The BNEF estimate for investment in large-scale hydropower (>50 MW) is based on some 12.6 GW of new capacity that secured financing during 2016. Some projects have a disclosed capital cost, but many do not; BNEF estimates the total investment in the latter group based on average cost per MW in different markets, ranging from USD 1.2 million in China to USD 6 million in Canada. Estimates are approximate only, due greatly to the fact that timing of the investment decision on a project may be about four years on average away from the moment of commissioning. As a result, a large share of the investment total for the projects commissioned in 2016 was actually invested in prior years; in addition, there was investment during 2016 for projects that were still under construction in 2017 and were not included in the BNEF estimates. Note that data for hydropower projects larger than 50 MW may differ somewhat between this GSR and the *Global Trends in Renewable Energy Investment 2017* due to different methodologies and data sources. *(→ See Hydropower section in Market and Industry Trends chapter.)*

2 National Energy Administration of China, national electric industry statistics as sourced from China's National Energy Board, 16 January 2017, http://www.nea.gov.cn/2017-01/16/c_135986964.htm.

POLICY LANDSCAPE

1 This section is intended to be only indicative of the overall landscape of policy activity and is not a definitive reference. Policies listed are generally those that have been enacted by legislative bodies. Some of the policies listed may not yet be implemented, or are awaiting detailed implementing regulations. It is obviously difficult to capture every policy, so some policies may be unintentionally omitted or incorrectly listed. Some policies also may be discontinued or very recently enacted. This report does not cover policies and activities related to technology transfer, capacity building, carbon finance and Clean Development Mechanism projects, nor does it highlight broader framework and strategic policies – all of which are still important to renewable energy progress. For the most part, this report also does not cover policies that are still under discussion or formulation, except to highlight overall trends. Information on policies comes from a wide variety of sources, including the International Energy Agency (IEA) and International Renewable Energy Agency (IRENA) Global Renewable Energy Policies and Measures Database, the US Database of State Incentives for Renewables & Efficiency (DSIRE), RenewableEnergyWorld.com, press reports, submissions from REN21 regional- and country-specific contributors and a wide range of unpublished data. Much of the information presented here and further details on specific countries appear on the "Renewables Interactive Map" at www.ren21.net. It is unrealistic to be able to provide detailed references for all sources here. **Table 3** and **Figures 45** through **48** are based on idem and on numerous sources cited throughout this section.

2 Ibid.

3 United Nations Framework Convention on Climate Change (UNFCCC), "Interim NDC registry", http://www4.unfccc.int/ndcregistry/Pages/Home.aspx, viewed 15 March 2017; NDC and INDC information also from Jørgen Villy Fenhann, UNEP DTU Partnership, Copenhagen, personal communication with REN21, 27 March 2017.

4 Paula Caballero et al., "Steely determination brings progress in climate talks in Marrakech", World Resources Institute, 19 November 2016, http://www.wri.org/blog/2016/11/steely-determination-brings-progress-climate-talks-marrakech.

5 The Climate Vulnerable Forum comprises Afghanistan, Bangladesh, Barbados, Bhutan, Burkina Faso, Cambodia, Colombia, Comoros, Costa Rica, the Democratic Republic of the Congo, the Dominican Republic, Ethiopia, Fiji, The Gambia, Ghana, Grenada, Guatemala, Haiti, Honduras, Kenya, Kiribati, Lebanon, Madagascar, Malawi, the Maldives, the Marshall Islands, Mongolia, Morocco, Nepal, Niger, Palau, Palestine, Papua New Guinea, the Philippines, Rwanda, Saint Lucia, Samoa, Senegal, South Sudan, Sri Lanka, Sudan, Tanzania, Timor-Leste, Tunisia, Tuvalu, Vanuatu, Vietnam and Yemen. It is an international partnership of countries highly vulnerable to global climate change. Climate Vulnerable Forum, "The Climate Vulnerable Forum vision", http://www.thecvf.org/marrakech-vision/, viewed 20 December 2016.

6 IRENA, "Coalition for advancing low carbon fuels launches at COP22", 20 November 2016, https://irenanewsroom.org/2016/11/20/coalition-for-advancing-low-carbon-fuels-launches-at-cop22/.

7 Richard Bridle and Lucy Kitson, *The Impact of Fossil-Fuel Subsidies on Renewable Electricity Generation* (London: International Institute for Sustainable Development (IISD), December 2014), http://www.iisd.org/sites/default/files/publications/impact-fossil-fuel-subsidies-renewable-electricity-generation.pdf. Methodologies for quantifying total subsidies around the world vary. The IEA estimates fossil fuel subsidies at USD 325 billion in 2015. The International Monetary Fund (IMF) seeks to include the cost of externalities in addition to direct payments. It values subsidies for coal at USD 3.1 trillion, for petroleum at USD 1.5 trillion and for natural gas at USD 510 billion in 2015. See IMF, "IMF Survey: Counting the cost of energy subsidies", 17 July 2015, http://www.imf.org/external/pubs/ft/survey/so/2015/NEW070215A.htm. By comparison, the IEA estimates renewable energy subsidies at around USD 150 billion. See IEA, *World Energy Outlook 2016, Executive Summary* (Paris: 2016), https://www.iea.org/publications/freepublications/publication/WorldEnergyOutlook2016ExecutiveSummaryEnglish.pdf.

8 See discussion and sources in endnote 1.

9 *IRENA, Renewable Energy Target Setting* (Abu Dhabi: 2015), http://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Target_Setting_2015.pdf.

10 European Commission (EC), "2030 Energy Strategy", https://ec.europa.eu/energy/en/topics/energystrategy/2030-energy-strategy, viewed 19 December 2016.

11 Jean Chemnick and Emily Holden, "7 questions about the 'Three Amigos' energy deal", *E&E News*, 30 June 2016, http://www.eenews.net/stories/1060039657.

12 IEA/IRENA Joint Policies and Measures database, "China 13th Electricity Development Five Year Plan (2016-2020)", 13 December 2016, http://www.iea.org/policiesandmeasures/pams/china/name-160313-en.php.

13 IEA/IRENA Joint Policies and Measures database, "China 13th Ocean Energy Development Five Year Plan (2016-2020)", 31 January 2017, http://www.iea.org/policiesandmeasures/pams/china/name-160750-en.php.

14 Florence Tan and Wilda Asmarini, "On the sunny side: Southeast Asian nations push into solar", *Reuters*, 2 November 2016, http://uk.reuters.com/article/uk-asia-solar-power-factbox-idUKKBN12X095; Tom Kenning, "Vietnam has 30 large-scale solar projects under development but FiT needed", PV-Tech, 2 November 2016, http://www.iisd.org/sites/default/files/publications/impact-fossil-fuel-subsidies-renewable-electricity-generation.pdf; Seerat Chabba, "South Korea to invest $36 billion in renewable energy by 2020", *International Business Times*, 5 July 2016, http://www.ibtimes.com/south-korea-invest-36-billion-renewable-energy-2020-2389326; "Taiwan committed to 20 percent renewable energy target: VP", Taiwan Today, 13 October 2016, http://www.taiwantoday.tw/ct.asp; "India set to install 10GW of renewables from 2017", ESI Africa, 3 November 2016, https://www.esi-africa.com/news/india-set-to-install-10gw-of-renewables-from-2017/.

15 Steve Hanley, "Cape Verde leads with 100% renewable electricity by 2020 target", CleanTechnica, 3 October 2016, http://cleantechnica.com/2016/10/03/cape-verde-leads-100-renewable-electricity-2020-target/; Olivier Ristau, "Climate host Morocco advances its energy transition", *Deutsche Welle*, 4 November 2016, http://www.dw.com/en/climate-host-morocco-advances-its-energy-transition/a-36257369; Steve Sawyer, Global Wind Energy Council (GWEC), personal communication with REN21, 29 November 2016; "Cuba seeks investors to boost clean, renewable energy", *Xinhua*, 21 August 2016, http://news.xinhuanet.com/english/2016-08/21/c_135621841.htm; IRENA, "Cuba seeks to expand role of renewable energy", 25 August 2016, http://www.irena.org/News/Description.aspx?NType=A&mnu=cat&PriMenuID=16&CatID=84&News_ID=1462; Carolyn Fortuna, "Aruba promises 100% clean electricity by 2020", CleanTechnica, 18 December 2016, https://cleantechnica.com/2016/12/18/aruba-promises-100-clean-electricity-2020/; Saurabh Mahapatra, "Jamaica will add 150 MW of renewable energy capacity this year", CleanTechnica, 28 June 2016, http://cleantechnica.com/2016/06/28/jamaica-will-add-150-mw-renewable-energy-capacity-year/; Moritz Borgmann, "Saudi Arabia announces 9.5 GW renewable energy target under new 'King Slman Renewable Energy Initiative'", Apricum Group, 25 April 2016, http://www.apricum-group.com/saudi-arabia-announces-9-5-gw-renewable-energy-target-new-king-salman-renewable-energy-initiative/; Mexico from Blanca Diaz Lopez, "Mexico targets addition of 5.4 GW of PV in next 3 years", *PV Magazine*, 2 January 2017, https://www.pv-magazine.com/2017/01/02/mexico-targets-addition-of-5-4-gw-of-pv-in-next-3-years/

16 Fortuna, op. cit. note 15.

17 Meghan Sapp, "Finland heads for 30% biofuel blending but more than half will be double-counted", Biofuels Digest, 24 November 2016, http://www.biofuelsdigest.com/bdigest/2016/11/24/finland-heads-for-30-biofuel-blending-but-more-than-half-will-be-double-counted/; Ministry of Economic Affairs and Employment of Finland, "Finland's new energy and climate strategy", http://tem.fi/en/energy-and-climate-strategy-2016, viewed 5 February 2017; Jim Lane, "Norway to boost biofuels blend levels to 20 percent", Biofuels Digest, 10 December 2016, http://www.biofuelsdigest.com/bdigest/2016/12/10/norway-to-bost-biofuels-blend-levels-to-20-percent/.

18 "Saudi minister says solar power should fuel national growth", PV Insider, 26 May 2016, http://analysis.newenergyupdate.com/csp-today/markets/saudi-minister-says-solar-power-should-

fuel-national-growth; Giles Parkinson and Sophie Vorrath, "Victoria aims for 40% renewables by 2025, to add 5,400 MW wind and solar", Renew Economy, 15 June 2016, http://reneweconomy.com.au/2016/victoria-aims-for-40-renewables-by-2025-to-add-5400mw-wind-and-solar-53932; Barry Cassell, "Alberta advances clean energy goals with more renewables", Renewable Energy World, 15 November 2016, http://www.renewableenergyworld.com/articles/2016/11/alberta-advances-clean-energy-goals-with-more-renewables.html.

19 Daniel Cusick, "Law advancing offshore wind finalized in Mass", *E&E News*, 9 August 2016, http://www.eenews.net/climatewire/2016/08/09/stories/1060041357.

20 Fiona Harvey, "UK will miss its 2020 renewable energy targets, warn MPs", *The Guardian* (UK), 9 September 2016, https://www.theguardian.com/environment/2016/sep/09/uk-will-miss-its-2020-renewable-energy-targets-warn-mps; EC, *Second Report on the State of the Energy Union* (Brussels: 1 February 2017), https://ec.europa.eu/commission/sites/beta-political/files/swd-energy-union-key-indicators_en.pdf.

21 "PV exceeds 2020 EU renewable energy target", *PV Magazine*, 17 June 2015, https://www.pv-magazine.com/2015/06/17/pv-exceeds-2020-eu-renewable-energy-target_100019858/.

22 EC, "State aid: Commission approves Greek support scheme for renewable electricity and cogeneration", press release (Brussels: 16 November 2016), http://europa.eu/rapid/press-release_IP-16-3707_en.htm.

23 Robert-Jan Bartunek and Alissa de Carbonnel, "EU set to limit priority for future renewable energy projects: draft", *Reuters*, 16 November 2016, http://www.reuters.com/article/us-eu-power-renewables-idUSKBN13B1EW.

24 bne IntelliNews, "Tension cools as EU approves Czech renewables support", 28 November 2016, http://www.intellinews.com/tension-cools-as-eu-approves-czech-renewables-support-111133/.

25 EC, "State aid: Commission approves four support measures for renewable energy in France", press release (Brussels: 12 December 2016), http://europa.eu/rapid/press-release_IP-16-4355_en.htm.

26 Kerstine Appunn, "EEG reform 2016 – switching to auctions for renewables", Clean Energy Wire, 8 July 2016, https://www.cleanenergywire.org/factsheets/eeg-reform-2016-switching-auctions-renewables.

27 Ilias Tsagas, "Greece: new renewable energy law provides feed-in premiums and virtual net-metering", *PV Magazine*, 9 August 2016, https://www.pv-magazine.com/2016/08/09/greece-new-renewable-energy-law-provides-feed-in-premiums-and-virtual-net-metering_100025713/#ixzz4O6OmarVK.

28 EC, "State aid: Commission approves amended Slovenian support scheme for renewable energy and high-efficiency cogeneration", press release (Brussels: 10 October 2016), http://europa.eu/rapid/press-release_IP-16-3361_en.htm.

29 Paul Gipe, "Small wind tariffs in Denmark 2016", Wind Works, 22 July 2016, http://www.wind-works.org/cms/index.php?id=64&tx_ttnews%5Btt_news%5D=4286&cHash=dc633ee84153112816daa44947f002c3; Alan Moore, "What is the future of renewables in the UK?" Renewable Energy Hub, 1 February 2016, https://www.renewableenergyhub.co.uk/blog/what-is-the-future-of-renewables-in-the-uk/.

30 Government of Ukraine, "Draft Law on Amendments to the Law of Ukraine on Electricity", 22 December 2016, Http://w1.c1.rada.gov.ua/pls/zweb2/webproc4_1?pf3511=60031.

31 Frank Haugwitz, Asia Europe Clean Energy (Solar) Advisory Co. Ltd. (AECEA), personal communication with REN21, 22 January 2017; Aamir Saeed, "Solar scale-up in Pakistan hits roadblock after payments slashed", *Reuters*, 20 September 2016, http://planetark.org/wen/74770; Alena Mae S. Flores, "Govt readies third round of FiT rates", *The Standard*, 30 May 2016, http://thestandard.com.ph/business/206918/govt-readies-third-round-of-fitrates.html.

32 Ministry of Energy and Mineral Resources, Republic of Indonesia, "Indonesia plans to add 5 GW of solar PV capacity in 2-3 years", Solar Server, 15 August 2016, http://www.solarserver.com/solar-magazine/solar-news/archive-2016/2016/kw33/indonesia-plans-to-add-5-gw-of-solar-pv-capacity-in-2-3-years.html; Alexander Richter, "Indonesia preparing move to fixed-price geothermal feed-in-tariff", ThinkGeoEnergy, 11 August 2016, http://www.thinkgeoenergy.com/indonesia-preparing-move-to-fixed-price-geothermal-feed-in-tariff/.

33 Tom Kenning, "Ghana to update feed-in tariffs to last 20 years", PV-Tech, 20 April 2016, https://www.pv-tech.org/news/ghana-to-update-feed-in-tariffs-to-last-20-years; "Kenya to scrap current feed-in-tariff system", ESI Africa, 25 October 2016, https://www.esi-africa.com/news/kenya-to-scrap-current-feed-in-tariff-system/; Tim Armsby et al., "Egypt announces second phase of feed-in tariff programme", Lexology, 12 September 2016, http://www.lexology.com/library/detail.aspx?g=08865856-b64c-4634-adc5-fb6d41977bd2.

34 Sam Pothecary, "Solar PV feed-in tariffs cut in Tamil Nadu", *PV Magazine*, 4 April 2016, https://www.pv-magazine.com/2016/04/04/solar-pv-feed-in-tariffs-cut-in-tamil-nadu_100024002/; "Japan's solar power feed-in tariff to fall 20% or more in 3 years", *Nikkei Asian Review*, 2 April 2016, http://asia.nikkei.com/Politics-Economy/Policy-Politics/Japan-s-solar-power-feed-in-tariff-to-fall-20-or-more-in-3-years; Brian Publicover, "Japan to include O&M requirements in new FiT regulation", Solar Plaza, 3 May 2016, http://www.solarplaza.com/channels/asset-management/11515/japan-include-om-requirements-new-fitregulation/; Christian Roselund, "Ontario to re-open the microFIT program on July 21 (updated with microFIT rates)", *PV Magazine*, 20 June 2016, http://www.pv-magazine.com/news/details/beitrag/ontario-to-re-open-the-microfit-program-on-july-21-updated-with-microfit-rates_100025083/; Sophie Vorrath, "Queensland lifts solar feed-in tariff by 17% in response to surging gas prices", Renew Economy, 26 May 2016, http://reneweconomy.com.au/queensland-lifts-solar-feed-in-tariff-by-17-in-response-to-surging-gas-prices-14171/.

35 Independent Electricity System Operator, "Newsroom", http://fit.powerauthority.on.ca/programupdates/newsroom, viewed 22 January 2017; "Queensland plans increase in size of solar systems eligible for FiT." Renewable Energy World, 3 January 2017, http://www.renewableenergyworld.com/articles/2017/01/queensland-plans-increase-in-size-solar-systems-eligible-for-fit.html.

36 "Solar PV feed-in tariffs cut in Tamil Nadu", *PV Magazine*, 4 April 2016, https://www.pv-magazine.com/2016/04/04/solar-pv-feed-in-tariffs-cut-in-tamil-nadu_100024002.

37 Haugwitz, op. cit. note 31.

38 Anindya Upadhyay, "Govt seeks bids for 300 MW of solar projects with storage", Live Mint, 22 July 2016, http://www.livemint.com/Industry/rct4UIaqTyVgLhVNyFBstL/India-seeks-bids-for-300-megawatt-of-solar-projects-with-sto.html; "India's largest rooftop solar tender to see record low tariffs", Bridge to India, 12 December 2016, http://www.bridgetoindia.com/indias-largest-rooftop-solar-tender-see-record-low-tariffs/.

39 Kenji Kaneko, "Japan announces schedule for implementation of bidding system for solar plants", Nikkei Business Publications, 26 October 2016, http://techon.nikkeibp.co.jp/atclen/news_en/15mk/102600919/; IEA/IRENA Joint Policies and Measures database, "Indonesia geothermal auctions 2016", 13 December 2016, http://www.iea.org/policiesandmeasures/pams/indonesia/name-160271-en.php; "World's largest photovoltaic solar plant to be established in Konya by 2018", *Daily Sabah*, 20 October 2016, https://www.dailysabah.com/energy/2016/10/20/worlds-largest-photovoltaic-solar-plant-to-be-established-in-konya-by-2018.

40 Government of New South Wales, "Procurement of Electricity from a Renewable Energy Project in NSW for Sydney Metro Northwest – TfNSW 2016/002", 21 January 2016, https://tenders.nsw.gov.au/?event=public.rft.showArchived&RFTUUID=61A292E1-F724-D7DD-74277856584945B6; Saurabh Mahapatra, "Tamil Nadu, India, issues 500 MW solar tender", CleanTechnica, 25 October 2016, https://cleantechnica.com/2016/10/25/tamil-nadu-india-issues-500-mw-solar-tender.

41 IEA/IRENA Joint Policies and Measures database, "Renewable Energy Law of Poland", 5 February 2016, http://www.iea.org/policiesandmeasures/pams/poland/name-145058-en.php; EC, op. cit. note 28; Tsagas, op. cit. note 27.

42 Ilias Tsagas, "Greece to tender PV capacity in December", *PV Magazine*, 24 October 2016, https://www.pv-magazine.com/2016/10/24/greece-to-tender-pv-capacity-in-december_100026623/; Ian Clover, "Poland to hold inaugural 100 MW solar auction later this month", PV-Tech. 6 December 2016, https://www.pv-magazine.com/2016/12/05/poland-to-hold-inaugural-100-mw-solar-auction-later-this-month_100027110/.

43 "France makes 3GW solar play", reNEWS, 24 August 2016,

http://renews.biz/103898/france-offers-3gw-solar-tender/; Tom Kenning, "Germany raises offering to 160MW in sixth solar tender", PV-Tech, 17 October 2016, http://www.pv-tech.org/news/germany-raises-offering-to-160mw-in-sixth-solar-tender; Bloomberg New Energy Finance, "Italy calls solar parity; Germany opts for auctions", http://www.theaustralian.com.au/business/business-spectator/italy-calls-solar-parity-germany-opts-for-auctions/news-story/2ab4a11cc3a7f7ba31b0e894914f0ac3, viewed 1st June 2017; Jonathan Gifford, "Holland: 2.5 GW of PV applications for autumn SDE+ round", *PV Magazine*, 10 November 2016, https://www.pv-magazine.com/2016/11/10/holland-2-5-gw-of-pv-applications-for-autumn-sde-round_100026865; IEA/IRENA Joint Policies and Measures database, "Netherlands offshore wind tenders", 27 September 2016, http://www.iea.org/policiesandmeasures/pams/netherlands/name-158566-en.php.

44 Climate Action, "Spain announces 3 GW renewables auction", 6 January 2017, http://www.climateactionprogramme.org/news/spain_announces_3_gw_renewables_auction.

45 German Federal Ministry for Economic Affairs and Energy, "Denmark and Germany sign first cooperation agreement on mutual cross-border pilot auctions for PV installations", press release (Bonn: 20 July 2016), https://www.cleanenergywire.org/news/eu-plan-low-carbon-economy-germany-scores-high-efficiency/denmark-and-germany-sign-first-cooperation-agreement-mutual-cross-border-pilot-auctions-pv-installations.

46 IEA/IRENA Joint Policies and Measures database, "Nigeria Feed-in Tariff for Renewable Energy Sourced Electricity", 18 March 2016, http://www.iea.org/policiesandmeasures/pams/nigeria/name-154529-en.php; "Nigeria approves solar energy sale price", ESI Africa, 28 July 2016, https://www.esi-africa.com/news/nigeria-approves-solar-energy-sale-price/.

47 This agreement was backed by the World Bank and international financial institutions under the Scaling Solar Program and the Zambian government. Muren Guler, "Sub-Saharan Africa looking for new mechanism to boost solar investments", Renewable Energy World, 1 September 2016, http://www.renewableenergyworld.com/articles/2016/09/sub-saharan-africa-looking-for-new-mechanisms-to-boost-solar-investments.html.

48 Maged Mahmoud et al., *Arab Future Energy Index AFEX 2016: Renewable Energy* (Cairo: Regional Center for Renewable Energy and Energy Efficiency, 2016), http://www.rcreee.org/sites/default/files/final_afex_re_2016.pdf.

49 Anna Hirtenstein, "Palestinians aim for more power independence with solar auctions", *Bloomberg*, 1 May 2016, http://www.bloomberg.com/news/articles/2016-05-02/palestinians-aim-for-more-power-independence-with-solar-auction; John Parnell, "Saudi Electric Company launches 100MW IPP tender", PV-Tech, 10 June 2016, http://www.pv-tech.org/news/saudi-electric-company-launches-100mw-ipp-tender; Mahmoud et al., op. cit. note 48.

50 Glenn Meyers, "Israel: Public Utility Authority plans 1 GW solar tender", Planet Save, 13 October 2016, http://planetsave.com/2016/10/13/israel-public-utility-authority-plans-1gw-solar-tender/; "Israel seeks bids to develop 500MW of solar capacity", *Energy Business Review*, 20 September 2016, http://solar.energy-business-review.com/news/israel-seeks-bids-to-develop-500mw-of-solar-capacity-200916-5009792.

51 Sam Pothecary, "New solar tenders planned for Jordan", *PV Magazine*, 12 September 2016, http://www.pv-magazine.com/news/details/beitrag/new-solar-tenders-planned-for-jordan_100026068/; Sam Pothecary, "New 200 MW solar PV tender announced in Jordan", *PV Magazine*, 15 November 2016, https://www.pv-magazine.com/2016/11/15/new-200-mw-solar-pv-tender-announced-in-jordan_100026911/.

52 "Solar developers stay away from Tamil Nadu tender", Bridge to India, 28 November 2016, http://www.bridgetoindia.com/solar-developers-stay-away-tamil-nadu-tender/; United Arab Emirates from "Saudi Arabia seeks $50bn of solar, wind investments, Jordan agrees $60/MWh PV price", New Energy Update, 17 January 2017, http://analysis.newenergyupdate.com/pv-insider/saudi-arabia-seeks-50bn-solar-wind-investments-jordan-agrees-60mwh-pv-price.

53 Argentina Ministry of Energy and Mines, *RenovAr Plan for Renewable Energy* (Buenos Aires: 2016), https://www.minem.gob.ar/servicios/archivos/6548/AS_14695676441.pdf; "International news: Argentina to launch unique RE programme", ESI Africa, 6 July 2016, https://www.esi-africa.com/news/international-news-argentina-launch-unique-re-programme/.

54 Conor Ryan, "Energy prices in Chile reportedly set to drop following major auction", PV-Tech, 17 August 2016, http://www.pv-tech.org/news/energy-prices-in-chile-reportedly-set-to-drop-following-major-auction; Kevin Levey and Loana Martin, "A case for cautious optimism: renewable energy auction in Latin America", Renewable Energy World, 20 September 2016, http://www.renewableenergyworld.com/articles/2016/09/a-case-for-cautious-optimism-renewable-energy-auctions-in-latin-america.html; Saurabh Mahapatra, "New low solar price record set in Chile – 2.91 cents/kWh", CleanTechnica, 18 August 2016, https://cleantechnica.com/2016/08/18/new-low-solar-price-record-set-chile-2-91¢-per-kwh/.

55 Saurabh Mahapatra, "El Salvador launches 150 MW renewable energy action", CleanTechnica, 25 February 2016, https://cleantechnica.com/2016/02/25/el-salvador-launches-150-mw-renewable-energy-auction/.

56 "Mexico selects 23 bidders for development of $4bn renewable energy projects", *Energy Business Reviews*, 29 September 2016, http://solar.energy-business-review.com/news/mexico-selects-23-bidders-for-development-of-4bn-renewable-energy-projects-290916-5018678.

57 Barry Cassell, "Alberta advances clean energy goals with more renewables", Renewable Energy World, 15 November 2016, http://www.renewableenergyworld.com/articles/2016/11/alberta-advances-clean-energy-goals-with-more-renewables.html.

58 Steve Sawyer, GWEC, personal communication with REN21, 2 November 2016.

59 Tom Kenning, "Brazil cancels 2016's first solar auction and delays second", PV-Tech, 29 July 2016, http://www.pv-tech.org/news/brazil-cancels-2016s-first-solar-auction-and-delays-second; "Brazil cancels licensing round for wind, solar projects", *Reuters*, 14 December 2016, http://af.reuters.com/article/energyOilNews/idAFL5N1E95LM; GWEC, *Global Wind Report – Annual Market Update 2016* (Brussels: April 2017), p. 30, http://www.gwec.net/strong-outlook-for-wind-power/.

60 Tom Kenning, "Brazil government open to dialogue after currency slump hits energy projects", PV-Tech, 25 August 2016, http://www.pv-tech.org/news/brazil-government-open-to-dialogue-after-currency-slump-hit-several-energy.

61 Suriname from Roger Sallent, Inter-American Development Bank (IDB), personal communication with REN21, 2 December 2016. Slovenia's new programme provides support for all technologies but is not open to installations already receiving support through the national feed-in policy. IEA/IRENA Joint Policy and Measures database, "Slovenia Net-Metering System", 9 February 2016, http://www.iea.org/policiesandmeasures/pams/slovenia/name-153216-en.php.

62 Tom Kenning, "Brazil's 'historic' net metering revision comes into force", PV-Tech, 1 March 2016, http://www.pv-tech.org/news/brazils-historic-net-metering-revision-comes-into-force.

63 Sam Pothecary, "Costa Rica's distributed solar back on track with new net metering prices", *PV Magazine*, 22 March 2016, http://www.pv-magazine.com/news/details/beitrag/costa-ricas-distributed-solar-back-on-track-with-new-net-metering-prices_100023835/; in Greece, virtual net metering is open to city and regional councils, schools, universities, farmers and farming associations, per Tsagas, op. cit. note 27.

64 Edison Electric Institute, "Solar Energy and Net Metering", January 2016, http://www.eei.org/issuesandpolicy/generation/NetMetering/Documents/Straight%20Talk%20About%20Net%20Metering.pdf.

65 California approved a net metering successor programme that allows all customers to maintain the full retail energy metering structure and receive full credit, while simultaneously establishing time-of-use rates. In Colorado, the state's largest electric utility reached a rate settlement under which it agreed to pay homeowners a premium for power produced by household solar rooftop systems during high demand periods. In Nevada, net metering incentives were restored to customers from whom the incentives had been retroactively revoked under a 2015 PUC ruling. GoGreenSolar, "Arizona decides to keep net metering...for now", Renewable Energy World, 2 September 2016, http://blog.gogreensolar.com/2016/09/arizona-decides-to-keep-net-metering-for-now.html; Jennifer Delony, "Solar industry rejoices as California regulators approve net metering successor program", 28 January 2016, http://www.renewableenergyworld.com/articles/2016/01/

solar-industry-rejoices-as-california-regulators-approve-net-metering-successor-program.html; Bob Berwyn, "Colorado settlement to pay solar owners higher rates for peak power", Inside Climate News, 24 August 2016, https://insideclimatenews.org/news/23082016/colorado-solar-panels-net-metering-peak-power-demand-xcelenergy-rate-settlement.

66 Krysti Shallenberger, "Updated: Arizona regulators end retail net metering in value-of-solar proceeding", Utility Dive, 21 December 2016, http://www.utilitydive.com/news/updated-arizona-regulators-end-retail-net-metering-in-value-of-solar-proce/432838/.

67 Origin Energy, *Changing from Gross to Net Metering* (Adelaide, Australia: January 2017), https://www.originenergy.com.au/content/dam/origin/residential/docs/solar/Changing_from_Gross_to_Net_Metering.pdf.

68 Robert Walton, "District of Columbia mayor signs 50% renewable energy standard", Utility Dive, 26 July 2016, http://www.utilitydive.com/news/district-of-columbia-mayor-signs-50-renewable-energy-standard/423265/; Solar Energy Industries Association, "Illinois sets modernized RPS | Robert Redford defends solar", *SEIA Weekly Array*, 7 December 2016; American Wind Energy Association (AWEA), "Wind industry applauds Maryland's move toward 25 percent renewable energy by 2020", press release (Washington, DC: 12 April 2016), http://www.awea.org/MediaCenter/pressrelease.aspx?ItemNumber=8694; 25x'25, "Michigan to increase RPS, retain net metering", Weekly REsource, 22 December 2016; Greg Alvarez, "Oregon decides to go 50 percent renewable energy", AWEA, 3 March 2016, http://www.aweablog.org/oregon-decides-to-go-50-percent-renewable-energy/; Richard Kessler, "Rhode Island set to raise renewables mandate to 40%", Recharge News, 22 June 2016, http://www.rechargenews.com/wind/1183359/rhode-island-set-to-raise-renewables-mandate-to-40-percent; Peter Maloney, "Vermont regulators implement rules for 75% renewable target", Utility Dive, 1 July 2016, http://www.utilitydive.com/news/vermont-regulators-implement-rules-for-75-renewables-target/421924/.

69 Chris Martin, "Ohio governor vetoes bill to extend freeze on renewable energy", Renewable Energy World, 30 December 2016, http://www.renewableenergyworld.com/articles/2016/12/ohio-governor-vetoes-bill-to-extend-freeze-on-renewable-energy.html.

70 "The Government of India launches an ambitious rooftop solar subsidy scheme", Bridge to India, 4 January 2016, http://www.bridgetoindia.com/blog/the-government-of-india-launches-an-ambitious-rooftop-solar-subsidyscheme/.

71 Seerat Chabba, "South Korea to invest $36 billion in renewable energy by 2020", *International Business Times*, 5 July 2016, http://www.ibtimes.com/south-korea-invest-36-billion-renewable-energy-2020-2389326.

72 "Sweden to ditch tax on solar energy in renewables push", *AFP/The Local*, 21 November 2016, http://www.thelocal.se/20161121/sweden-to-ditch-tax-on-solar-energy-in-renewables-push.

73 Toby Sterling, "Netherlands to get rid of subsidies", *E&E News*, 8 December 2016, http://www.eenews.net/climatewire/2016/12/08/stories/1060046835; US Department of Energy, "Production tax credit", https://energy.gov/savings/renewable-electricity-production-tax-credit-ptc, viewed 26 February 2017.

74 James Wood, "Alberta to buy renewable power as it phases out coal", Energy Wire, 7 November 2016, http://www.eenews.net/energywire/2016/11/07/stories/1060045321.

75 25x'25, "FL voters remove property taxes on commercial, industrial solar panels", Weekly REsource, 2 September 2016; "State offers $7.7 million in renewable energy rebates until 2018", *Milwaukee Independent*, 24 October 2016, http://www.milwaukeeindependent.com/curated/state-offers-7-7-million-in-renewable-energy-rebates-until-2018/.

76 IEA/IRENA Joint Policies and Measures database, "Subsidy for solar PV with storage installations", 18 March 2016, http://www.iea.org/policiesandmeasures/pams/germany/name-154525-en.php.

77 The policy aims to install 100 MW of capacity in Andhra Pradesh and 200 MW in Karnataka. Saurabh, "India to tender 300 MW solar power storage tender", Cleantechies, 31 July 2016, http://cleantechies.com/2016/07/31/india-to-tender-300-mw-solar-power-storage-tender/.

78 Suriname from Roger Sallent, op. cit. note 61.

79 25X'25, "DOE announces $18 million to develop solar storage solutions", Weekly REsource, 22 January 2016.

80 Ilias Tsagas, "Jordan initiates the Green Corridor tender; increases PV target", *PV Magazine*, 21 October 2016, http://www.pv-magazine.com/news/details/beitrag/jordan-initiates-the-green-corridor-tender-increases-pvtarget_100026611/.

81 Government of Sweden, "Focus on investments in solar cells and new technology", 21 September 2015, http://www.regeringen.se/pressmeddelanden/2015/09/fokus-pa-investeringar-i-solceller-och-ny-teknik/.

82 Andrew Burger, "California ramps up energy storage plans with enactment of four new bills", Renewable Energy World, 28 September 2016, http://www.renewableenergyworld.com/articles/2016/09/california-ramps-up-energy-storage-plans-with-enactment-of-four-new-bills.html.

83 Christian Roselund, "Iran to pay 35% premium for solar, wind plants with domestic content", *PV Magazine*, 5 February 2016, https://www.pv-magazine.com/2016/02/05/iran-to-pay-35-premium-for-solar-wind-plants-with-domestic-content_100023084/#axzz3zRhDvJDR.

84 Anna Hirtenstein and Onur Ant, "Turkey seeking renewables industry with make-it-here rules", *Bloomberg*, 21 November 2016, https://www.bloomberg.com/news/articles/2016-11-22/turkey-seeking-renewable-energy-industry-with-make-it-here-rules.

85 "Will high domestic content requirement fuel or hinder Turkish solar sector growth?" *PV Magazine*, 30 January 2017, https://www.pv-magazine.com/2017/01/30/will-high-domestic-content-requirements-fuel-or-hinder-turkish-solar-sector-growth/.

86 Anindya Upadhyay, "Modi said to plan $3.1 billion boost for India's solar factories", *Bloomberg*, 17 October 2016, https://www.bloomberg.com/news/articles/2016-10-18/modi-said-to-plan-3-1-billion-boost-for-india-s-solar-factories.

87 25X25', "White House launches plan to broaden solar access, energy efficiency", Weekly REsource, 22 July 2016, http://www.25x25.org/index.php?option=com_content&task=view&id=1370&Itemid=246

88 International Finance Corporation, "IFC provides its first financing package for solar-powered homes in Mexico", 12 November 2016, http://www.ifc.org/wps/wcm/connect/topics_ext_content/ifc_external_corporate_site/cb_home/news/feature_urbi_nov12

89 Todd Olinsky-Paul, "States support clean energy for low-income residents", Renewable Energy World, 29 February 2016, http://www.renewableenergyworld.com/ugc/articles/2016/02/states-support-clean-energy-for-lowincome-residents.html.

90 Benjamin Storrow, "Cuomo announces funding for low-income solar", *E&E News*, 8 December 2016, http://www.eenews.net/climatewire/2016/12/08/stories/1060046837; Melanie Santiago-Mosier, "A bright spot for low-income solar in Illinois energy legislation", Renewable Energy World, 5 December 2016, http://www.renewableenergyworld.com/ugc/articles/2016/12/02/a-bright-spot-for-lowincome-solar-in-illinois-energy-legislation.html.

91 IEA, *Medium-Term Renewable Energy Market Report 2016* (Paris: 2016), https://www.iea.org/newsroom/news/2016/october/medium-term-renewable-energy-market-report-2016.html.

92 Ibid.

93 Ibid.

94 Ibid.

95 Ibid.

96 EC, "Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: An EU Strategy on Heating and Cooling" (Brussels: 16 February 2016), https://ec.europa.eu/transparency/regdoc/rep/1/2016/EN/1-2016-51-EN-F1-1.PDF.

97 European Parliament, "2016/2058(INI) – 13/09/2016 Text adopted by Parliament, single reading", 13 September 2016, http://www.europarl.europa.eu/oeil/popups/summary.do?id=1451967&t=e&l=en.

98 Bärbel Epp, "Residential Energy Efficiency Credit Line (REECL) 3 in Bulgaria", solarthermalworld, 16 October 2016, http://www.solarthermalworld.org/content/residential-energy-efficiency-credit-line-reecl-3-bulgaria.

99 RES Legal, "Subsidies (EEEOP, EDIOP)", 21 June 2016, http://www.res-legal.eu/search-bycountry/hungary/single/s/res-hc/t/promotion/aid/subsidy-megujulo-energia-alapu-tersegfejlesztes/

lastp/143/.

100 A second programme, Casa Eficiente, with an expected budget of USD 107 million (EUR 100 million) will provide subsidised loans covering a wide range of energy efficiency measures. Ricardo Battisti, "Italy: Conto Termico 2.0 refers to expected yield", solarthermalworld, 12 February 2016, http://www.solarthermalworld.org/content/italy-conto-termico-20-refers-expected-yield; Gestore Servizi Energetici, "Thermal account (DM 28/12/12)", http://www.gse.it/it/Conto%20Termico/Pages/default.aspx, viewed 20 December 2016.

101 Bärbel Epp, "State subsidies for solar thermal energy in Macedonia", solarthermalworld, 14 February 2017, http://www.solarthermalworld.org/content/state-subsidies-solar-thermal-energy-macedonia.

102 IEA, op. cit. note 91.

103 Filipa Cardoso, "Portugal: Two new incentive schemes on the horizon", solarthermalworld, 18 July 2016, http://www.solarthermalworld.org/content/portugal-two-new-incentive-schemes-horizon.

104 Mihai Vintila, "Romania: Hike in Green House Programme applications", solarthermalworld, 30 October 2016, http://www.solarthermalworld.org/content/romania-hike-green-house-programme-applications.

105 IEA, op. cit. note 91; Frank Stier, "Slovakia: Solar collectors second most favourite choice for green homes", solarthermalworld, 15 January 2016, http://www.solarthermalworld.org/content/slovakia-solar-collectors-second-most-favourite-choice-green-homes.

106 Edie, "Government proposes major RHI reform with removal of support for solar thermal", 4 March 2016, http://www.edie.net/news/11/Renewable-Heat-Incentive-RHI-reform-Government-DECC-consultation-2016/; Philipp Kronsbein, "Solar thermal to stay in the UK Renewable Heat Incentive", Sun Wind Energy, 15 December 2016, http://www.sunwindenergy.com/solar-thermal/solar-thermal-to-stay-uk-renewable-heat-incentive.

107 The criticism of the policy came to be known as the so-called cash-for-ash scandal. Cost overruns were estimated to be around USD 604 million (GBP 490 million). "RHI scandal: RHI 'cash for ash' scandal to cost NI taxpayers GBP490", *BBC News*, 23 December 2016, http://www.bbc.com/news/uk-northern-ireland-38414486.

108 Eva Augsten, "Switzerland: New buildings to reach nearly zero energy standard by 2020", solarthermalworld, 24 January 2015, http://www.solarthermalworld.org/content/switzerland-new-buildings-reach-nearly-zero-energy-standard-2020; Bärbel Epp, "Switzerland: Solar thermal market decline, unclear policy situation", solarthermalworld, 28 July 2016, http://www.solarthermalworld.org/content/switzerland-solar-thermal-market-decline-unclear-policy-situation.

109 This policy was adopted in 2015 and was expected to come into effect in 2017. Epp, op. cit. note 108.

110 Bärbel Epp, "South Africa: Invitation to tender comes several months later than expected", solarthermalworld, 4 January 2016, http://www.solarthermalworld.org/content/south-africa-invitation-tender-comes-several-months-later-expected.

111 Bärbel Epp, "Lesotho, Mozambique and Zimbabwe: Solar thermal policies under development", solarthermalworld, 10 March 2016, http://www.solarthermalworld.org/content/lesotho-mozambique-and-zimbabwe-solar-thermal-policies-under-development.

112 Alejandro Diego Rosell, "Chile: New tax credits – better late than never", solarthermalworld, 2 March 2016, http://www.solarthermalworld.org/content/chile-new-tax-credits-better-late-never.

113 Anil Misra, "UNIDO India: Great potential and efforts to increase awareness of concentrating solar thermal", solarthermalworld, 2 December 2016, http://www.solarthermalworld.org/content/unido-india-great-potential-and-efforts-increase-awareness-concentrating-solar-thermal.

114 Bärbel Epp, "USA; SunShot funds development of cost-effective concentrating collectors", solarthermalworld, 29 August 2016, http://www.solarthermalworld.org/content/usa-sunshot-funds-development-cost-effective-concentrating-collectors; IEA, op. cit. note 91.

115 Alliance for Green Heat, "Tax-credits & incentives", http://www.forgreenheat.org/incentives/federal.html, viewed 6 February 2017.

116 Meghan Sapp, "New York State's Clean Heating Fuel Tax Credit extended through 2020", Biofuels Digest, 2 January 2017, http://www.biofuelsdigest.com/bdigest/2017/01/02/new-york-states-clean-heating-fuel-tax-credit-extended-through-2020/.

117 IEA, op. cit. note 91.

118 Meghan Sapp, "Higher soy oil prices rekindle food vs fuel debate in Argentina", Biofuels Digest, 7 June 2016, http://www.biofuelsdigest.com/bdigest/2016/06/07/higher-soy-oil-prices-rekindle-food-vs-fuel-debate-in-argentina/.

119 Sarantis Michalopoulos, "Commission under fire over post-2020 biofuels targets", Euractiv, 1 December 2016, http://www.euractiv.com/section/energy/news/commission-under-fire-over-post-2020-biofuels-targets/.

120 Natural Resources Canada, "Guiding principles for sustainable biofuels in Canada", 12 January 2016, http://www.nrcan.gc.ca/energy/alternative-fuels/resources/3663.

121 See discussion and sources in endnote 1.

122 Jim Lane, "Biofuels mandates around the world 2017", Biofuels Digest, 28 December 2016, http://www.biofuelsdigest.com/bdigest/2016/12/28/biofuels-mandates-around-the-world-2017/.

123 Ibid.

124 25x'25, "Mexico opens up U.S. ethanol trade opportunities", Weekly REsource, 2 September 2016; Geoff Hayward, "Mexico approves national mandate for blending fuel ethanol", Think Bioenergy, 2 September 2016, http://thinkbioenergy.com/mexico-approves-national-ethanol-mandate/.

125 Ibid.; Meghan Sapp, "Malaysia's long-awaited B10 to be implemented by year's end", Biofuels Digest, 13 September 2016, http://www.biofuelsdigest.com/bdigest/2016/09/13/malaysias-long-awaited-b10-to-be-implemented-by-years-end/; Lane, op. cit. note 122.

126 Meghan Sapp, "India aiming for E22.5 and B15 with new non-conventional feedstocks policy", Biofuels Digest, 5 July 2016, http://www.biofuelsdigest.com/bdigest/2016/07/05/india-aiming-for-e22-5-and-b15-with-new-non-conventional-feedstocks-policy/.

127 Lane, op. cit. note 122.

128 Jim Lane, "Queensland sets new ethanol, biodiesel mandates for 2017", Biofuels Digest, 23 December 2017, http://www.biofuelsdigest.com/bdigest/2016/12/23/queensland-sets-new-ethanol-biodiesel-mandates-for-2017/; Darren House, "Industry concerns over impending Queensland biofuel mandate", *Convenience and Impulse Retailing*, 6 October 2016, http://c-store.com.au/2016/10/06/industry-voices-concerns-impending-queensland-biofuel-mandate/.

129 Meghan Sapp, "Queensland government launches E10 OK campaign", Biofuels Digest, 17 October 2016, http://www.biofuelsdigest.com/bdigest/2016/09/27/queensland-government-launches-e10-ok-campaign.

130 Meghan Sapp, "US District Court says Minnesota's B10 doesn't conflict with RFS", Biofuels Digest, 3 October 2016, http://www.biofuelsdigest.com/bdigest/2016/10/03/us-district-court-says-minnesotas-b10-doesnt-conflictwith-rfs/.

131 Meghan Sapp, "Argentina extends tax breaks for biodiesel through 2017", Biofuels Digest, 4 January 2017, http://www.biofuelsdigest.com/bdigest/2017/01/04/argentina-extends-tax-breaks-for-biodiesel-through-2017/; Ilari Kauppila, "Swedish tax cuts increase biodiesel use, ethanol fails to keep up", 24 October 2016, http://biofuels-news.com/display_news/11248/Swedish_tax_cuts_increase_biodiesel_use__ethanol_fails_to_keep_up/; Meghan Sapp, "Thailand agrees to trial B20 in trucks and B10 for military and government use", Biofuels Digest, 23 June 2016, http://www.biofuelsdigest.com/bdigest/2016/06/23/thailand-agrees-to-trial-b20-in-trucks-and-b10-for-military-and-government-use/.

132 Meghan Sapp, "Hawaii governor signs Renewable Fuels Production Tax Credit into law", Biofuels Digest, 11 July 2016, http://www.biofuelsdigest.com/bdigest/2016/07/11/hawaiian-governor-signs-renewable-fuels-production-tax-credit-into-law/; Meghan Sapp, "Iowa Senate extends biofuel tax credits through 2025", Biofuels Digest, 14 April 2016, http://www.biofuelsdigest.com/bdigest/2016/04/14/iowa-senate-extends-biofuel-tax-credits-through-2025/.

133 Meghan Sapp, "Argentina hits biodiesel industry again with

another boost to export tax", Biofuels Digest, 14 March 2016, http://www.biofuelsdigest.com/bdigest/2016/03/14/argentina-hits-biodiesel-industry-again-with-another-boost-to-export-tax/; Meghan Sapp, "Brazil drops PIS/Cofins tax exemption on ethanol as of January 1", Biofuels Digest, 2 January 2017, http://www.biofuelsdigest.com/bdigest/2017/01/02/brazil-drops-piscofins-tax-exemption-on-ethanol-as-of-january-1/; Wes Swift, "No guarantee US biodiesel tax credit gets extended this term: Grassley spokeswoman", Platts, 22 November 2016, https://www.platts.com/latest-news/agriculture/houston/no-guarantee-us-biodiesel-tax-credit-gets-extended-21141388.

134 International Civil Aviation Organization, "Historic agreement reached to mitigate international aviation emissions", press release (Montreal: 6 October 2016), https://www.icao.int/Newsroom/Pages/FR/Historic-agreement-reached-to-mitigate-international-aviation-emissions.aspx.

135 Jim Lane, "Denmark sets 0.9% advanced biofuels blending mandates for 2020", Biofuels Digest, 18 December 2016, http://www.biofuelsdigest.com/bdigest/2016/12/18/denmark-sets-0-9-advanced-biofuels-blending-mandate-for-2020/.

136 Meghan Sapp, "Australian Renewable Energy Agency gives A$2.4 million grant for biorefinery project", Biofuels Digest, 28 June 2016, http://www.biofuelsdigest.com/bdigest/2016/06/28/australian-renewable-energy-agency-gives-a2-4-million-grant-for-biorefinery-project/.

137 Meghan Sapp, "Obama administration launches Sustainable Biofuels Innovation Challenge", Biofuels Digest, 15 November 2016, http://www.biofuelsdigest.com/bdigest/2016/11/15/obama-administration-launches-sustainable-biofuels-innovation-challenge/; Meghan Sapp, "DOE approves $90 million for biorefinery projects", Biofuels Digest, 9 May 2016, http://www.biofuelsdigest.com/bdigest/2016/05/09/doe-approves-90-million-for-biorefinery-projects/; "US Energy Department funds low-carbon jet fuel demonstration project", Renewable Energy World, 6 January 2017, http://www.renewableenergyworld.com/articles/2017/01/us-energy-department-funds-low-carbon-jet-fuel-demonstration-plant.html.

138 Jim Lane, "White House releases 'Federal Alternative Jet Fuel Research and Development Strategy'", Biofuels Digest, 31 July 2016, http://www.biofuelsdigest.com/bdigest/2016/07/31/white-house-releases-federal-alternative-jet-fuel-research-and-development-strategy/; California Environmental Protection Agency, "Public Workshop to Discuss Potential LCFS Rulemaking Items", 24 October 2016, https://www.arb.ca.gov/fuels/lcfs/lcfs_meetings/workshoppresentation_102416.pdf.

139 Government of India Ministry of Shipping, "Ministry of Shipping plans 160.64 mega watt renewable energy projects at major ports by 2017", press release (New Delhi: 11 August 2016), http://pib.nic.in/newsite/PrintRelease.aspx?relid=148737.

140 US National Renewable Energy Laboratory, "Electric vehicle grid integration", http://www.nrel.gov/transportation/project_ev_grid_integration.html, viewed 8 February 2017.

141 Cities account for 65% of global primary energy supply as of 2014. IRENA, *Renewable Energy in Cities* (Abu Dhabi: October 2016), http://www.irena.org/DocumentDownloads/Publications/IRENA_Renewable_Energy_in_Cities_2016.pdf.

142 Japan for Sustainability, "Renewable energy on the rise in Japan: 100 self-sufficient municipalities, Oita largest prefectural supplier by self-sufficiency ratio", 4 September 2016, http://www.japanfs.org/en/news/archives/news_id035635.html.

143 ICLEI–Local Governments for Sustainability, "Australian Capital Territory, powered by 100% renewable energy by 2020, heads towards zero emissions by 2050", 20 May 2016, http://www.iclei.org/details/article/australian-capital-territory-powered-by-100-renewable-energy-by-2020-on-zero-emissions-path-by-205.html.

144 Solar Novus, "Boulder, Colorado becomes latest US city to commit to 100% clean energy", Solar Novus, 1 September 2016, http://www.solarnovus.com/boulder-colorado-becomes-latest-us-city-to-commit-to-100-clean-energy_N10285.html; Go 100% Renewable Energy, "Salt Lake City – 100% renewable electricity by 2032", http://www.go100percent.org/cms/index.php?id=77&tx_ttnews%5Btt_news%5D=428&cHash=5b212ba3bd7ecffe803d7fc3d9961df5, viewed 7 January 2017; Go 100% Renewable Energy, "St. Petersburg – 100% renewable energy city", http://www.go100percent.org/cms/index.php?id=77&tx_ttnews%5Btt_news%5D=434&cHash=6517213bd898f2dbdad1053f8f1546fa, viewed 7 January 2017.

145 Michelle Kinman, "Los Angeles to chart path to 100% renewable energy", Environment California, 16 September 2016, http://www.environmentcalifornia.org/news/cae/los-angeles-chart-path-100-renewable-energy.

146 Katherina McKenna, "Government to run on green power by 2025", *Guelph Mercury Tribune*, 2 November 2016, http://www.guelphmercury.com/news-story/6943842-government-to-run-on-green-power-by-2025-mckenna/.

147 Kenji Kaneko, "Tokyo aims to increase ration of renewable energy-derived electricity to 20% by 2030", *Nikkei BP*, 3 March 2016, http://techon.nikkeibp.co.jp/atclen/news_en/15mk/030400422/?ST=msbe.

148 Annie Kilian, "City of Cape Town sets target of sourcing 20% energy needs from renewables", *Engineering News*, 22 March 2016, http://www.engineeringnews.co.za/article/city-of-cape-town-sets-target-of-sourcing-20-energy-needs-from-renewables-2016-03-22/rep_id:4136.

149 New York City Office of the Mayor, "Climate Week: Solar power In NYC nearly quadrupled since Mayor de Blasio took office and administration expands target", 23 September 2016, http://www1.nyc.gov/office-of-the-mayor/news/767-16/climate-week-solar-power-nyc-nearly-quadrupled-since-mayor-de-blasio-took-office-and.

150 Saqib Rahim, "NYC details how it can move to 'renewables-based' grid", *E&E News*, 28 September 2016, http://www.eenews.net/climatewire/2016/09/28/stories/1060043540; Julian Spector, "New York City sets the first citywide energy storage target", Greentech Media, 27 September 2016, https://www.greentechmedia.com/articles/read/new-york-city-becomes-first-to-set-citywide-energy-storage-target.

151 Maryke van Staden, Chang Deng-Beck and Cesar Carreño, *carbonn® Climate Registry 2015-2016 Digest* (Bonn: Bonn Center for Local Climate Action and Reporting, ICLEI–Local Governments for Sustainability, 2016), http://e-lib.iclei.org/wp-content/uploads/2016/11/ccr-report-2015_2016-Digest-web.pdf.

152 US Department of Energy, "Cities leading through energy analysis and planning", https://www.energy.gov/eere/cities-leading-through-energy-analysis-and-planning, viewed 6 February 2017.

153 "Santa Monica approves solar requirement for new construction", Renewable Energy World, 3 May 2016, http://www.renewableenergyworld.com/articles/2016/05/santa-monica-approves-solar-requirement-for-new-construction.html; Anne Mulken, "City approves first-of-its-kind zero-net-energy rule for homes", Energy Wire, 31 October 2016, http://www.eenews.net/climatewire/2016/10/31/stories/1060045031.

154 Bärbel Epp, "California: San Francisco passes first mandate with solar thermal option", solarthermalworld, 14 July 2016, http://www.solarthermalworld.org/content/california-san-francisco-passes-first-mandate-solar-thermal-option.

155 IEA, op. cit. note 91.

156 Alister Doyle, "Oslo's radical 'climate budget' aims to halve carbon emissions in four years", *Reuters*, 29 September 2016, http://planetark.org/wen/74814.

157 Meghan Sapp, "New York City approves biodiesel blending bill for bio-heat", Biofuels Digest, 28 September 2016, http://www.biofuelsdigest.com/bdigest/2016/09/28/new-york-city-approves-biodiesel-blending-bill-for-bioheat/.

158 Saqib Rahim, "NYC details how it can move to 'renewables-based' grid", *E&E News*, 28 September 2016, http://www.eenews.net/climatewire/2016/09/28/stories/1060043540; NYC Retrofit Accelerator, https://retrofitaccelerator.cityofnewyork.us/, viewed 28 January 2017.

159 Doyle, op. cit. note 156.

160 Tom Gardner, "Reykjavik unveils plan to limit urban sprawl to become carbon neutral by 2040", *Reuters*, 13 September 2016, http://planetark.org/wen/74754.

161 "Seattle-Tacoma signs groundbreaking new sustainable fuel agreement", *Airport World*, 31 October 2016, http://www.airport-world.com/news/general-news/5896-seattle-tacoma-signs-groundbreaking-new-sustianablefuel-agreement.html; Meghan Sapp, "Sacramento County turns to renewable LNG for 60 vehicles in its fleet", Biofuels Digest, 8 September 2016, http://www.biofuelsdigest.com/bdigest/2016/09/08/sacramento-county-turns-to-renewable-lng-for-60-vehicles-in-its-fleet/.

162 Meghan Sapp, "Mumbai drops import tax on ethanol from April 1", Biofuels Digest, 22 February 2016, http://www.biofuelsdigest.com/bdigest/2016/02/22/mumbai-drops-import-tax-on-ethanol-from-april-1/.

163 C40 Cities, *Deadline 2020* (London: 2016), http://www.c40.org/researches/deadline-2020.

164 Covenant of Mayors for Climate & Energy, "About", http://www.covenantofmayors.eu/index_en.html, viewed 9 February 2017.

165 Albana Kona et al., *Covenant of Mayors: Greenhouse Gas Emissions Achievement and Projections* (Luxembourg: Publications Office of the European Union, 2016), http://publications.jrc.ec.europa.eu/repository/bitstream/JRC103316/jrc103316_com%20achievements%20and%20projections_online.pdf.

166 Climate Summit for Local and Regional Leaders, *Marrakech Roadmap for Action* (Marrakech: 14 November 2016), http://media.wix.com/ugd/bfe783_fbcf44e818e744a7bebbd0f14687df4c.pdf.

167 Covenant of Mayors, "The Covenant of Mayors in Sub-Saharan Africa, launch event at COP22", 19 December 2016, http://www.covenantofmayors.eu/news_en.html?id_news=792.

168 Habitat III, "The New Urban Agenda", https://habitat3.org/the-new-urban-agenda/, viewed 9 February 2017.

ENABLING TECHNOLOGIES AND ENERGY SYSTEMS INTEGRATION

1 US Department of Energy (DOE), Office of Electricity Delivery & Energy Reliability, *Insights Into Advanced Distribution Management Systems* (Washington, DC: February, 2015), https://www.smartgrid.gov/files/ADMS-Guide_2-11.2015.pdf.

2 M. Stanley Whittingham, "History, evolution, and future status of energy storage", *Proceedings of the IEEE*, vol. 100, Special Centennial Issue (May 2012): 1518-34, http://ieeexplore.ieee.org/document/6184265.

3 See, for example, Clean Energy Ministerial, "Electric Vehicles Initiative (EVI)", http://www.cleanenergyministerial.org/Our-Work/Initiatives/Electric-Vehicles/Policy-Opportunities, viewed 26 February 2017; California Air Resources Board, "Zero Emission Vehicle Program", https://www.arb.ca.gov/msprog/zevprog/zevprog.htm, viewed 26 February 2017.

4 International Renewable Energy Agency (IRENA), "Chapter 4 – Innovations in technology", in *REthinking Energy 2017: Accelerating the Global Energy Transformation* (Abu Dhabi: 2017), http://www.irena.org/DocumentDownloads/Publications/IRENA_REthinking_Energy_2017.pdf.

5 Jacquelin Cochran et al., *Flexibility in 21st Century Power Systems* (Golden, CO: National Renewable Energy Laboratory (NREL), 2014), http://www.nrel.gov/docs/fy14osti/61721.pdf; David Jacobs et al., *RE-TRANSITION: Transitioning to Policy Frameworks for Cost-Competitive Renewables* (Utrecht, The Netherlands: IEA Technology Collaboration Programme for Renewable Energy Technology Deployment (IEA-RETD), 2016), http://iea-retd.org/wp-content/uploads/2016/03/IEA-RETD_RE-TRANSITION.pdf; IRENA, "Chapter 2 – Policies, regulations and market design", in *REthinking Energy 2017*, op. cit. note 4; Garrett Fitzgerald, Chris Nelder and James Newcomb, *Electric Vehicles as Distributed Energy Resources* (Basalt, CO: Rocky Mountain Institute (RMI), 2016), http://www.rmi.org/pdf_evs_as_DERs; Garrett Fitzgerald et al., *The Economics of Battery Energy Storage: How Multi-use, Customer-sited Batteries Deliver the Most Services and Value to Customers and the Grid* (Basalt, CO: RMI, 2015), https://rmi.org/insights/reports/economics-battery-energy-storage/; Ramteen Sioshansi, Paul Denholm and Thomas Jenkin, "Market and policy barriers to deployment of energy storage", *Economics of Energy and Environmental Policy*, vol. 1, no. 2 (2012), p. 47, http://www.iaee.org/en/publications/eeeparticle.aspx?id=20.

6 Craig Morris and Martin Pehnt, "Sector coupling", in *Energy Transition – The German Energiewende Book* (2016), https://book.energytransition.org/sector-coupling; European Political Strategy Center, Toward Low-Emission Mobility: *Driving the Modernisation of the EU Economy*, EPSC Strategic Notes (Brussels: 20 July 2016), http://ec.europa.eu/transport/sites/transport/files/themes/strategies/news/doc/2016-07-20-decarbonisation/2016-07-20-strategic-note-issue18-low-emission-mobility.pdf; Henrik Klinge Jacobsen and Stephanie Ropenus, Agora Energiewende, "A Snapshot of the Danish Energy Transition in the Power Sector: An Overview", presentation, 12 November 2015, https://www.agora-energiewende.de/fileadmin/Projekte/2015/integration-variabler-erneuerbarer-energien-daenemark/1.2_Stephanie_Ropenus_and_Henrik_K._Jacobsen_Presentation_12112015.pdf; Kurt Rohrig, Fraunhofer Institute for Wind and Energy System Technology, and Dietrich Schmidt, Fraunhofer Institute for Building Physics, "Coupling the Electricity and Heat Sectors: The Key to the Transformation of the Energy System", presentation at Workshop on Renewables and Energy Systems Integration, Golden, CO, September 2014, http://iiesi.org/assets/pdfs/iiesi_sept_rohrig.pdf.

7 IRENA, op. cit. note 4; Fitzgerald, Nelder and Newcomb, op. cit. note 5; Fitzgerald et al., op. cit. note 5; Sioshansi, Denholm and Jenkin, op. cit. note 5. Also based on input from Matthijs van Leeuwen, Norton Rose Fulbright LLP, and from Owen R. Zinaman, NREL, Golden, CO, personal communications with REN21, January-March 2017.

8 IRENA, *REthinking Energy 2017*, op. cit. note 4, p. 76.

9 Sioshansi, Denholm and Jenkin, op. cit. note 5. **Figure 49** based on input from Matthijs van Leeuwen, Norton Rose Fulbright LLP, Amsterdam, personal communication with REN21, March 2017.

10 Insight Energy, *Policy Report – Business Models for Flexible Production and Storage*, prepared for European Commission (Brussels: 2015), http://www.innoenergy.com/wp-content/uploads/2016/06/PR-4_Business-models.pdf; Scott P. Burger and Max Luke, *Business Models for Distributed Energy Resources: A Review and Empirical Analysis* (Cambridge, MA: MIT Energy Initiative, 2016), https://energy.mit.edu/wp-content/uploads/2016/04/MITEI-WP-2016-02.pdf.

11 DOE, Office of Electricity Delivery & Energy Reliability, "DOE Global Energy Storage Database", www.energystorageexchange.org, viewed January 2017.

12 International Energy Agency (IEA), *Technology Roadmap – Energy Storage* (Paris: March 2014), https://www.iea.org/publications/freepublications/publication/TechnologyRoadmapEnergystorage.pdf; IRENA, *Thermal Energy Storage – Technology Brief* (Abu Dhabi: 2013), https://www.irena.org/DocumentDownloads/Publications/IRENA-ETSAP%20Tech%20Brief%20E17%20Thermal%20Energy%20Storage.pdf.

13 DOE, op. cit. note 11. Downward adjustment was made for one 150 MW molten salt thermal storage installation in the United States, which was not built; pumped storage total of 150 GW from International Hydropower Association (IHA), 2017 *Key Trends in Hydropower* (London: 2017), https://www.hydropower.org/2017-key-trends-in-hydropower; total of 159.5 GW of pumped storage, including mixed plants, from IRENA, *Renewable Capacity Statistics 2017* (Abu Dhabi: April 2017), http://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Capacity_Statistics_2017.pdf. **Figure 52** based on data from DOE, op. cit. note 1. Downwards adjustment made for one 150 MW molten salt thermal storage installation in the United States, which was not built; and from IHA, op. cit. this note.

14 Pumped storage total of 150 GW from IHA, op. cit. note 13; total of 159.5 GW of pumped storage, including mixed plants, from IRENA, op. cit. note 13.

15 DOE, op. cit. note 11. Downwards adjustment made for one 150 MW molten salt thermal storage installation in the United States, which was not built.

16 DOE, Office of Electricity Delivery & Energy Reliability, "DOE Global Energy Storage Database: Projects", http://www.energystorageexchange.org/projects, viewed 20 March 2017.

17 Ibid.

18 Ibid.

19 Ibid.

20 Ibid.

21 Ibid. **Figure 51** based on DOE, op. cit. note 11. Downwards adjustment made for one 150 MW molten salt thermal storage installation in the United States, which was not built.

22 Ibid.

23 Rob Nikolewski, "Utilities meet tight energy storage deadline", *San Diego Union-Tribune*, 13 September 2016, http://www.sandiegouniontribune.com/business/energy-green/sdut-energy-storage-deadline-2016sep13-story.html.

24 GTM Research, *US Energy Storage Monitor: 2016 Year in Review and Q1 2017 Executive Summary* (March 2017), p. 10, https://www.greentechmedia.com/research/report/us-energy-storage-monitor-q1-2017.

25 Jason Deign, "Who will benefit from South Korea's solar-plus-storage incentive?" Greentech Media, 5 October 2016, https://www.greentechmedia.com/articles/read/who-will-benefit-from-south-koreas-storage-incentive.

26 Namgil Paik, KEPCO, "KEPCO's Frequency Regulation Energy Storage System Project", presentation at IEA-ISGAN Workshop, Paris, 11 October 2016, http://www.iea-isgan.org/bbs/board.php?bo_table=sub3_11a&wr_id=4.

27 DOE, Office of Electricity Delivery & Energy Reliability, "DOE Global Energy Storage Database: Data visualization", http://www.energystorageexchange.org/projects/data_visualization, updated 16 August 2016.

28 Takuya Yamazaki, Agency for Natural Resources and Energy, Japan Ministry of Economy, Trade and Industry, "Japan's Electricity Market Reform and Beyond", presentation, 7 July 2015, https://www.iea.org/media/workshops/2015/esapplenaryjuly2015/Yamazaki.pdf.

29 DOE, op. cit. note 27.

30 DOE, op. cit. note 11.

31 Kai-Philipp Kairies et al., *Wissenschaftliches Mess- und Evaluierungsprogramm Solarstromspeicher, Jahresberricht 2016* (Aachen, Germany: Stromrichter-technik und

Elektrische Antriebe, RWTH Aachen University, prepared for Bundesministerium für Wirtschaft und Energie (BMWi), 2016), p. 45, http://www.speichermonitoring.de/fileadmin/user_upload/Speichermonitoring_Jahresbericht_2016_Kairies_web.pdf; Sebastian Hermann, German Environment Agency, personal communication with REN21, February 2017.

32 Martin Ammon, EuPD Research, "Status Quo and Potentials for the Residential Segment", presentation at European PV and Energy Storage Market Briefing, Frankfurt, Germany, 16 February 2017, slides 20, 21; EuPD Research, "The market is talking about Tesla, German battery storage companies leading in market shares", press release (Bonn: 26 October 2016), http://www.eupd-research.com/en/home/view-details/the-market-is-talking-about-tesla-german-battery-storage-companies-leading-in-market-shares/.

33 AES Energy Storage, "AES Netherlands Advancion energy storage array now serving European grid", press release (Vlissingen, The Netherlands: 13 January 2016), http://aesenergystorage.com/2016/01/13/aes-netherlands-advancion-energy-storage-array-now-serving-european-grid/.

34 National Grid, "EFR tender results of 26 August 2016", http://www2.nationalgrid.com/Enhanced-Frequency-Response.aspx, viewed 26 February 2017; Jeff St. John, "UK's National Grid goes big into energy storage with 201 MW of fast-acting batteries", Greentech Media, 30 August 2016, https://www.greentechmedia.com/articles/read/uks-national-grid-goes-big-into-energy-storage-with-201mw-of-fast-acting-ba.

35 China National Energy Administration, "Notification on Promoting the Participation of Energy Storage in the Compensation (Market) Mechanism of Electric Power Ancillary Services in the Three Northern China Regions" (Beijing: 2016), http://zfxxgk.nea.gov.cn/auto92/201606/t20160617_2267.htm. See also Andy Colthorpe, "China announced nearly 600MW of energy storage in Q3 2016", Energy Storage News, 15 December 2016, http://www.energy-storage.news/news/china-announced-nearly-600mw-of-energy-storage-in-q3-2016.

36 Australian Energy Council, *Renewable Energy in Australia: How Do We Really Compare?* (Melbourne: 2015), https://www.energycouncil.com.au/media/1318/2016-06-23_aec-renewables-fact-sheet.pdf; Sophie Vorrath, "Mercedes Benz set to launch home battery storage in Australia", One Step Off the Grid, 29 June 2016, http://onestepoffthegrid.com.au/mercedes-benz-set-to-launch-home-battery-storage-in-australia/.

37 See, for example, Peter Maloney, "One good year deserves another: energy storage in 2016", Renewable Energy World, 27 January 2016, http://www.renewableenergyworld.com/articles/2016/01/one-good-year-deserves-another-energy-storage-in-2016.html.

38 Australian Renewable Energy Agency, *Energy Storage Study: Funding Knowledge and Sharing Priorities* (Canberra: 2015), pp. 63-68, https://arena.gov.au/files/2015/07/AECOM-Energy-Storage-Study.pdf.

39 Nigel Morris, "Battery storage: Is Australia on the track to be the world's biggest market?" One Step Off the Grid, 8 February 2017, https://onestepoffthegrid.com.au/battery-storage-australia-track-world-biggest-market.

40 "CSP plant illuminated Bokpoort community at official inauguration", *ESI Africa*, 15 March 2016, https://www.esi-africa.com/news/csp-plant-illuminates-bokpoort-community-at-official-inauguration; "Khi Solar One kicks into commercial operation", ESI Africa, 8 February 2016, https://www.esi-africa.com/news/khi-solar-one-kicks-into-commercial-operation/; "SA thermal solar plant hits project milestone", ESI Africa, 30 March 2016, https://www.esi-africa.com/news/sa-thermal-solar-plant-hits-project-milestone.

41 Jennifer Zhang, "Shouhang Dunhang 10MW molten salt tower CSP plant will put into operation, open to visitors on December 29th", CSP Plaza, 9 November 2016, http://en.cspplaza.com/shouhang-dunhuang-10mw-molten-salt-tower-csp-plant-will-put-into-operation-open-to-visitors-on-december-29th.html; NREL, "SunCan Dunhuang 10 MW Phase 1", 11 January 2017, https://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=6315.

42 Werner Weiss, Institute for Sustainable Technologies (AEE INTEC), Gleisdorf, Austria, personal communication with REN21, 31 January 2017.

43 Ibid.

44 RWE International, "Innogy signs contract to acquire BELECTRIC Solar & Battery", press release (Essen, Germany: 29 August 2016), http://www.belectric.com/fileadmin/MASTER/pdf/press_releases/BEL_PM_2016-08-29_Erwerb_BELECTRIC_EN.pdf; Saft, "Total takes control of Saft Groupe after the successful tender offer which will be reopened from July 19 to August 2, 2016", press release (Paris: 18 July 2016), http://www.saftbatteries.com/press/press-releases/total-takes-control-saft-groupe-after-successful-tender-offer-which-will-be-re.

45 Zachary Shahan, "Panasonic dominates EV battery cell production rankings… with Gigafactory on Horizon", CleanTechnica, 31 July 2016, https://cleantechnica.com/2016/07/31/panasonic-dominates-ev-battery-cell-production-rankings-gigafactory-horizon/.

46 Dee-Ann Durbin, "Tesla opens Gigafactory to expand battery production, sales", *Bloomberg*, 27 July 2016, https://www.bloomberg.com/news/articles/2016-07-26/tesla-opens-gigafactory-to-expand-battery-production-sales; Karl-Erik Stromsta, "Tesla begins turning out battery cells at Gigafactory", Recharge News, 4 January 2017, http://www.rechargenews.com/solar/1204073/tesla-begins-turning-out-battery-cells-at-gigafactory.

47 Navigant Research, "LG Chem, Panasonic, and Samsung SDI score highest in assessment of lithium ion battery manufacturers", press release (Boulder, CO: 3 December 2015), https://www.navigantresearch.com/newsroom/lg-chem-panasonic-and-samsung-sdi-score-highest-in-assessment-of-lithium-ion-battery-manufacturers.

48 Jie Ma, "Battery maker helping power China electric car boom plans IPO", *Bloomberg*, 1 September 2016, https://www.bloomberg.com/news/articles/2016-09-01/battery-maker-helping-power-china-electric-car-boom-plans-ipo.

49 Daimler, "Daimler starts deliveries of Mercedes-Benz energy storage units for private homes", press release (Stuttgart/Kamenz: 22 April 2016), http://media.daimler.com/marsMediaSite/en/instance/ko/Daimler-startsdeliveries-of-Mercedes-Benz-energy-storage-un.xhtml?oid=10044927; Ian Clover, "Over to you, storage", *PV Magazine*, 11 November 2016, http://www.pv-magazine.com/news/details/beitrag/the-pv-magazine-weekly-news-digest_100026880/.

50 Jason Deign, "Germany's second-biggest utility plans to launch a residential solar-plus-storage offering", Greentech Media, 4 March 2016, https://www.greentechmedia.com/articles/read/germanys-second-biggest-utility-plans-to-launch-a-solar-plus-storage-offeri; E.ON, "About us: 2000-2016", http://www.eon.com/en/about-us/profile/history/2000-2016.html, viewed 10 March 2017.

51 Julia Pyper, "Sonnen launches a home battery for self-consumption at a 40% reduced cost", Greentech Media, 7 July 2016, https://www.greentechmedia.com/articles/read/Sonnen-Launches-a-Home-Battery-for-Self-Consumption-at-a-40-Reduced.

52 EuPD Research, op. cit. note 32.

53 "California companies form partnerships for solar+storage", Renewable Energy World, 3 May 2016, http://www.renewableenergyworld.com/articles/pt/2016/05/california-companies-form-partnership-for-solar-storage.html; "Verengo Solar and Swell Energy announce residential energy storage partnership", Market Wired, 27 April 2016, http://www.marketwired.com/press-release/verengo-solarand-swell-energy-announce-residential-energy-storagepartnership-2118740.htm; Clover, op. cit. note 49.

54 Sungrow, "Sungrow-Samsung SDI officially launches", press release (Hefei, China: 12 July 2016), http://en.sungrowpower.com/event-press/news/322.html.

55 James Paton, "Enphase says Australia energy storage demand twice its forecast", Renewable Energy World, 1 June 2016, http://www.renewableenergyworld.com/articles/2016/06/enphase-says-australia-energy-storage-demand-twice-its-forecast.html.

56 Brian Parkin, "GE Ventures buys stake in Sonnen to boost position in solar energy storage market", Renewable Energy World, 6 June 2016, http://www.renewableenergyworld.com/articles/2016/06/ge-ventures-buys-stake-in-sonnen-to-boost-position-in-solar-energy-storage-market.html; Bernd Radowitz, "Envision takes stake in Sonnen in $85m financing round", Recharge News, updated 25 October 2016, http://www.rechargenews.com/solar/1182485/

envision-takes-stake-in-sonnen-in-usd-85m-financing-round.

57 William Steel, "Tesla Powerpack arrives in Europe", Renewable Energy World, 29 December 2016, http://www.renewableenergyworld.com/articles/2016/12/tesla-powerpack-arrives-in-europe.html; "Sungrow successfully installs the world's largest PV & energy storage microgrid plant", Penn Energy, 26 October 2016, http://www.pennenergy.com/articles/pennenergy/2016/10/sungrow-successfully-installs-the-world-s-largest-pv-energy-storage-microgrid-plant.html.

58 "Solar power deals and company news", Recharge News, updated 25 April 2016, http://www.rechargenews.com/solar/867268/solar-power-deals-and-company-news.

59 SkyPower, "SkyPower enters into agreement with BYD to submit joint bid for 750 MW of solar energy development in India", press release (Vancouver: 13 May 2016), http://www.skypower.com/skypower-enters-into-agreement-with-byd-to-submit-joint-bid-for-750-mw-of-solar-energy-development-in-india/; see also "Solar power deals and company news", Recharge News, 9 May 2016, http://www.rechargenews.com/solar/1183694/solar-power-deals-and-company-news.

60 E.ON already has a grid-connected battery project under way in Arizona, from E.ON, "E.ON aims to establish itself as an energy storage provider for the US market", press release (Essen, Germany: 3 March 2017), http://www.eon.com/en/media/news/press-releases/2017/3/3/eon-aims-to-establish-itself-as-an-energy-storage-provider-for-the-us-market.html.

61 Stornetic, "Wind firming with flywheels", press release (Jülich, Germany: 26 September 2016), http://stornetic.com/assets/downloads/Press_release_Wind_firming_with_flywheels.pdf.

62 Stornetic, "Stornetic launches new megawatt energy storage unit", press release (Jülich, Germany: 15 February 2016), http://stornetic.com/assets/downloads/Press_release_Stornetic_DuraStor_1000.pdf; EDF and Stornetic, "EDF and Stornetic start project on advanced smart grids storage solutions", press release (Paris and Jülich, Germany: 17 November 2016), http://stornetic.com/assets/downloads/Press_release_EDF_and_STORNETIC_start_project.pdf.

63 James Blackman, "German firm touts flywheel storage system for train operators", Energy Storage News, 12 September 2016, http://www.energy-storage.news/news/german-firm-touts-flywheel-storage-system-for-train-operators.

64 Lazard's Levelized Cost of Storage Version 2.0 (December 2016), pp. 19-21, https://www.lazard.com/media/438042/lazard-levelized-cost-of-storage-v20.pdf.

65 McKinsey & Company and Bloomberg New Energy Finance (BNEF), *An Integrated Perspective on the Future of Mobility* (October 2016), p. 15, http://www.bbhub.io/bnef/sites/4/2016/10/BNEF_McKinsey_The-Future-of-Mobility_11-10-16.pdf.

66 Strategen estimates based on projected cost information collected from vendors and public information sources.

67 Lazard's Levelized Cost of Storage Version 2.0, op. cit. note 64.

68 Ibid.

69 Ibid.

70 William Steel, "Storing energy in the sea – a new design for marine energy storage", Renewable Energy World, 9 September 2016, http://www.renewableenergyworld.com/articles/2016/09/storing-energy-in-the-sea-a-new-design-for-marine-energy-storage.html.

71 Sara Knight, "Germany: GE has won a contract to supply the turbines for a novel pilot project combining wind energy with a hydro pumped storage plant", *Windpower Monthly*, 30 September 2016, http://www.windpowermonthly.com/article/1410777/ge-supply-combined-wind-hydro-pumped-storage-pilotproject; Elizabeth Ingram, "Pilot project combining wind and pumped storage hydro under construction in Germany", Hydro World, 6 October 2016, http://www.hydroworld.com/articles/2016/10/pilot-project-combining-wind-and-pumped-storage-hydro-under-construction-in-germany.html.

72 Peter Maloney, "NYC targets 100 MWh energy storage by 2020", Utility Dive, 28 September 2016, http://www.utilitydive.com/news/nyc-targets-100-mwh-energy-storage-by-2020/427041/.

73 Robert Walton, "Facing stricter climate goals, California passes 4 bills to boost energy storage", Utility Dive, 2 September 2016, http://www.utilitydive.com/news/facing-stricter-climate-goals-california-passes-4-bills-to-boostenergy-st/425671/.

74 Rob Nikolewski, "Utilities meet tight energy storage deadline", *San Diego Union-Tribune*, 13 September 2016, http://www.sandiegouniontribune.com/business/energy-green/sdut-energy-storage-deadline-2016sep13-story.html.

75 Peter Maloney, "One good year deserves another: energy storage in 2016", Renewable Energy World, 27 January 2016, http://www.renewableenergyworld.com/articles/2016/01/one-good-year-deserves-another-energy-storage-in-2016.html.

76 Glenn Meyers, "Massachusetts passes 3rd US energy storage mandate", CleanTechnica, 12 August 2016, https://cleantechnica.com/2016/08/12/massachusetts-passes-3rd-us-energy-storage-mandate/.

77 Minimum Technical Requirement regulations issued by government-owned Puerto Rican electric power company Autoridad de Energia Electrica, from Andy Colthorpe, "Puerto Rico introduces mandate for energy storage in new renewable projects", PV-Tech, 17 December 2013, https://www.pv-tech.org/news/puerto_rico_introduces_mandate_for_energy_storage_in_new_renewables_project.

78 Maloney, op. cit. note 75.

79 The policy aims to install 100 MW of capacity in Andhra Pradesh and 200 MW in Karnataka. Saurabh, "India to tender 300 MW solar power storage tender", Cleantechies, 31 July 2016, http://cleantechies.com/2016/07/31/india-to-tender-300-mw-solar-power-storage-tender/.

80 Suriname from Roger Sallent, Inter-American Development Bank, personal communication with REN21, 2 December 2016.

81 European Commission, *Energy Storage: Proposed Policy Principles and Definition* (Brussels: June 2016), https://ec.europa.eu/energy/sites/ener/files/documents/Proposed%20definition%20and%20principles%20for%20energy%20storage.pdf.

82 US Federal Energy Regulatory Commission (FERC), "Notice of Proposed Rulemaking", 17 November 2016, https://www.ferc.gov/whats-new/comm-meet/2016/111716/E-1.pdf.

83 FERC, "Order 755", 20 October 2011, https://www.ferc.gov/whats-new/comm-meet/2011/102011/E-28.pdf.

84 "Germany's solar+storage subsidy extended to 2018", PV Magazine, 22 February 2016, https://www.pv-magazine.com/2016/02/22/germanys-solarstorage-subsidy-extended-to-2018_100023314/; IEA/IRENA Joint Policies and Measures Database, "Subsidy for solar PV with storage installations", 18 March 2016, http://www.iea.org/policiesandmeasures/pams/germany/name-154525-en.php.

85 IEA Photovoltaic Power Systems Programme (IEA-PVPS), *Trends in Photovoltaic Applications, 2016: Survey Report of Selected IEA Countries Between 1992 and 2015* (Paris: 2016), p. 13, http://www.ieapvps.org/fileadmin/dam/public/report/national/Trends_2016_-_mr.pdf.

86 Government of Sweden, "Focus on investments in solar cells and new technology", 21 September 2015, http://www.regeringen.se/pressmeddelanden/2015/09/fokus-pa-investeringar-i-solceller-och-ny-teknik/.

87 IEA-PVPS, op. cit. note 85, p. 44; "India not doing enough to capture energy storage opportunity", Bridge to India, 14 March 2017, http://www.bridgetoindia.com/india-not-enough-capture-energy-storage-opportunity/.

88 Seerat Chabba, "South Korea to invest $36 billion in renewable energy by 2020", *International Business Times*, 5 July 2016, http://www.ibtimes.com/south-korea-invest-36-billion-renewable-energy-2020-2389326.

89 Susan Kraemer, "When is energy storage eligible for the 30 percent ITC", Renewable Energy World, 17 February 2016, http://www.renewableenergyworld.com/articles/2016/02/when-is-energy-storage-eligible-for-the-30-percent-itc.html.

90 25X'25, "DOE announces $18 million to develop solar storage solutions", Weekly REsource, 22 January 2016.

91 California Public Utilities Commission, "Self-Generation Incentive Program", http://www.cpuc.ca.gov/sgip/, viewed 20 March 2017.

92 The incentive was launched in May 2014 by the New York State Energy Research and Development Agency, from Maloney, op. cit. note 75.

93 Adelaide City Council website, www.adelaidecitycouncil.com; IEA-PVPS, op. cit. note 85, p. 44.

94 European Heat Pump Association (EHPA), personal

communication with REN21, November 2016-March 2017.

95 IEA, *Medium-Term Renewable Energy Market Report 2016* (Paris: 2016), p. 241.

96 Ibid., p. 241.

97 John W. Lund and Tonya L. Boyd, "Direct utilization of geothermal energy 2015 worldwide review", *Geothermics*, vol. 60 (March 2016), pp. 66-93, http://dx.doi.org/10.1016/j.geothermics.2015.11.004.

98 Top European markets from EHPA, op. cit. note 94.

99 EHPA, *European Heat Pump Market and Statistics Report 2016* (Brussels: 2016).

100 Ibid.

101 Ibid.

102 Lund and Boyd, op. cit. note 97. Top European markets from EHPA, op. cit. note 94.

103 Ibid., both references.

104 EHPA, "Heat pump sales in Germany – 2015", 26 January 2016, http://www.ehpa.org/about/news/article/heat-pump-sales-in-germany-2015/.

105 Finnish Heat Pump Association, *Heat Pump Market in Finland 2016* (Turku, Finland: no date), http://www.sulpu.fi/documents/184029/189661/Heat%20Pump%20Market%20in%20Finland%2C%202016%20slides%2Cf.pptx.

106 Lund and Boyd, op. cit. note 97.

107 Ibid.

108 Cooper Zhao, China Heat Pump Alliance, personal communication with REN21, 9 December 2016.

109 Lund and Boyd, op. cit. note 97.

110 Ibid.

111 Jun Young Choi, Energy Technology Center, Korea Testing Laboratory, personal communication with REN21, November 2016.

112 Ibid.

113 EHPA, op. cit. note 94.

114 Ibid.

115 Midea, "Midea and Clivet complete the share transfer of Clivet S.p.A", press release (Foshan City, China: 31 October 2016), http://www.midea.com/global/about_midea/News/201610/t20161031_207063.shtml; United Technologies, "Riello Group joins UTC Climate, Controls & Security", press release (Montluel, France: 31 May 2016), http://www.ccs.utc.com/ccs/en/worldwide/news/news-article/riello_group_joins_utc_climate__controls___security.aspx; Mitsubishi Electric, "Mitsubishi Electric changes name of DeLclima to MELCO Hydronics and IT Cooling", press release (Tokyo: 22 March 2016), http://www.mitsubishielectric.com/news/2016/0322.html.

116 Nibe, "NIBE förvärvar huvudparten av brittiskägda Enertech Group", press release (Markaryd, Sweden: 28 September 2016), http://www.nibe.com/se/investerare-press/pm-news-acquisitions-other/2016---news-aquisitions-other/2016-09-28-nibe-forvarvar-huvudparten-av-brittiskagda-enertech-group.html; Nibe, "NIBE-LSB Agreement act clearance from US Federal Trade Commission", press release (Markaryd, Sweden: 27 June 2016), http://www.nibe.com/investors-media/pm-news-acquisitions-other/2016---news-aquisitions-other/2016-06-27-nibe-lsb-agreement-act-clearance-from-us-federal-trade-comission.html.

117 EHPA, op. cit. note 94.

118 Solarpower Europe, Eurobat and EHPA, *Solar and Storage* (Brussels: April 2016), http://www.solarpowereurope.org/fileadmin/user_upload/documents/Policy_Papers/Solar_and_Storage_Position_Paper_2016.pdf.

119 EHPA, personal communication with REN21, March 2017.

120 Ibid.

121 IEA, op. cit. note 95.

122 Mihai Vintila, "Romania: Hike in Green House Programme applications", solarthermalworld, 30 October 2016, http://www.solarthermalworld.org/content/romania-hike-green-house-programme-applications; IEA, op. cit. note 95; Frank Stier, "Slovakia: Solar collectors second most favourite choice for green homes", solarthermalworld, 15 January 2016, http://www.solarthermalworld.org/content/slovakia-solar-collectors-second-most-favourite-choice-green-homes.

123 Federal Office for Economic Affairs and Export Control of Germany, *Report 2015/2016* (Eschborn, Germany: February 2016), http://www.bafa.de/SharedDocs/Downloads/EN/Federal_Office/bafa_report_2015_2016.pdf.

124 UK Department for Business, Energy & Industrial Strategy, *The Renewable Heat Incentive: A Reformed Scheme – Government Response to Consultation* (London: December 2016), https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/577024/RHI_Reform_Government_response_FINAL.pdf; UK Office of Gas and Electricity Markets (Ofgem), "Factsheet: Important changes to the Domestic RHI scheme" (London: 2016), https://www.ofgem.gov.uk/system/files/docs/2016/12/drhi_factsheet_consultationresponse_v1_14_dec_2016.pdf.

125 NC Clean Energy Technology Center, Database of State Incentives for Renewables & Efficiency, http://www.dsireusa.org.

126 NREL, "Geothermal Policymakers' Guidebooks: Current state policies for geothermal heating and cooling", http://www.nrel.gov/docs/fy11osti/49477.pdf, viewed 1 March 2017.

127 Saqib Rahim, "NYC details how it can move to 'renewables-based' grid", *E&E News*, 28 September 2016, http://www.eenews.net/climatewire/2016/09/28/stories/1060043540; NYC Retrofit Accelerator, https://retrofitaccelerator.cityofnewyork.us/, viewed 28 January 2017.

128 Zhao, op. cit. note 108.

129 Ibid.

130 NREL, "Electric vehicle grid integration", http://www.nrel.gov/transportation/project_ev_grid_integration.html, viewed 10 April 2017.

131 Rainer Hinrichs-Rahlwes, German Renewable Energy Federation (BEE), Berlin, personal communication with REN21, 1 December 2016.

132 European Alternative Fuels Observatory (EAFO), "European Union", http://www.eafo.eu/eu, viewed March 2017; EV-Volumes, "Global Plug-in Sales for 2016", http://www.ev-volumes.com/country/total-world-plug-in-vehicle-volumes/, viewed 13 March 2017; Inside EVs, "Monthly Plug-In Sales Scorecard", http://insideevs.com/monthly-plug-in-sales-scorecard, viewed February 2016. **Figure 52** from EV-Volumes, op. cit. this note.

133 EAFO, op. cit. note 132; EV-Volumes, op. cit. note 132; Inside EVs, op. cit. note 132.

134 Ibid., all references.

135 Ibid., all references.

136 Ibid., all references.

137 Jose Pontes, "China electric cars = record 43,441 sales in November", CleanTechnica, updated 22 December 2016, https://cleantechnica.com/2016/12/22/china-electric-cars-sales-record-43441-november/.

138 Sales data for the United States from Inside EVs, op. cit. note 132; David Shepardson and Bernie Woodall, "Electric vehicle sales fall far short of Obama goal", *Reuters*, 20 January 2016, http://www.reuters.com/article/usautos-electric-obama-insight-idUSKCN0UY0F0.

139 Inside EVs, op. cit. note 132.

140 Fred Lambert, "Norway keeps electric vehicle tax exemption until 2020, positions itself to stay EV leader", Electrek, 9 November 2016, https://electrek.co/2016/11/09/norway-keeps-electric-vehicle-tax-exemption-until-2020-positions-itself-to-stay-ev-leader; David Jolly, "Norway is a model for encouraging electric car sales", *New York Times*, 16 October 2015, https://www.nytimes.com/2015/10/17/business/international/norway-is-global-model-for-encouraging-sales-of-electric-cars.html; Chris Nelder, "EVs charge ahead with new technologies and business models", Rocky Mountain Institute, 21 June 2016, https://www.rmi.org/news/evs-charge-ahead-new-technologies-business-models/.

141 EAFO, "Europe", http://www.eafo.eu/europe, viewed 17 March 2017

142 EAFO, "Netherlands", http://www.eafo.eu/content/netherlands, viewed 13 March 2017; EV-Volumes, "Europe Plug-in Sales for 2016", http://www.ev-volumes.com/, viewed 13 March 2017.

143 EAFO website, http://www.eafo.eu, viewed 6 January 2017; EV Sales, "China buses overview (through 2010 to 2015)", 18 September 2016, http://ev-sales.blogspot.com/2016/09/china-buses-overview-through-2010-to.html.

144 IEA, *Global EV Outlook 2015* (Paris: 2015), p. 1, http://www.iea.org/media/topics/transport/GlobalEV_Outlook2015Update_1page.pdf.

145 Living Lab Smart Charging, "The Dutch revolution in smart charging of electric vehicles", press release (Arnhem, The Netherlands: 17 October 2016), http://www.prnewswire.com/news-releases/the-dutch-revolution-in-smart-charging-of-electric-vehicles-597268791.html; Living Lab Smart Charging, "FAQ", https://www.livinglabsmartcharging.nl/nl/Living-Lab-Smart-Charging/FAQ, viewed 22 March 2017; Living Lab Smart Charging, "325 Gemeenten helpen Living Lab Smart Charging", https://www.livinglabsmartcharging.nl/nl/gemeenten, viewed 22 March 2017.

146 Camille von Kaenel, "How car charging is going the way of Airbnb", *E&E News*, 2 August 2016, http://www.eenews.net/climatewire/2016/08/02/stories/1060041063; Ariel Wittenberg, "Fast-charge plugs do not fit all electric cars", *Scientific American*, 1 August 2016, https://www.scientificamerican.com/article/fast-charge-plugs-do-not-fit-all-electric-cars/.

147 Wittenberg, op. cit. note 146.

148 Jonathan Coopersmith, "What fax machines can teach us about electric cars", Texas A&M University, 7 March 2017, https://liberalarts.tamu.edu/blog/2017/03/07/what-fax-machines-can-teach-us-about-electric-cars/.

149 Heather Allen, Partnership on Sustainable, Low Carbon Transport (SLoCaT), personal communication with REN21, 5 December 2016.

150 Union of the Electric Industry (Eurelectric), *Smart Charging: Steering the Charge, Driving the Change* (Brussels: March 2015), http://www.eurelectric.org/media/169888/20032015_paper_on_smart_charging_of_electric_vehicles_finalpsf-2015-2301-0001-01-e.pdf.

151 Ibid.

152 EV Sales, "World top 20 December 2016 (updated)", 31 January 2017, http://ev-sales.blogspot.de/2017_01_01_archive.html.

153 Ibid.

154 Ibid.; Nissan News, "Renault-Nissan Alliance hits milestone of 350,000 electric vehicles sold, maintains position as global EV leader", 13 September 2016, http://nissannews.com/en-US/nissan/usa/channels/us-united-states-nissan/releases/renault-nissan-alliance-hits-milestone-of-350-000-electric-vehicles-sold-maintains-position-as-global-ev-leader.

155 EV Sales, op. cit. note 152.

156 Volkswagen AG, "Shaping the Future of the Volkswagen Group: Initiatives Strategy 2025" (Wolfsburg, Germany: 1 June 2016), https://www.volkswagenag.com/presence/konzern/pdf/Group_Initiatives_Strategy_2025.pdf.

157 "Volkswagen CEO: Building our own battery factory makes sense", *Fortune*, 21 November 2016, http://fortune.com/2016/11/21/volkswagen-ceo-battery-factory/.

158 "Daimler to invest 10 billion euros in electric vehicles – paper", *Reuters*, 25 November 2016, http://uk.reuters.com/article/uk-daimler-usa-diesel-idUKKBN13K1VW; Elisabeth Behrmann, "Mercedes hastens electric-car shift as combustion era fades", *Bloomberg*, 29 March 2017, https://www.bloomberg.com/news/articles/2017-03-29/mercedes-hastens-electric-car-rollout-as-combustion-era-fades.

159 Tesla Inc., "About Tesla", https://www.tesla.com/about, viewed 8 March 2017; Wikipedia, "BYD Auto", https://en.wikipedia.org/wiki/BYD_Auto, viewed 8 March 2017.

160 Apple has spent more on research and development for vehicles and related services in recent years than it did on the Apple Watch, iPad and iPhone combined, according to Morgan Stanley, cited in Chris Nelder, "EVs charge ahead with new technologies and business models", RMI, 21 June 2016, https://www.rmi.org/news/evs-charge-ahead-new-technologies-business-models/.

161 "95% of China's electric vehicle startups face wipeout", *Bloomberg*, 29 August 2017, https://www.bloomberg.com/news/articles/2016-08-28/most-of-china-s-electric-car-startups-face-wipeout-by-new-rules; figure of 200 also from Doug Young, "New energy: inferior cars, corruption plague China EV sector", Young's China Business Blog, 19 July 2016, http://www.youngchinabiz.com/en/new-energy-inferior-cars-corruption-plague-china-ev-sector/.

162 "Nissan Leaf with 300 km range on sale by 2017", Electric Vehicle News, 7 May 2014, http://www.electric-vehiclenews.com/2014/05/nissan-leaf-with-300-km-range-on-sale.html; "Chevrolet Bolt electric range could be able to go over 300 km per charge", News18, 21 October 2015, http://www.news18.com/news/auto/chevrolet-bolt-electric-range-could-be-able-to-go-over-300-km-per-charge-1154645.html.

163 Alex Davies, "We drive the $30K Chevy Bolt, GM's Tesla-walloping electric car", *Wired*, 13 September 2016, https://www.wired.com/2016/09/chevrolet-bolt-range-epa-rating/.

164 "Mercedes-Benz EQ SUV will go on sale by 2020", *Economic Times*, 1 November 2016, http://economictimes.indiatimes.com/slideshows/auto/mercedes-benz-eq-suv-will-go-on-sale-by-2020/10-evs-to-come-by-2025/slideshow/55184199.cms; Green Car Congress, "Volkswagen investing €3.5B in German plants for e-mobility and digitalization; MEB production, pilot plant for batteries and modules", 18 November 2016, http://www.greencarcongress.com/2016/11/20161118-vwmeb.html.

165 Fred Lambert, "5 major automakers join forces to deploy 400 ultra-fast (350 kW) charging stations for electric vehicles in Europe", Electrek, 29 November 2016, https://electrek.co/2016/11/29/ultra-fast-charging-electric-car-network-bmw-mercedes-ford-vw/; Jolly, op. cit. note 140; Peter Campbell, "Electric car rivals plan €1bn ultrafast charging network", *Financial Times*, 29 November 2016, https://www.ft.com/content/1db52960-b62d-11e6-961e-a1acd97f622d.

166 Jay Cole, "GM: Chevrolet Bolt arrives in 2016, $145/kWh cell cost, Volt margin improves $3,500", Inside-EVs, 2016, http://insideevs.com/gm-chevrolet-bolt-for-2016-145kwh-cell-cost-volt-margin-improves-3500/, viewed 6 January 2017.

167 Wittenberg, op. cit. note 146; Fred Lambert, "BMW and Nissan partner to build 174 more DC fast-charging stations for their electric vehicles", Electrek, 24 January 2017, https://electrek.co/2017/01/24/bmw-nissan-dc-fast-charging-stations-electric-vehicles/.

168 See, for example, Camille von Kaenel, "Kan. regulators slam the brakes on charging stations", *E&E News*, 19 September 2016, http://www.eenews.net/climatewire/2016/09/19/stories/1060043025. Also see von Kaenel, op. cit. note 146.

169 "The electric car places heavy demands on its batteries", All About Batteries, http://www.allaboutbatteries.com/electric_cars.html, viewed 14 March 2017.

170 Ibid.; Frankfurt School-UNEP Collaborating Centre for Climate & Sustainable Energy Finance and BNEF, *Global Trends in Renewable Energy Investment 2016* (Frankfurt: 2016), pp. 38, 39, http://fs-unep-centre.org/sites/default/files/publications/globaltrendsinrenewableenergyinvestment2016lowres_0.pdf; John Voelcker, "Electric-car battery costs: Tesla $190 per kwh for pack, GM $145 for cells", Green Car Reports, 28 April 2016, http://www.greencarreports.com/news/1103667_electric-car-battery-costs-tesla-190-per-kwh-for-pack-gm-145-for-cells.

171 Christopher Arcus, "Battery lifetime: how long can electric vehicle batteries last?" CleanTechnica, 31 May 2016, https://cleantechnica.com/2016/05/31/battery-lifetime-long-can-electric-vehicle-batteries-last/.

172 Öko Institute, "Electric buses take new forms", Öko News, 7 July 2016, http://www.oekonews.at/index.php?mdoc_id=1108048.

173 Allen, op. cit. note 149.

174 Ibid.

175 Steve Mollman, "Santiago's subway system will soon be powered most by solar and wind energy", Quartz, 24 May 2016, http://qz.com/691078/santiagos-subway-system-will-soon-be-powered-mostly-by-solar-and-wind-energy/.

176 FeiFei Shen, "Hanergy unveils solar-powered cars to expand use of technology", Renewable Energy World, 7 July 2016, http://www.renewableenergyworld.com/articles/2016/07/hanergy-unveils-solar-powered-cars-to-expand-use-of-technology.html; "China plans for solar-powered cars", *E&E News*, 6 July 2016, http://www.eenews.net/climatewire/2016/07/06/stories/1060039807.

177 "Uganda launches Africa's first solar-powered bus", ESI Africa, 4 August 2016, https://www.esi-africa.com/news/uganda-launches-africas-first-solar-powered-bus/; "Solar jeepneys will soon ply the streets", Tempo, 6 July 2016, http://tempo.com.ph/2016/07/06/solar-jeepneys-will-soon-ply-the-streets/; Mushfique Wadud, "Cheap solar ambulances to speed into service in rural Bangladesh", *Reuters*, 14 February 2017, http://news.trust.org/item/20170214110125-vmv7z/?source=spotlight.

178 Stanley Carvalho, "Solar plane circles globe in first for clean energy", *Reuters*, 27 July 2016, http://planetark.org/wen/74684.

179 Clean Energy Ministerial, op. cit. note 3.

180 See, for example, California Air Resources Board, op. cit. note 3.

181 ZEV Alliance, "International alliance aims for all new cars to be zero-emission by 2050", press release (Paris: 3 December 2015), http://www.zevalliance.org/wp-content/uploads/2016/09/IZEVA_pr_20151203.pdf. The International ZEV Alliance includes Germany, the Netherlands, Norway and the United Kingdom in Europe; California, Connecticut, Maryland, Massachusetts, New York, Oregon, Rhode Island and Vermont in the United States; and Québec in Canada.

182 Green Deal, "C-198 Electric Transport Green Deal 2016-2020", http://www.greendeals.nl/wp-content/uploads/2016/04/Green-Deal-Electric-Transport-2016-2020.pdf, viewed 13 January 2017; Peter Vermeij and Baerte de Brey, "Urban Future in the Netherlands. Ready to Cooperate, Charge & Go", presentation at World Mobility Summit 2016, Germany, 2016, http://www.emove360.com/wp-content/uploads/2016/11/Urban-future-in-the-Netherlands_-Hr.-Peter-Vermeij.pdf.

183 Ånund Killingtveit, Department of Civil and Environmental Engineering, Norwegian University of Science and Technology, personal communication with REN21, March 2017.

184 Katy Barnato, "This country has hit a major milestone for electric cars – here's how", CNBC, 24 May 2016, http://www.cnbc.com/2016/05/24/this-country-has-hit-a-major-milestone-for-electric-cars-heres-how.html.

185 Element Energy, *Pathways to High Penetration of Electric Vehicles* (Cambridge, UK: 17 December 2013), p. iv, https://www.theccc.org.uk/wp-content/uploads/2013/12/CCC-EV-pathways_FINAL-REPORT_17-12-13-Final.pdf.

186 "India not doing enough to capture energy storage opportunity", op. cit. note 87; Huma Siddiqui, "E-vehicles, solar power plants on mind, India looks to source lithium from Latin America", *Financial Express*, 28 February 2017, http://www.financialexpress.com/market/commodities/e-vehicles-solar-power-plants-on-mind-india-looks-to-source-lithium-from-latin-america/562907/. Also see Government of India, Ministry of Heavy Industries and Public Enterprises, "Fame India Scheme", press release (Delhi: 23 November), http://pib.nic.in/newsite/mbErel.aspx?relid=154119.

187 Li Fusheng, "Road map outlined for new energy industry", *China Daily*, 31 October 2016, http://www.chinadaily.com.cn/business/motoring/2016-10/31/content_27226277.htm.

188 "China's coal capital is spending millions to go green", *Bloomberg*, 16 October 2016, https://www.bloomberg.com/news/articles/2016-10-16/china-s-poisonous-coal-capital-is-spending-millions-to-go-green.

189 Governor's Interagency Working Group on Zero-Emission Vehicles, 2016 ZEV *Action Plan: An Updated Roadmap Toward 1.5 Million Zero-emission Vehicles on California Roadways by 2025* (Sacramento, CA: Office of Governor Edmund G. Brown Jr., October 2016), p. 4, https://www.gov.ca.gov/docs/2016_ZEV_Action_Plan.pdf; Alliance of Automobile Manufacturers, ZEV Facts, "ZEV state", http://www.zevfacts.com/zev-states.html, 2016, viewed 13 January 2017.

190 California Environment Protection Agency, *2016 Annual Evaluation of Hydrogen Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development* (Sacramento, CA: July 2016), p. 63, https://www.arb.ca.gov/msprog/zevprog/ab8/ab8_report_2016.pdf.

191 German Federal Ministry for Economic Affairs and Energy (BMWi), "Minister Gabriel: The purchase grant gives a key boost to electric mobility", press release (Berlin: 27 April 2016), http://www.bmwi.de/Redaktion/EN/Meldung/20160427-foerderung-elektromobilitaet.html; Österreichischer Automobil-, Motorrad- und Touringclub (ÖAMTC), "E-Autos werden mit 4.000 Euro pro Pkw gefördert", https://www.oeamtc.at/thema/elektromobilitaet/e-autos-werden-mit-4-000-euro-pro-pkw-gefoerdert-17579318, viewed 27 April 2017.

192 "Japan now has more EV charging stations than gas stations", *E&E News*, 11 May 2016, http://www.eenews.net/climatewire/2016/05/11/stories/1060037002.

193 Michael Martina and Jake Spring, "China hits two more vehicle makers for green subsidy breaches", *Reuters*, 10 October 2016, http://planetark.org/wen/74835.

194 See, for example, Ibid.; Doug Young, "New energy: inferior cars, corruption plague China EV sector", Young's China Business Blog, 19 July 2016, http://www.youngchinabiz.com/en/new-energy-inferior-cars-corruption-plague-china-ev-sector/; Jane Cai, "Is China's electric car dream turning into a zombie nightmare?" *South China Morning Post*, 2 January 2017, http://www.scmp.com/news/china/economy/article/2057439/chinas-electric-car-dream-turning-zombie-nightmare.

195 "India not doing enough to capture energy storage opportunity", op. cit. note 87; Cai, op. cit. note 194.

196 Art van der Giessen and Carla van der Linden, "Electric mobility Is Here" (Amsterdam: March 2016), https://www.amsterdam.nl/publish/pages/799470/planam-03-2016_art1.pdf.

197 "China's coal capital is spending millions to go green", op. cit. note 188.

198 Ibid.

199 Zhang Chun, "Beijing limits on car registration boost electric vehicles", Climate Change News, 28 November 2016, http://www.climatechangenews.com/2016/11/28/beijing-limits-on-car-registration-boost-electric-vehicles/.

ENERGY EFFICIENCY

1 International Energy Agency (IEA), *Energy Efficiency Market Report 2016* (Paris: 2016), http://www.iea.org/eemr16/files/medium-term-energy-efficiency-2016_WEB.PDF; IEA, *Capturing the Multiple Benefits of Energy Efficiency* (Paris: 2014), http://www.iea.org/publications/freepublications/publication/Captur_the_MultiplBenef_ofEnergyEficiency.pdf.

2 In the IEA "2 degrees scenario", for example, energy efficiency accounts for 38% of emissions reductions to 2050. IEA, *Energy Technology Perspectives 2016* (Paris: 2016), https://www.iea.org/publications/freepublications/publication/EnergyTechnologyPerspectives2016_ExecutiveSummary_EnglishVersion.pdf.

3 IEA, *Energy Efficiency Market Report 2016*, op. cit. note 1, Chapter 4.

4 Ibid., p. 22.

5 Enerdata, *Global Energy Statistical Yearbook 2016* (Grenoble, France: 2016), https://yearbook.enerdata.net/.

6 Sustainable Energy for All (SEforALL), *Global Tracking Framework Report: Progress Toward Sustainable Energy 2015* (Washington, DC: World Bank and IEA, 2016), http://www.se4all.org/sites/default/files/GTF-2105-Full-Report.pdf. Energy efficiency also is key to achieving other Sustainable Development Goals, per Agneta Persson, "Energy efficiency – required for all Agenda 2030 Sustainable Development Goals", European Council for an Energy Efficient Economy (eceee), 7 February 2017, www.eceee.org/all-news/columns/energy-efficiency-required-forall-agenda-2030-sustainable-development-goals.

7 Enerdata, op. cit. note 5.

8 Enerdata, op. cit. note 5. Monetary units are shown at constant purchasing power parity (PPP). This adjustment reflects differences in general price levels and relates energy consumption to the real level of economic activity in a country. Using PPP instead of exchange rates increases the value of GDP in regions with lower costs of living, and therefore lowers their energy intensities. **Figure 53** from Enerdata, op. cit. note 5.

9 Enerdata, op. cit. note 5.

10 IEA, *Energy Efficiency Market Report 2016*, op. cit. note 1.

11 Enerdata, op. cit. note 1; Economic Consulting Associates, *Made in Vietnam Energy Plan* (London: 2016), http://auschamvn.org/wp-content/uploads/2016/10/Made-in-Vietnam-Energy-Plan-MVEP-v12.pdf.

12 IEA, *Energy Efficiency Market Report 2016*, op. cit. note 1.

13 Ma Tianjie, "China raises its low carbon ambitions in new 2020 targets", chinadialogue, 5 January 2017, https://www.chinadialogue.net/article/show/single/en/9532-China-raises-its-low-carbon-ambitions-in-new-2-2-targets.

14 IEA, *Energy Efficiency Market Report 2016*, op. cit. note 1. Ralph Torrie, Christopher Stone and David Layzell, "Understanding energy systems change in Canada 1: decomposition of total energy intensity", *Journal of Energy Economics,* vol. 56 (May 2016), pp. 101-06, http://dx.doi.org/10.1016/j.eneco.2016.03.012.

15 IEA, *Energy Efficiency Market Report 2016*, op. cit. note 1.

16 Ibid.

17 IEA, *Key World Energy Statistics* (Paris: 2016), https://www.iea.org/publications/freepublications/publication/KeyWorld2016.pdf.

18 Thermal power plants include gas, coal, oil, biomass and multi-fuel (e.g., gas/oil, coal/biomass). PBL Netherlands Environmental Assessment Agency and European Commission (EC) Joint Research Centre, *Trends in Global CO2 Emissions: 2016 Report* (The Hague: 2016), http://edgar.jrc.ec.europa.eu/news_docs/jrc-2016-trends-in-global-co2-emissions-2016-report-103425.pdf.

19 World Energy Council, "Efficiency of power generation", Energy Efficiency Indicators, https://www.wec-indicators.enerdata.eu/power-generation-efficiency.html, viewed 6 April 2017.

20 World Energy Council, *Energy Efficiency: A Straight Path Towards Energy Sustainability* (London: 2016), https://www.worldenergy.org/publications/2016/energy-efficiency-a-straight-path-towards-energysustainability/. Co-generation (CHP) increases overall efficiency by capturing waste heat and using it to meet thermal energy demand.

21 World Energy Council, "Efficiency of gas-fired power plants", Energy Efficiency Indicators, https://www.wec-indicators.enerdata.eu/world-gas-fired-power-plants-efficiency-level.html, viewed 6 April 2017.

22 World Energy Council, op. cit. note 20.

23 See, for example, "Electricity transmission and distribution losses in India", in US Energy Information Administration (EIA), *International Energy Outlook 2016* (Washington, DC: 2016), Chapter 5, https://www.eia.gov/outlooks/ieo/electricity.cfm.

24 IEA, *World Energy Balances 2016* (Paris: 2016), https://www.iea.org/bookshop/724-World_Energy_Balances_2016; IEA, *World Energy Outlook 2016* (Paris: 2016), p. 550, http://www.worldenergyoutlook.org/publications/weo-2016/.

25 IEA, *World Energy Outlook 2016*, op. cit. note 24, p. 550.

26 IEA, *Tracking Clean Energy Progress* (Paris: 2016), https://www.iea.org/etp/tracking2016/.

27 Matthew Ulterino and Eric Bloom, Executive Summary: *Energy Efficient Buildings: Europe. Energy Efficient HVAC, Lighting, Insulation and Glazing, Building Controls, and Energy Service Companies: Market Analysis and Forecasts* (Boulder, CO: Navigant Research, 2014), https://ovacen.com/wp-content/uploads/2014/09/edificios-energeticamente-eficientes-en-europa.pdf.

28 Europe from IEA, *Energy Efficiency Market Report 2016*, op. cit. note 1; *New Buildings Institute, 2016 List of Zero Net Energy Buildings* (Portland, OR: 2016), http://newbuildings.org/wp-content/uploads/2016/10/GTZ_2016_List.pdf.

29 IEA, op. cit. note 26.

30 World Energy Council, "Average electricity consumption per electrified household", Energy Efficiency Indicators, http://wec-indicators.enerdata.eu/household-electricity-use.html, viewed 6 April 2017.

31 **Figure 54** from Ibid. Data for Commonwealth of Independent States consist of Kazakhstan, the Russian Federation and Ukraine. Data for North America consist of the United States and Canada.

32 IEA, *Energy Efficiency Market Report 2015: Market Trends and Medium-Term Prospects* (Paris: 2015), www.iea.org/publications/freepublications/publication/MediumTermEnergyefficiencyMarketReport2015.pdf.

33 Ibid.

34 IEA, *World Energy Outlook 2015* (Paris: 2015), p. 400, https://www.iea.org/newsroom/news/2015/november/world-energy-outlook-2015.html.

35 World Energy Council, "Energy intensity of service sector (to value added)", Energy Efficiency Indicators, http://wec-indicators.enerdata.eu/services-energy-intensity.html, viewed 6 April 2017. **Figure 55** from idem.

36 IEA, *Energy Efficiency Market Report 2016*, op. cit. note 1.

37 IEA, op. cit. note 32.

38 World Energy Council, "Energy intensity of industry (to value added)", Energy Efficiency Indicators, http://wec-indicators.enerdata.eu/industry-energy-intensity-world-level-trends.html, viewed 6 April 2017. **Figure 56** from idem.

39 IEA, *Energy Efficiency Market Report 2016*, op. cit. note 1, p. 43.

40 Ibid., p. 43.

41 Brian Motherway, "Energy efficiency goes global", eceee, 22 November 2016, http://www.eceee.org/all-news/columns/brian-motherway/energy-efficiency-goes-global/.

42 Bruno Lapillonne et al., *Energy Efficiency Trends in Industry in EU Countries* (Grenoble, France: Odyssee-MURE, July 2016), http://www.odyssee-mure.eu/publications/policy-brief/industry-policy-brief-energyefficiency-trends.pdf.

43 ADEME and EnR, Synthesis: *Energy Efficiency Trends and Policies in the EU: An Analysis Based on the ODYSSEE and MURE Databases*, 2015, http://www.odyssee-mure.eu/publications/br/energy-efficiency-trendspolicies-in-europe.html.

44 World Energy Council, "Energy intensity of transport to GDP", Energy Efficiency Indicators, https://www.wec-indicators.enerdata.eu/transport-energy-intensity.html, viewed 6 April 2017

45 Ibid.

46 IEA, *Energy Efficiency Market Report 2016*, op. cit. note 1, p. 104.

47 Global Fuel Economy Initiative (GFEI) and IEA, *International Comparison of Light-Duty Vehicle Fuel Economy 2005–2015: Ten Years of Fuel Economy Benchmarking* (Paris: 2016). http://www.globalfueleconomy.org/media/418761/wp15-ldv-comparison.pdf.

48 Ibid.

49 Ibid.

50 G20 China, "G20 Energy Efficiency Leading Programme", 2016, https://ec.europa.eu/energy/sites/ener/files/documents/G20%20Energy%20Efficiency%20Leading%20Programme.pdf.

51 On a final energy basis, the top 10 most efficient US EVs exceed 100 miles per gallon equivalent (MPGe), and hybrid vehicles have ratings of 42-56 MPGe. By contrast, the most efficient internal combustion engine vehicle (diesel) has a US rating of 37 MPGe, from US Department of Energy, "Compare new and used diesel vehicles", 2015, www.fueleconomy.gov/feg.

52 IEA, Global EV Outlook. *Understanding the Electric Vehicle Landscape to 2020* (Paris: 2013), https://www.iea.org/publications/freepublications/publication/GlobalEVOutlook_2013.pdf.

53 IEA data on energy consumption and International Civil Aviation Organization passenger-kilometre data cited in IEA, op. cit. note 26.

54 EIA, A*nnual Energy Outlook 2015 with Projections to 2040* (Washington, DC: April 2015), https://www.eia.gov/outlooks/archive/aeo15/pdf/0383(2015).pdf.

55 Ibid.

56 Global BRT Data website, http://brtdata.org, viewed 29 February 2016.

57 United Nations Environment Programme (UNEP), *Emissions Gap Report 2016* (Nairobi: 2016), http://web.unep.org/emissionsgap/.

58 IEA, *Energy Efficiency Market Report 2016*, op. cit. note 1, p. 15.

59 Ibid., p. 90.

60 CDP Carbon Action, *Why Companies Need Emissions Reduction Targets* (London: December 2014), www.cdp.net/CDPResults/Carbon-action-report-2014.pdf.

61 IEA, *Energy Efficiency Market Report 2014* (Paris: 2014), https://www.iea.org/publications/freepublications/publication/EEMR2014.pdf.

62 Renewable Energy Policy Network for the 21st Century (REN21), *Renewables 2016 Global Status Report* (Paris: 2016), http://www.ren21.net/wp-content/uploads/2016/10/REN21_GSR2016_FullReport_en_11.pdf.

63 World Business Council for Sustainable Development, *A Handbook on Creating Dynamic Local Markets for Energy Efficient Buildings* (Geneva: November 2016), http://www.wbcsd.org/contentwbc/download/1953/24821; "LV19 Energy Efficiency National Fund", MURE database, www.measures-odyssee-mure.eu/public/mure_pdf/general/LV19.PDF, updated 30 September 2016.

64 Maksym Sysoiev, "Ukraine's Energy Efficiency Fund", Dentons, 26 October 2016, www.globalenergyblog.com/ukraines-energy-efficiency-fund.

65 Organisation for Economic Co-operation and Development, *Green Investment Banks: Scaling up Private Investment in Low-carbon, Climate-resilient Infrastructure* (Paris: 2016), http://www.oecd.org/env/cc/green-investment-banks-9789264245129-en.htm.

66 Jan Ellen Spiegel, "Does Connecticut's Green Bank hold the secret to the future of clean energy?" InsideClimate News, 12 December 2016, https://insideclimatenews.org/news/07122016/connecticut-greenbank-renewable-energy-finance-trump.

67 African Development Bank et al., *2015 Joint Report on Multilateral Development Banks' Climate Finance* (Washington, DC: 2015), https://www.adb.org/sites/default/files/institutional-document/189560/mdb-joint-report-2015.pdf.

68 European Bank for Reconstruction and Development (EBRD), "Green Climate Fund allocates US$ 378 million to EBRD green projects", press release (London: 20 October 2016), http://www.ebrd.com/news/2016/green-climate-fund-allocates-us-378-million-to-ebrd-green-projects.html.

69 Virginia Wiseman, "Sustainable Energy Finance Update: Africa in the Spotlight", International Institute for Sustainable Development (IISD), 1 December 2016, http://sdg.iisd.org/news/sustainable-energy-finance-update-africa-in-the-spotlight/.

70 EBRD, op. cit. note 68.

71 Wiseman, op. cit. note 69.

72 Ibid.

73 Ibid.

74 Asian Development Bank, "ADB to fund millions of energy-efficient LED lights, pumps across India", press release (Manila: 2 October 2016), https://www.adb.org/news/adb-fund-millions-energy-efficient-led-lights-pumps-across-india.

75 Wiseman, op. cit. note 69.

76 Ibid.

77 COWI et al., *Study on the Potential of Green Bond Finance for Resource-efficient Investments* (Brussels: EC, 2016), http://ec.europa.eu/environment/enveco/pdf/potential-green-bond.pdf.

78 Andrew Burger, "Green bonds now playing a feature role in climate smart development", Renewable Energy World, 28 November 2016, http://www.renewableenergyworld.com/articles/2016/11/green-bonds-now-playing-a-feature-role-in-climate-smart-development.html.

79 Aline Robert, "France becomes second country to issue green bonds", Euractiv, 3 January 2017, http://www.euractiv.com/section/euro-finance/news/france-becomes-second-country-to-issue-green-bonds/.

80 Burger, op. cit. note 78.

81 International Partnership for Energy Efficiency Cooperation, "Energy Efficiency Finance Task Group", https://ipeec.org/cms/21-energy-efficiency-finance-task-group-eeftg-.html, viewed 23 March 2017.

82 BPIE, "DEEP, disclosing market data to increase transparency and drive more energy efficiency investments in Europe", http://bpie.eu/news/deep-disclosing-market-data-to-increase-transparency-and-drive-more-energy-efficiency-investments-in-europe/, viewed 23 March 2017.

83 REN21, op. cit. note 62.

84 Beth Gardiner, "Energy efficiency may be the key to saving trillions", *New York Times*, 30 November 2014, https://www.nytimes.com/2014/12/01/business/energy-environment/energy-efficiency-may-be-the-key-to-saving-trillions.html?_r=0; World Bank, "More light with less energy: how energy efficiency can fast-track energy access goals", 30 July 2015, http://www.worldbank.org/en/news/feature/2015/07/30/more-light-with-less-energy-how-energy-efficiency-can-fast-track-energy-access-goals.

85 "Chapter 6: Residential and Commercial Buildings", in Intergovernmental Panel on Climate Change, *IPCC Fourth Assessment Report: Climate Change 2007* (Cambridge, UK and New York: 2007), http://www.ipcc.ch/publications_and_data/ar4/wg3/en/ch6s6-7.html.

86 REN21, "1 Gigaton Coalition Survey" (Paris: 2016).

87 United Nations Framework Convention on Climate Change (UNFCCC), "INDC – Submissions", http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx; Jørgen Villy Fenhann, UNEP DTU Partnership, Copenhagen, personal communication with REN21, 27 March 2017.

88 REN21, op. cit. note 86.

89 Federative Republic of Brazil, *Intended Nationally Determined Contribution* (Brasilia: 28 September 2015), http://www4.unfccc.int/submissions/INDC/Published%20Documents/Brazil/1/BRAZIL%20iNDC%20english%20FINAL.pdf.

90 ASEAN Centre for Energy, ASEAN *Plan of Action for Energy Cooperation (APAEC) 2016-2025* (Jakarta: 2015).

91 REN21 Policy Database.

92 IEA, *Energy Efficiency Market Report 2016*, op. cit. note 1.

93 Ibid.

94 "NOR8 Energy Policy (Energimeldingen)", MURE database, http://www.measures-odyssee-mure.eu/public/mure_pdf/general/NOR8.PDF, updated October 2016.

95 Council of Ministers, Republic of Belarus, "On approval of the Concept energy security" (Minsk: 23 December 2015), http://minenergo.gov.by (using Google Translate); Council of Ministers, Republic of Belarus, "Registered in the National Register of Legal Acts, Belarus, N 5/41892", 31 March 2016, http://minenergo.gov.by/wp-content/uploads/ПСМ-248-от-28.03.2016_Энергосбережение.docx?csspreview=true (using Google Translate).

96 eceee, "Buildings in the Clean Energy Package – a BPIE guide", 1 December 2016, http://www.eceee.org/all-news/news/news-2016/2016-12-01b/.

97 European Environment Agency, *Trends and Projections in Europe 2016 – Tracking Progress Towards Europe's Climate and Energy Targets* (Brussels: 2016), http://www.eea.europa.eu/publications/trends-and-projections-in-europe.

98 See, for example, Jan Rosenow et al., "Efficiency first: from principle to practice with real world examples from across Europe", Regulatory Assistance Project, 14 November 2016, www.raponline.org/knowledgecenter/efficiency-first-from-principle-to-practice-with-real-world-examples-from-across-europe/.

99 EC, "National Energy Efficiency Action Plans and Annual Reports", https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficiency-directive/national-energy-efficiency-action-plans.

100 Federal Republic of Nigeria, *National Energy Efficiency Action Plans (NEEAP)* (2015–2030) (Abuja: 14 July 2016), www.power.gov.ng/Press%20Release/NATIONAL%20ENERGY%20EFFICIENCY%20ACTION%20PLANS.pdf; Rainer Quitzow et al., *Mapping of Energy Initiatives and Programs in Africa* (Eschborn, Germany: European Union Energy Initiative Partnership Dialogue Facility, May 2016), http://www.euei-pdf.org/sites/default/files/field_publication_file/mapping_of_initiatives_final_report_may_2016.pdf.

101 Energy Efficiency Services Limited, "How India Scaled Up Energy Efficiency via Innovative Business Models", 16 November 2016, http://eeslindia.org/writereaddata/Report%20Energy%20Efficiency.pdf.

102 "Uganda: conserves 30MW via energy saver bulbs", ESI Africa, 22 July 2016, https://www.esi-africa.com/news/energy-saver-bulbs-uganda-conserve-power/.

103 Naoki Asanuma, "Japan sees the future and it is zero-energy homes", *Nikkei Asian Review*, 2 July 2016, http://asia.nikkei.com/Tech-Science/Tech/Japan-sees-the-future-and-it-is-zero-energy-homes.

104 For examples of plans, see United Nations Economic Commission for Europe, *Analysis of National Case Studies on Policies to Promote Energy Efficiency Investments* (New York and Geneva: 2015), www.unece.org/fileadmin/DAM/energy/se/pdfs/geee/pub/ESE.44_ECE.ENERGY.97.pdf.

105 REN21, "Renewables Global Status Report Questionnaire" (Paris: 2016).

106 Kari Lydersen, "Illinois energy bill: After race to the finish, what does it all mean?" *Midwestern Energy News*, 8 December 2016, http://midwestenergynews.com/2016/12/08/illinois-energy-bill-after-race-to-the-finish-what-does-it-all-mean/; Nick Magrisso, "Future energy jobs bill: a path for Illinois to a bright clean energy economy", Natural Resources Defense Council, 5 December 2016, https://www.nrdc.org/experts/nick-magrisso/future-energy-jobs-bill-path-illinois-bright-clean-energy-economy.

107 EC, "Energy Efficiency Directive", https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficiency-directive, viewed 23 March 2017.

108 Europe from "RECs in reverse", Environmental Finance, 14 December 2016, https://www.environmental-finance.com/content/analysis/recs-in-reverse.html; Tom Kenning, "China plans 'green certificates' trading market to support renewables", PV-Tech, 4 March 2016, https://www.pv-tech.org/news/china-plans-green-certificates-trading-market-to-support-renewables; Tsevetomira Tsanova, "Indian renewable energy certificate sales jump at FY 2015/16 end", Renewables Now, 31 March 2016, https://renewablesnow.com/news/indian-renewable-energy-certificate-sales-jump-at-fy-2015-16-end-519172/; Victorian Energy Efficiency Target, "Certificates (VEECs)", www.veet.vic.gov.au/public/Public.aspx?id=Certificates(VEECs), viewed 6 April 2017.

109 Noah M. Sachs, "The limits of energy efficiency markets in climate-change law", *University of Illinois Law Review, vol. 2016, no. 5* (2016), pp. 2237-69. https://illinoislawreview.org/print/volume-2016-issue-5/the-limits-of-energy-efficiency-markets-in-climate-change-law/.

110 IEA Building Energy Efficiency Policies Database, www.iea.org/beep, viewed 22 November 2016.

111 REN21, op. cit. note 86.

112 Anne C. Mulkern, "City approves first-of-its-kind zero-net-energy rule for homes", *E&E News*, 31 October 2016, www.eenews.net/climatewire/2016/10/31/stories/1060045031.

113 IEA, op. cit. note 110, viewed March 2016.

114 IEA, *Energy Efficiency Market Report 2016*, op. cit. note 1, p. 14.

115 IEA 4E, *Achievements of Appliance Energy Efficiency Standards and Labelling Programs – A Global Assessment* (Paris: 2015), p. 1, www.iea.org/publications/freepublications/publication/4E_S_L_Report_180915.pdf.

116 IEA, *Energy Efficiency Market Report 2016*, op. cit. note 1, p. 76.

117 Eight countries plus EU as of 2014, per International Council on Clean Transportation, "Global Passenger Vehicle Standards", 2014, www.theicct.org/info-tools/global-passenger-vehicle-standards.

118 SEforALL, op. cit. note 6.

119 Ibid.

120 Ibid.

121 EC, op. cit. note 107.

122 REN21, op. cit. note 86.

123 Ibid.

124 Ibid. As of 2014, a new Energy Efficiency and Conservation Bill was being developed to address these issues. Ministry of Water and Environment for Uganda, *Uganda's Intended Nationally Determined Contribution (INDC)* (Kampala: 2015), http://www4.unfccc.int/submissions/INDC/Published%20Documents/Uganda/1/INDC%20Uganda%20final%20%2014%20October%20%202015,%20minor%20correction,28.10.15.pdf; Uganda Ministry of Energy and Mineral Development, "The Energy Efficiency and Conservation Department" (Kampala: undated), http://www.energyandminerals.go.ug/downloads/ERDreportEnergy%20efficiancyandconservation1.pdf.

125 Sustainable Energy Authority of Ireland, "Warmth and Wellbeing pilot scheme", http://www.seai.ie/Grants/Warmth-and-Wellbeing, viewed 23 March 2017.

126 Ivetta Gerasimchuk, *Fossil-Fuel Subsidy Reform: Critical Mass for Critical Change* (Austin: University of Texas at Austin, 2015), www.stanleyfoundation.org/climatechange/Gerasimchuk-Fossil-FuelSubsidyReform.pdf.

127 Ibid.

128 Tim Farrell and Ksenia Petrichenko, "The Global Energy Efficiency Accelerator Platform: Overview of Progress", presented at Workshop on Global Energy Efficiency Accelerator Platform and Progress in Accelerating Industrial Energy Efficiency, 19 October 2016, https://www.unece.org/fileadmin/DAM/energy/se/pp/eneff/7th_IFESD_Baku_Oct.2016/3GEEE_Acceler/Tim.Farrell.pdf.

129 GFEI, "in-country work", http://www.globalfueleconomy.org/in-country, viewed 23 March 2017.

130 Copenhagen Centre on Energy Efficiency, "Belgrade lays the first brick in its Building Efficiency Accelerator", 11 November 2016, http://www.energyefficiencycentre.org/nyheder/nyhed?id=2A50A0C7-B6C2-490E-A225-ED42328AE5E7.

131 UNEP, District Energy in Cities website, http://www.districtenergyinitiative.org, viewed 6 April 2017; Stefan Jungcurt, "Energy update: Non-state actors, regional initiatives show progress towards energy transition", IISD, 22 November 2016, http://sdg.iisd.org/news/energy-update-non-state-actors-regional-initiatives-show-progress-towards-energy-transition/.

132 Jungcurt, op. cit. note 131.

133 Ibid.

134 IEA, op. cit. note 2.

135 Steven Nadel, "2017 is looking like a good year for energy efficiency as investments grow", American Council for an Energy-Efficient Economy, 4 January 2017, http://aceee.org/blog/2017/01/2017-looking-good-year-energy.

136 Kata Tüttö, "Cities can play a key role in combating climate change", *The Parliament Magazine*, 12 October 2015, https://www.theparliamentmagazine.eu/articles/opinion/cities-can-play-key-role-combating-climate-change; ICLEI Global website, www.iclei.org, viewed 29 January 2016; C40 website, www.c40.org, viewed 29 January 2016.

137 Tony Venables, University of Oxford and International Growth Centre, "Building Functional and Low Carbon Cities", presentation, 2016, http://www.cccep.ac.uk/wp-content/uploads/2016/06/Venables.pdf.

138 Ibid.

139 Ibid.

FEATURE: DECONSTRUCTING BASELOAD

1 Hydropower can serve a variety of roles in power markets depending on resource endowments and physical topology, water management needs, and other social and environmental factors. In some countries, such as Brazil and China, hydropower can be primarily a baseload source of energy, while in others, hydropower may be restricted to providing load-following (mid-merit) functions. Still in others, pumped storage hydropower can function well as a source of peaking generation. For more, see Arun Kumar et al., "Chapter 5: Hydropower", in Intergovernmental Panel on Climate Change (IPCC), *Special Report on Renewable Energy Sources and Climate Change Mitigation* (Cambridge, UK: 2011), http://www.ipcc.ch/pdf/special-reports/srren/Chapter%20 5%20Hydropower.pdf.

2 Aaron Leopold, Power for All, personal communication with Renewable Energy Network for the 21st Century (REN21), 29 January 2017.

3 See, for example, Bloomberg New Energy Finance, *Bloomberg New Energy Outlook 2016: Global Overview* (London: 2016), https://www.bloomberg.com/company/new-energy-outlook/, and International Energy Agency (IEA) Technology Collaboration Programme for Renewable Energy Technology Deployment (IEA-RETD), *RETRANSITION – Transitioning to Policy Frameworks for Cost-Competitive Renewables* (Paris: 2016), http://iea-retd.org/archives/publications/re-transition.

4 See, for example, IEA Clean Coal Centre, *Increasing the Flexibility of Coal-fired Power Plants* (London: 2014), http://www.iea-coal.org.uk/documents/83500/9158/Increasing-the-flexibility-of-coal-fired-power-plants,-CCC/242.

5 Increasing flexibility entails specifically steeper ramping requirements, lower minimum turndown requirements and shorter lead-time for operating instructions. See, for example, Jaquelin Cochran et al., *Flexibility in 21st Century Power Systems* (Golden, CO: National Renewable Energy Laboratory (NREL), 2014), http://www.nrel.gov/docs/fy14osti/61721.pdf, and Aaron Bloom et al., *Eastern Renewable Generation Integration Study* (Golden, CO: NREL, 2016). **Figure 59** based on IEA, *Getting Wind and Sun onto the Grid - A Manual for Policy Makers* (Paris: 2017), http://www.iea.org/publications/insights/insightpublications/Getting_Wind_and_Sun.pdf and on REN21, *Renewables Global Futures Report – Great Debates Towards 100% Renewable Energy* (Paris: 2017), http://www.ren21.net/gfr.

6 See, for example, Cochran et al., op. cit. note 5, and IEA, *Flexible Power Systems to Integrate Large Shares of Renewables: The Value of Interconnections* (Paris: 2014), https://www.iea.org/media/workshops/2015/techplatformchinasmartgrid2015/FlexiblePowerSystemstointegratelargesharesofrenewables-Thevalueofinterconnections.pdf.

7 Cochran et al., op. cit. note 5.

8 Paul Denholm, "The Role of Storage and Demand Response", Greening the Grid, 2015, http://www.nrel.gov/docs/fy15osti/63041.pdf.

9 Greening the Grid, "Ancillary services", http://greeningthegrid.org/integration-in-depth/ancillary-services.

10 Smart inverters are those that include digital architecture and bi-directional communications capabilities. See, for example, NREL, *Advanced Inverter Functions to Support High Levels of Distributed Solar* (Golden, CO: 2015), http://www.nrel.gov/docs/fy15osti/62612.pdf, and A.S. Awad, M. Abdel-Rahman and M. Abdel Latif Badr, "Low-voltage ride-through capability characterization of wind farms", *Electric Power Components and Systems*", vol. 40, no. 16 (2012), pp. 1808–19, http://www.tandfonline.com/doi/abs/10.1080/15325008.2012.722584.

11 Lori Bird, Jaquelin Cochran and Xi Wang, *Wind and Solar Energy Curtailment: Experience and Practices in the United States* (Golden, CO: NREL, 2014), http://www.nrel.gov/docs/fy14osti/60983.pdf.

12 Jaquelin Cochran, Debra Lew and Nikhil Kumar, *Flexible Coal: Evolution from Baseload to Peaking Plant*, 21st Century Power Partnership, 2013, http://www.nrel.gov/docs/fy14osti/60575.pdf.

13 Suzanne Pritchard, "The future for hydro – roundtable discussion", *International Water Power & Dam Construction*, 2 March 2015, http://www.waterpowermagazine.com/features/featurethe-future-for-hydro-4523007.

14 Power-technology.com, "Tehri Pumped Storage Plant, India", http://www.power-technology.com/projects/tehri-pumped-storage-plant, viewed 28 March 2017.

15 Eoin Burke Kennedy, "Over 23% of electricity demand now supplied by wind", *Irish Times*, 23 December 2015, http://www.irishtimes.com/business/energy-and-resources/over-23-of-electricity-demand-now-supplied-throughwind-1.2479486.

16 Brattle Group, *Integrating Renewable Energy into the Electricity Grid: Case Studies Showing How System Operators Are Maintaining Reliability* (Cambridge, MA: 2015), http://info.aee.net/hubfs/EPA/AEEI-Renewables-Grid-Integration-Case-Studies.pdf?t=1480709130819.

17 Uruguay Secretary of Energy, Ministry of Industry, Energy and Mining, *Balance Energético Preliminar 2016* (Montevideo: 2017), http://www.dne.gub.uy/web/energia/-/balance-energetico-nacion-1; Jonathan Watts, "Uruguay makes dramatic shift to nearly 95% electricity from clean energy", *The Guardian* (UK), 3 December 2015, http://www.theguardian.com/environment/2015/dec/03/uruguay-makes-dramatic-shift-to-nearly-95-clean-energy; Uruguay Secretary of Energy, Ministry of Industry, Energy and Mining, personal communication with REN21, May 18, 2017.

18 IEA, op. cit. note 5.

19 International Renewable Energy Agency (IRENA), *REthinking Energy 2017: Accelerating the Global Energy Transformation* (Abu Dhabi: 2017), p. 75, http://www.irena.org/DocumentDownloads/Publications/IRENA_REthinking_Energy_2017.pdf.

20 IEA, op. cit. note 5; IRENA, op. cit. note 19, p. 75. **Table 4** based on IEA, op. cit. note 5, and on REN21, op. cit. note 5.

21 Practical Action, *Poor People's Energy Outlook 2016* (Bourton on Dunsmore, Rugby, Warwickshire, UK: 2016), http://infohub.practicalaction.org/oknowledge/bitstream/11283/620101/1/PPEO2016.pdf.

22 See, for example, IRENA, *Planning for the Renewable Future: Long-term Modeling and Tools to Expand Variable Renewable Power in Emerging Economies* (Abu Dhabi: 2017), http://www.irena.org/DocumentDownloads/Publications/IRENA_Planning_for_the_Renewable_Future_2017.pdf, and Jessica Katz, "The Evolution of Power System Planning with High Levels of Variable Renewable Energy", Greening the Grid, 2016, http://greeningthegrid.org/resources/factsheets/the-evolution-of-power-system-planning-with-high-levels-of-variable-renewable-generation.

23 Rachael Wilson and Bruce Biewald, *Best Practices in Electric Utility Integrated Resource Planning* (Montpelier, VT: RAP, 2013), http://www.raponline.org/wp-content/uploads/2016/05/rapsynapse-wilsonbiewald-bestpracticesinirp-2013-jun-21.pdf.

24 Department of Energy, Republic of South Africa, "Integrated Resource Plan", http://www.energy.gov.za/files/irp_frame.html; Obed Attah Yeboah, "Power Sector Master Plan in the Works", B&FT Online, 16 September 2016, http://thebftonline.com/business/energy/20991/power-sector-master-plan-inthe-works-.html; for an example of an IRP in a developed country, see, for example, PacifiCorp, "Integrated Resource Plan", http://www.pacificorp.com/es/irp.html.

25 See, for example, Greening the Grid, "Renewable Energy Zones: Delivering Clean Power to Meet Demand", 2016, http://greeningthegrid.org/resources/factsheets/renewable-energy-zones.

26 Arthur Neslen, "Portugal runs for four days straight on renewable energy alone", *The Guardian* (UK), 18 May 2016, https://www.theguardian.com/environment/2016/may/18/portugal-runs-for-four-days-straight-on-renewable-energy-alone; Uruguay Secretary of Energy, Ministry of Industry, Energy and Mining, op. cit. note 17; Adam Withnall, "Cape Verde: The African country that plans to run on 100% renewable energy by 2020", *The Independent* (UK), 29 September 2016, http://www.independent.co.uk/news/world/africa/cape-verde-the-africancountry-that-plans-to-run-on-100-renewable-energy-by-2020-a7337426.html.

27 Arthur Neslen, "Wind power generates 140% of Denmark's electricity demand", *The Guardian* (UK), 10 July 2015, https://www.theguardian.com/environment/2015/jul/10/denmark-wind-windfarm-power-exceed-electricity-demand; Agora Energiewende, *Die Energiewende im Stromsektor: Stand der Dinge 2016* (Berlin: January 2017), p. 7, https://www.agora-energiewende.de/fileadmin/Projekte/2017/Jahresauswertung_2016/

Die_Energiewende_im_Stromsektor_2016_DE.pdf.

28 Withnall, op. cit. note 26; IRENA, *Renewable Islands: Settings for Success* (Abu Dhabi: 2014), p. 8, http://www.irena.org/DocumentDownloads/Publications/GREIN_Settings_for_Success.pdf.

29 Kathryn M. O'Neill, "Going off grid: Tata researchers tackle rural electrification", Massachusetts Institute of Technology, 21 January 2016, http://news.mit.edu/2016/tata-researchers-tackle-rural-electrification-0121.

30 W. Brian Arthur, "Competing technologies, increasing returns and lock-in by historical events", *Economic Journal*, vol. 99, no. 394 (1989), pp. 116-31, https://www.jstor.org/stable/2234208?seq=1#page_scan_tab_contents; Gregory Unruh, "Understanding carbon lock-in", *Energy Policy*, vol. 28, no. 12 (2000), http://www.sciencedirect.com/science/article/pii/S0301421500000707.

31 See, for example, IRENA, *REmap: Roadmap for a Renewable Energy Future* (Abu Dhabi: 2016), http://www.irena.org/DocumentDownloads/Publications/IRENA_REmap_2016_edition_report.pdf, and Jaquelin Cochran et al., *Integrating Variable Renewable Energy in Electric Power Markets: Best Practices from International Experience* (Golden, CO: NREL, 2012), http://www.nrel.gov/docs/fy12osti/53732.pdf.

32 Additional information on these strategies and best practices can be found in Cochran et al., op. cit. note 31; IRENA, op. cit. note 22; and IEA, op. cit. note 5. See also Debra Lew et al., *Wind and Solar Curtailment* (Golden, CO: NREL, 2013), http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.390.1983&rep=rep1&type=pdf.

REFERENCE TABLES

1 **Table R1** from the following sources: **Bio-power** based on 2015 forecast data in International Energy Agency (IEA), *Medium-Term Renewable Energy Market Report 2015* (Paris: 2015), https://www.iea.org/bookshop/708-Medium-Term_Renewable_Energy_Market_Report_2015, except for the following: U.S. Federal Energy Regulatory Commission, "Office of Energy Projects Energy Infrastructure Update for December 2015," http://www.ferc.gov/legal/staff-reports/2015/dec-infrastructure.pdf; Brazilian Electricity Regulatory Agency (ANEEL), "Banco de informacoes de geração", http://www.aneel.gov.br/apl[cacoes/capacidadebrasil/combustivel.cfm, viewed 9 May 2016; China National Renewable Energy Centre, provided by Amanda Zhang, Chinese Renewable Energy Industries Association, personal communication with REN21, 26 April 2016; Germany preliminary statistics from Bundesministerium für Wirtschaft und Energie, *Erneuerbare Energien in Deutschland, Daten zur Entwicklung im Jahr 2015* (Berlin: February 2016), http://www.erneuerbare-energien.de/EE/Redaktion/DE/Downloads/erneuerbare-energien-in-zahlen-2015.pdf; UK Department of Energy & Climate Change, "Energy Trends Section 6 – Renewables" (London: March 2016), Table 6.1, https://www.gov.uk/government/statistics/energy-trends-section-6-renewables, viewed 22 April 2016; Government of India, Ministry of New and Renewable Energy (MNRE), "Physical progress (achievements) – up to the month of December 2015," http://www.mnre.gov.in/mission-and-vision-2/achievements/; MNRE, "Physical progress (achievements) – up to the month of December 2014," http://www.mnre.gov.in/mission-and-vision-2/achievements/; Japan from Hironao Matsubara, Institute for Sustainable Energy Policies (ISEP), Japan, personal communication with REN21, 10 April 2016. **Geothermal power** from sources in endnote 1 in Geothermal Power and Heat section of Market and Industry Trends chapter. **Hydropower** from sources in endnote 5 of this section. **Ocean power** from International Renewable Energy Agency (IRENA), *Renewable Capacity Statistics 2017* (Abu Dhabi: April 2017), http://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Capacity_Statistics_2017.pdf. **Solar PV** from sources in endnote 6 of this section. **CSP** from sources in endnote 7 of this section. **Wind power** from sources in endnote 9 of this section. **Modern bio-heat** based on the following: 297 GW_{th} of bioenergy heat plant capacity installed as of 2008, from Helena Chum et al., "Bioenergy", in Ottmar Edenhofer et al., eds., *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation* (Cambridge, UK and New York, NY: Cambridge University Press, 2011), http://www.ipcc.ch/pdf/special-reports/srren/Chapter%202%20Bioenergy.pdf. Projections based on this number have been made for past GSRs. The combination of the Chum et al. data, plus past GSR projections, was used to estimate 2014 values of 305 GW_{th} using a linear regression. The 2015 value presented here assumes a 3.5% growth rate from that 305 GW_{th} value, based on the same percent increase for modern heat generation as presented in IEA, op. cit. this note, p. 242. Note that accurate heat data, including from bioenergy, are very difficult to obtain as most capacity installations and output are not metered. Even if plant capacities are known, there is often no knowledge of whether a 1 MW_{th} plant, for example, is used for 80 hours or 8,000 hours per year. **Geothermal heating** capacity derived from John W. Lund and Tonya L. Boyd, "Direct utilization of geothermal energy: 2015 worldwide review", in *Proceedings of the World Geothermal Congress 2015* (Melbourne, Australia: 19–25 April 2015), and from Luis C.A. Gutiérrez-Negrín, International Geothermal Association and Mexican Geothermal Association, personal communication with REN21, March 2015. Capacity figure for 2015 is extrapolated from 2014 values (from sources) by weighted-average growth rate across eight categories of geothermal direct use: space heating, bathing and swimming, greenhouse heating, aquaculture, industrial use, snow melting and cooling, agricultural drying and other. The weighted-average five-year annual growth rate for capacity is 6.0% compared to 5.9% simple growth rate for the same period. The weighted-average five-year annual growth rate for utilisation is 3.5% compared to 3.3% simple growth rate for the same period. **Solar collectors for water heating** estimates based on Franz Mauthner, AEE – Institute for Sustainable Technologies (AEE INTEC), personal communication with REN21, April 2016, and on Franz Mauthner and Werner Weiss, *Solar Heat Worldwide: Markets and Contribution to the Energy Supply 2014* (Gleisdorf, Austria: IEA Solar Heating and Cooling Programme (IEA SHC), May 2016). See Solar Thermal Heating and Cooling section in Market and Industry Trends chapter and related endnotes for more details. **Ethanol, biodiesel and HVO production** data from sources in endnote 3 of this section.

2 **Table R2** from the following sources: **For all global data**, see endnote 1 for this section and other relevant reference tables. For more-specific data and sources, see Global Overview chapter and Market and Industry Trends chapter and related endnotes. For sources for **BRICS, EU and individual countries,** see endnote for Figure 5 in Global Overview chapter. **Per capita data** based on capacity data provided in Reference Table R2 and on 2015 country population data from World Bank, "Population, total", World Development Indicators, http://data.worldbank.org/indicator/SP.POP.TOTL, updated 23 March 2017.

3 **Table R3** from the following sources: fuel ethanol data from F.O. Licht, "Fuel Ethanol: World Production by Country", 2016; biodiesel and HVO data from F.O. Licht, "Biodiesel: World Production, by Country", 2017, with permission from F.O. Licht/Licht Interactive Data. Preliminary 2015 data that appeared in GSR 2016 have been updated where possible.

4 **Table R4** from the following sources: See endnote 1 of Geothermal section in Market and Industry Trends chapter.

5 **Table R5** from the following sources: Global capacity estimate based on International Hydropower Association (IHA), *2017 Key Trends in Hydropower* (London: April 2017), http://www.hydropower.org, on IHA, *2016 Hydropower Status Report* (London: May 2016), http://www.hydropower.org, and on IHA, personal communication with REN21, March-April 2017. Total installed capacity is 1,246 GW (31.5 GW added), less 150 GW of pumped storage (6.4 GW added). Country data from the following sources: **China:** total capacity, capacity growth, utilisation and investment from China National Energy Administration (CNEA), summary of national electric industry statistics for 2016, http://www.nea.gov.cn/2017-01/16/c_135986964.htm; capacity additions in 2016, including pumped storage, from China Electricity Council, annual report on national power system, 25 January 2017, http://www.cec.org.cn/yaowenkuaidi/2017-01-25/164285.html; capacity, including pumped storage, at year-end 2015 from CNEA, *13th Five-Year-Plan for Hydro Power Development* (Beijing: 29 November 2016), http://www.nea.gov.cn/135867663_14804701976251n.pdf. **Brazil:** 5,292 MW (5,002 MW large hydro, 203 MW small hydro and 87 MW very small hydro) added in 2016, from National Agency for Electrical Energy (ANEEL), "Resumo geral dos novos empreendimentos de geração", http://www.aneel.gov.br/documents/655816/15224356/Resumo_Geral_das_Usinas_março_2017.zip, updated March 2017; large hydro capacity is listed as 91,499 MW at end-2016, small (1-30 MW) hydro as 4,941 MW and very small (less than 1 MW) hydro as 484 MW (compared to 398 MW in the previous year), for a total of 96,925 MW. **United States:** capacity from US Energy Information Administration (EIA), *Electric Power Monthly*, February 2017, Tables 6.2.B and 6.3, http://www.eia.gov/electricity/monthly. **Canada:** data for 2015 only from Statistics Canada, "Table 127-0009 installed generating capacity, by class of electricity producer", http://www5.statcan.gc.ca/cansim. **Russian Federation:** capacity from System Operator of the Unified Energy System of Russia, *Report on the Unified Energy System in 2016* (Moscow: January 2017), http://www.so-ups.ru/fileadmin/files/company/reports/disclosure/2017/ups_rep2016.pdf. **India:** installed capacity in 2016 (units larger than 25 MW) of 43,139 MW from Government of India, Ministry of Power, Central Electricity Authority, "All India installed capacity (in MW) of power stations", December 2016, http://www.cea.nic.in/reports/monthly/installedcapacity/2016/installed_capacity-12.pdf; capacity additions in 2016 (greater than 25 MW) of 415 MW from idem, "Executive summary of the power sector (monthly)", http://www.cea.nic.in/monthlyarchive.html; installed capacity in 2016 (<25 MW) of 4,325 MW from Government of India, MNRE, "Physical progress (achievements)", http://www.mnre.gov.in/mission-and-vision-2/achievements/, viewed 19 January 2017; capacity additions in 2016 (<25 MW) of 148 MW based on difference of year-end 2016 figure (above) and year-end 2015 figure (4,177 MW) from MNRE, idem. **Ecuador:** capacity from IHA, op. cit. this note, all three references; **Ethiopia:** capacity from IHA, op. cit. this note, all three references; **Vietnam:** capacity from IHA, op. cit. this note, all three references; **Peru:** IHA, op. cit. this note, all three references, and from Government of Peru, Organismo Supervisor de la Inversión en Energía y Minería, inventory of hydropower projects, http://www.osinergmin.gob.pe/empresas/electricidad/proyectos/generacion, viewed May 2017.

6 **Table R6** from the following sources: Unless noted otherwise, data for end-2015 from IEA Photovoltaic Power Systems Programme (IEA PVPS), *Trends in Photovoltaic Applications, 2016: Survey Report of Selected IEA Countries Between 1992 and 2015* (Paris: 2016), http://www.iea-pvps.org/fileadmin/dam/public/report/national/Trends_2016_-_mr.pdf, and from SolarPower Europe, *Global Market Outlook for Solar Power 2016–2020* (Brussels: 2016). Data for 2016 from IEA PVPS, *Snapshot of Global Photovoltaic Markets 2016* (Paris: April 2017), p. 4, http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/IEA-PVPS_-__A_Snapshot_of_Global_PV_-_1992-2016.pdf, and from sources provided below. This report aims to provide all solar PV data in direct current (DC) units. Note that some countries (e.g., Canada, Chile, Japan since 2012, and Spain) report data officially in alternating current (AC); for consistency across countries, AC data were converted to DC by the relevant sources listed. Additional country sources include: **China:** Dazhong Xiao, "2016 photovoltaic power generation statistics", National Energy Board, 4 February 2017, http://www.nea.gov.cn/2017-02/04/c_136030860.htm (using Google Translate). **United States:** GTM Research, personal communication with REN21, 2 May 2017, and GTM Research, cited in US Solar Energy Industries Association (SEIA), "Solar Market Insight Report 2016 Year in Review", http://www.seia.org/research-resources/solar-market-insight-report-2016-year-review, viewed 2 May 2017. **Japan:** IEA PVPS, *Snapshot of Global Photovoltaic Markets 2016*, op. cit. this note, and Gaëtan Masson, IEA PVPS and Becquerel Institute, personal communication with REN21, 9 May 2017. **India:** End-2015 from IEA PVPS, *Trends in Photovoltaic Applications*, op. cit. this note. Additions in 2016 and year-end capacity based on data from Government of India, MNRE, "Physical progress (achievements)", data as on 31 December 2016, http://www.mnre.gov.in/mission-and-vision-2/achievements, viewed 19 January 2017, and from MNRE, "Physical progress (achievements)", data as on 31 December 2015, viewed 1 February 2016, and assuming that India had 225 MW of CSP capacity (with no 2016 additions) in both years (See CSP section in Market and Industry Trends chapter and Reference Table R7). **United Kingdom:** UK Department for Business, Energy & Industrial Strategy, "Solar Photovoltaics Deployment in the UK February 2017", updated 30 March 2017, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/585828/Solar_photovoltaics_deployment_March_2017.xlsx. **Germany:** Bundesministerium für Wirtschaft und Energie (BMWi), *Zeitreihen zur Entwicklung der erneuerbaren Energien in Deutschland, unter Verwendung von Daten der Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat) (Stand: Februar 2017)*, p. 7, http://www.erneuerbare-energien.de/EE/Redaktion/DE/Downloads/zeitreihen-zur-entwicklung-der-erneuerbaren-energien-in-deutschland-1990-2016.pdf. **Republic of Korea:** IEA PVPS, *Snapshot of Global Photovoltaic Markets 2016*, op. cit. this note, and Jaehong Seo, KOPIA, presentation for International Green Energy Conference 2017, Daegu, Republic of Korea, 5-6 April 2017, provided by Frank Haugwitz, Asia Europe Clean Energy (Solar) Advisory Co. Ltd., personal communication with REN21, 8 May 2017. **Australia:** Australian PV Institute, "Australian PV market since April 2001", http://pv-map.apvi.org.au/analyses, viewed 2 May 2017. See Solar PV section in Market and Industry Trends chapter and related endnotes for additional statistics and details.

7 **Table R7** compiled from the following sources: CSP Today, "Projects Tracker", http://social.csptoday.com/tracker/projects, viewed on numerous dates leading up to 27 March 2017; US National Renewable Energy Laboratory, "Concentrating solar power projects by project name", http://www.nrel.gov/csp/solarpaces/by_project.cfm, viewed on numerous dates leading up to 27 March 2017; REN21, *Renewables 2016 Global Status Report* (Paris: 2016), pp. 67-69, http://www.ren21.net/wp-content/uploads/2016/10/REN21_GSR2016_FullReport_en_11.pdf; IRENA, *Renewable Capacity Statistics 2017* (Abu Dhabi: 2017), http://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Capacity_Statistics_2017.pdf. In some cases, information from the above sources was verified against additional country-specific sources, as cited in the endnotes for the CSP section. Global CSP data are based on commercial facilities only; demonstration or pilot facilities are excluded. Differences between IRENA and REN21 data are due primarily to inclusion of pilot and demonstration facilities in the IRENA report.

8 **Table R8** from the following sources: cumulative solar thermal capacity in operation nationally and globally at end-2015 from Monika Spörk-Dür, AEE INTEC, Gleisdorf, Austria, personal communications with REN21, March-May 2017; Werner Weiss and Monika Spörk-Dür, *Solar Heat Worldwide: Markets and Contribution to the Energy Supply 2015* (Gleisdorf, Austria: IEA SHC, 2017). Gross additions on a national level from the following associations and experts: David Ferrari, Sustainability Victoria, Melbourne, Australia; Werner Weiss, AEE INTEC, Vienna, Austria; Marcelo Mesquita, ABRASOL, São Paulo, Brazil; Hongzhi Cheng, Shandong SunVision Management Consulting, Dezhou, China; Denmark from Daniel Trier, PlanEnergi, Skørping, Denmark, and from Jan-Olof Dalenbäck, Chalmers University of Technology, Göteborg, Sweden; Richard Loyen, Enerplan, La Ciotat, France; Marco Tepper, BSW Solar, Berlin, Germany; Costas Travasaros, Greek Solar Industry Association (EBHE), Piraeus, Greece; Jaideep Malaviya, Solar Thermal Federation of India (STFI), Pune, India; Eli Shilton, Elsol, Kohar-yair, Israel; Federico Musazzi, ANIMA, the Federation of Italian Associations in the Mechanical and Engineering Industries, Milano, Italy; Kumiko Saito, Solar System Development Association (SSDA), Tokyo, Japan; Daniel Garcia, Solar Thermal Manufacturers Organisation (FAMERAC), Mexico City, Mexico; Janusz Staroscik, Association of Manufacturers and Importers of Heating Appliances (SPIUG), Warsaw, Poland; Karin Kritzinger, Centre for Renewable and Sustainable Energy Studies, Univeristy of Stellenbosch, Stellenbosch, South Africa; Pascual Polo, Spanish Solar Thermal Association (ASIT), Madrid, Spain; David Stickelberger, Swissolar, Zurich, Switzerland; Kung-Ming Chung, Energy Research Center of the National Cheng Kung University (NCKU), Tainan City, Chinese Taipei; Turkey from Kutay Ülke, Bural Heating (formerly Ezinç Metal), Kayseri, Turkey, and from Krystyna Dawson, BSIRA, Berkshire, United Kingdom; Les Nelson, Solar Heating & Cooling Programs at the International Association of Plumbing and Mechanical Officials (IAPMO), Ontario, CA, United States, all personal communications with REN21, February-April 2017. Gross additions for South Africa were not available at the time of publication, so it is assumed that they remained stable from 2015 to 2016. Gross additions of Denmark for 2016 do not include the new district heating plant in Brønderslev (26,929 m^2), which consists of parabolic trough collectors. Total gross additions worldwide for 2016 are based on estimates from Spörk-Dür, op. cit. this note.

9 **Table R9** from the following sources: Global Wind Energy Council (GWEC), *Global Wind Report: Annual Market Update 2016* (Brussels: April 2017), http://www.gwec.net/strong-outlook-for-wind-power/; FTI Consulting, *Global Wind Market Update – Demand & Supply 2016, Part Two – Demand Side Analysis* (London: March 2017); World Wind Energy Association (WWEA), *WWEA Annual Report 2016* (Bonn: May 2017), http://www.wwindea.org/; *WindEurope, Wind in Power 2016 European Statistics* (Brussels: 9 February 2017), https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Statistics-2016.pdf. Additional sources listed where relevant. **China:** 2015 year-end official data from China Electricity Council, cited by China National Energy Administration (CNEA), provided by Shi Pengfei, Chinese Wind Energy Association (CWEA), personal communication with REN21, 21 March 2017; 2016 official data from China National Energy Board, cited in Dazhong Xiao, CNEA, "2016 wind power and grid operation", 26 January 2017, www.nea.gov.cn/2017-01/26/c_136014615.htm (using Google Translate); unofficial 2015 and 2016 data based on CWEA, provided by Shi, op. cit. this note. **United States:** American Wind Energy Association, "U.S. Wind Industry Fourth Quarter 2016 Market Update" (Washington, DC: 26 January 2017), http://awea.files.cms-plus.com/FileDownloads/pdfs/4Q2016%20AWEA%20Market%20Report%20Public%20Version.pdf, and AWEA, *AWEA U.S. Wind Industry Annual Market Report Year Ending 2016* (Washington, DC: April 2017), http://www.awea.org/AnnualMarketReport.aspx?ItemNumber=10217. **Germany:** BMWI, op. cit. note 6. **India:** 2015 year-end total from Government of India, MNRE, "Physical progress (achievements) up to the month of December 2015", www.mnre.gov.in/mission-and-vision-2/achievements, viewed 1 February 2016; 2016 additions and year-end total from Government of India, Ministry of Power, Central Electricity Authority, *All India Installed Capacity, Monthly Report January 2017* (New Delhi: 2017), Table: "All India Installed Capacity (in MW) of Power Stations (As on 31.01.2017) (Utilities)", http://www.cea.nic.in/reports/monthly/installedcapacity/2017/installed_capacity-01.pdf. **Brazil:** Associação Brasileira de Energia Eólica (ABEEólica), "Dados Mensais", January 2017, http://www.abeeolica.org.br/wp-content/uploads/2017/01/Dados-Mensais-ABEEolica-01.2017-1.pdf, pp. 4, 6. Note that

Brazil had 10,123.9 MW at end-2016 from Agência Nacional de Energia Elétrica (ANEEL), "Informações Gerenciais", December 2016, http://www.aneel.br/informacoes-gerenciais. **France:** WindEurope, op. cit. this note. Note that France had 11,670 MW in operation as of 31 December 2016, from RTE Réseau de transport d'électricité, *Bilan Électrique Français 2016: Synthèse presse* (Paris: 2016), p. 5, http://www.rte-france.com/sites/default/files/2016_bilan_electrique_synthese.pdf. **Turkey:** Turkish Wind Energy Association, *Turkish Wind Energy Statistics Report* (Ankara: January 2017), pp. 4, 5, http://www.tureb.com.tr/files/tureb_sayfa/duyurular/2017_duyurular/subat/turkiye_ruzgar_enerjisi_istatistik_raporu_ocak_2017.pdf. **The Netherlands:** 2015 and 2016 data based on WindEurope, op. cit. this note. Note that the Netherlands added 815 MW for a total of 4,206 MW, from Centraal Bureau voor de Statistiek, "Hernieuwbare elektriciteit; productie en vermogen", 28 February 2017, http://statline.cbs.nl/Statweb/publication/?DM=SLNL&PA=82610NED&D1=7&D2=2-4&D3=25-26&HDR=T,G2&STB=G1&VW=T. **United Kingdom:** 2015 and 2016 data based on WindEurope, op. cit. this note. Note that the United Kingdom had 14,292 MW at end-2015 and 15,696 MW at end-2016, based on preliminary data from UK Department for Business, Energy & Industrial Strategy, *National Statistics, Energy Trends Section 6: Renewables,* updated 30 March 2017, Table 6.1 "Renewable electricity capacity and generation", p. 69, https://www.gov.uk/government/statistics/energy-trends-section-6-renewables. **Canada:** Canadian Wind Energy Association (CanWEA), "Installed capacity", http://canwea.ca/wind-energy/installed-capacity/, viewed 17 February 2017. **Spain:** WindEurope, op. cit. this note. Additions in 2016 of 38 MW from Spanish Wind Power Association (AEE) using the official certificate of commissioning as the criterion, cited in GWEC, "Spain installed 38 wind power megawatts in 2016", 14 March 2017, http://www.gwec.net/spain-installed-38-wind-power-megawatts-in-2016/. **Italy:** WindEurope, op. cit. this note. See Wind Power section in Market and Industry Trends chapter and related endnotes for further statistics and details.

10 **Table R10** from IEA, World Energy Outlook 2016 Energy Access Database, http://www.worldenergyoutlook.org/resources/energydevelopment/energyaccessdatabase/, viewed 28 March 2017, and from Sustainable Energy for All (SEforALL), Africa Hub Country Database, https://www.se4all-africa.org/se4all-in-africa/country-data/, viewed 28 March 2017.

11 **Table R11** from the following sources: IEA, op. cit. note 10; SEforALL, op. cit. note 10; Chile and Mexico from SEforALL, *Global Tracking Framework: Progress Toward Sustainable Energy* (Washington, DC: 2017), http://gtf.esmap.org/data/files/download-documents/eegp17-01_gtf_summary_for_web_0428.pdf.

12 **Table R12** from submissions by report contributors and from various institutional reports and websites.

13 **Table R13** from Ibid.

14 **Table R14** from Frankfurt School-UNEP Collaborating Centre for Climate & Sustainable Energy Finance and Bloomberg New Energy Finance (BNEF), *Global Trends in Renewable Energy Investment 2017* (Frankfurt: April 2017), pp. 32-33, http://fs-unep-centre.org/publications/global-trends-renewable-energy-investment-2016.

15 **Table R15** from the following sources: REN21 database; submissions by report contributors; various industry reports; EUROSTAT, *Energy from Renewable Sources: Shares* (Brussels: 2016), http://ec.europa.eu/eurostat/web/energy/data/shares. For online updates, see the "Renewables Interactive Map" at www.ren21.net.

16 **Table R16** from the following sources: REN21 database; submissions by report contributors; various industry reports; EUROSTAT, op. cit. note 15. For online updates, see the "Renewables Interactive Map" at www.ren21.net.

17 **Table R17** from the following sources: REN21 database; submissions by report contributors; various industry reports; EUROSTAT, op. cit. note 15. IEA statistics based on data from IEA, "Electricity Information 2015, www.iea.org/statistics, as modified by REN21. Targets for the EU-28 were set in each country's National Renewable Energy Action Plan (NREAP), available at http://ec.europa.eu/energy/en/topics/renewable-energy/national-action-plans; certain NREAP targets have been revised subsequently. For online updates, see the "Renewables Interactive Map" at www.ren21.net.

18 **Table R18** from the following sources: REN21 database; submissions by report contributors; various industry reports; EurObserv'ER. Targets for the EU-28 were set in each country's National Renewable Energy Action Plan (NREAP), available at http://ec.europa.eu/energy/en/topics/renewable-energy/national-action-plans; certain NREAP targets have been revised subsequently. For online updates, see the "Renewables Interactive Map" at www.ren21.net.

19 **Table R19** from the following sources: REN21 database; submissions by report contributors; various industry reports. For online updates, see the "Renewables Interactive Map" at www.ren21.net.

20 **Table R20** from the following sources: All available policy references, including the IEA/IRENA online Global Renewable Energy Policies and Measures database, published sources as given in the endnotes for the Policy Landscape chapter of this report, and submissions from report contributors.

21 **Table R21** from the following sources: REN21 database; submissions by report contributors; various industry reports; EurObserv'ER. Targets for the EU-28 were set in each country's NREAP, available at http://ec.europa.eu/energy/en/topics/renewable-energy/national-action-plans; certain NREAP targets have been revised subsequently. For online updates, see the "Renewables Interactive Map" at www.ren21.net.

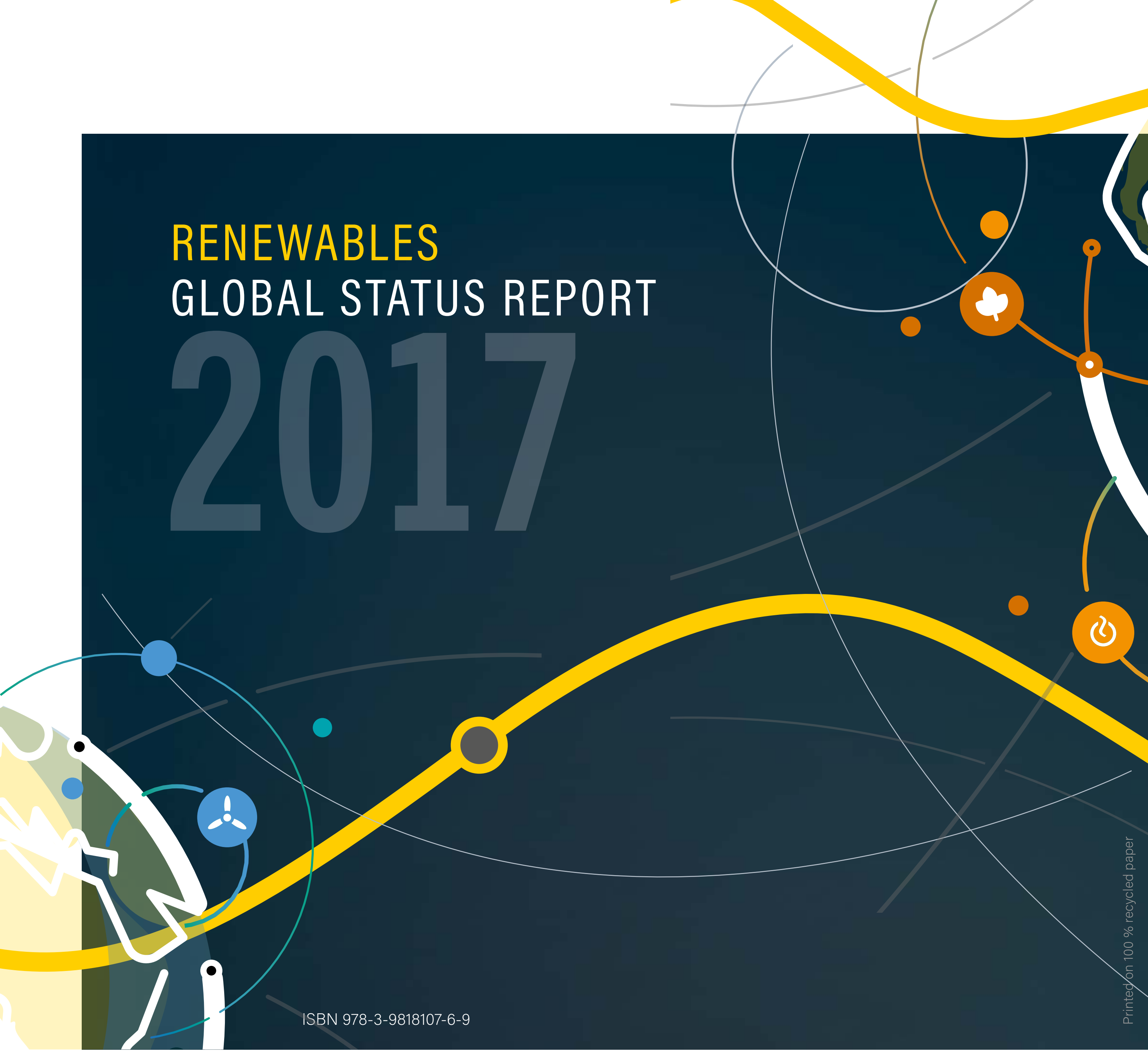
22 **Table R22** from the following sources: All available policy references, including the IEA/IRENA online Global Renewable Energy Policies and Measures database, published sources as given in the endnotes for the Policy Landscape chapter of this report, and submissions from report contributors.

23 **Table R23** from REN21 database compiled from all available policy references plus submissions from report contributors. EU targets and shares from EUROSTAT, op. cit. note 15. For online updates, see the "Renewables Interactive Map" at www.ren21.net. Targets for the EU-28 and Energy Community countries were set in each country's NREAP; certain NREAP targets have been revised subsequently. For online updates, see the "Renewables Interactive Map" at www.ren21.net.

24 **Table R24** from the following sources: REN21 database; submissions by report contributors; various industry reports; EUROSTAT, op. cit. note 15. For online updates, see the "Renewables Interactive Map" at www.ren21.net.

25 **Table R25** from Ibid., from IRENA and from Jim Lane, "Biofuels Mandates Around the World: 2015", Biofuels Digest, 3 January 2016, http://www.biofuelsdigest.com/bdigest/2016/01/03/biofuels-mandates-around-the-world-2016.

26 **Table R26** from REN21 database compiled from all available policy references plus submissions from report contributors the following sources: For selected targets and policies, see: EU Covenant of Mayors; C40 Cities; ICLEI – Local Governments for Sustainability; REN21, *Global Futures Report* (Paris: 2013); and REN21, Institute for Sustainable Energy Policies and ICLEI, *2011 Global Status Report on Local Renewable Energy Policies* (Paris: May 2011). For additional information on sources see endnote 1 for the Policy Landscape chapter.



REN21 Secretariat
c/o UNEP
1 Rue Miollis
Building VII
75015 Paris
France

www.ren21.net

REN21 Renewable Energy Policy Network for the 21st Century