

# RENEWABLES 2023

# GLOBAL STATUS REPORT



ENERGY  
SUPPLY

2023  
COLLECTION

# REN21 MEMBERS

## INDUSTRY ASSOCIATIONS

Africa Minigrids Developers Association (AMDA)  
Alliance for Rural Electrification (ARE)  
American Council on Renewable Energy (ACORE)  
Associação Lusófona de Energias Renováveis (ALER)  
Associação Portuguesa de Energias Renováveis ((APREN)  
Chinese Renewable Energy Industries Association (CREIA)  
Clean Energy Council (CEC)  
Euroheat & Power (EHP)  
European Heat Pump Association (EHPA)  
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)  
RE100/Climate Group  
RES4Africa Foundation  
SolarPower Europe (SPE)  
Union International de Transport Publique (UITP)  
World Bioenergy Association (WBA)  
World Wind Energy Association (WWEA)

## SCIENCE AND ACADEMIA

AEE – Institute for Sustainable Technologies (AEE-INTEC)  
Council on Energy, Environment and Water (CEEW)  
Fundación Bariloche (FB)  
International Institute for Applied Systems Analysis (IIASA)  
International Solar Energy Society (ISES)  
National Renewable Energy Laboratory (NREL)  
National Research University Higher School of Economics Russia (HSE)  
South African National Energy Development Institute (SANEDI)  
The Energy and Resources Institute (TERI)  
University of Technology – Institute for Sustainable Futures (UTS)  
World Resources Institute (WRI)

## INTER-GOVERNMENTAL ORGANISATIONS

Asia Pacific Energy Research Center (APEREC)  
Asian Development Bank (ADB)  
ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE)  
Electric Power Council of the Commonwealth of Independent States (EPC)  
European Commission (EC)  
Global Environment Facility (GEF)  
International Energy Agency (IEA)  
International Renewable Energy Agency (IRENA)  
Islamic Development Bank (IsDB)  
Organización Latinoamericana de Energía (OLADE)  
Regional Center for Renewable Energy and Energy Efficiency (RCREEE)  
United Nations Development Programme (UNDP)  
United Nations Environment Programme (UNEP)  
United Nations Industrial Development Organization (UNIDO)  
World Bank (WB)

## GOVERNMENTS

Afghanistan  
Australia  
Austria  
Brazil  
Denmark  
Dominican Republic  
Georgia  
Germany  
India  
Mexico  
Morocco  
Norway  
Rio Negro  
Republic of Korea  
South Africa  
South Australia  
Spain  
United Arab Emirates  
United States of America  
Zimbabwe

## PRESIDENT

Arthouros Zervos

## NGOS

350.org  
Association Africaine pour l'Electrification Rurale (Club-ER)  
CDP  
CLASP  
Clean Cooking Alliance (CCA)  
Climate Action Network International (CAN-I)  
Coalition de Ciudades Capitales de las Americas (CC35)  
Energy Cities  
European Youth Energy Network (EYEN)  
Fundación Renovables (FER)  
Global Forum on Sustainable Energy (GFSE)  
Global Women's Network for the Energy Transition (GWNENET)  
Greenpeace International  
ICLEI – Local Governments for Sustainability  
Institute for Sustainable Energy Policies (ISEP)  
International Electrotechnical Commission (IEC)  
Jeune Volontaires pour l'Environnement (JVE)  
Mali Folkecenter (MFC)  
Power for All  
Renewable Energy and Energy Efficiency Partnership (REEEP)  
Renewable Energy Institute (REI)  
Renewables Grid Initiative (RGI)  
SLOCAT Partnership on Sustainable, Low Carbon Transport  
Solar Cookers International (SCI)  
Sustainable Energy for All (SEforAll)  
Sustainable Energy Africa  
The Global 100% Renewable Energy Platform (Global 100%RE)  
World Council for Renewable Energy (WCRE)  
World Future Council (WFC)  
World Wide Fund for Nature (WWF)

## MEMBERS AT LARGE

Michael Eckhart  
David Hales  
Kirsty Hamilton  
Peter Rae  
Arthouros Zervos

## EXECUTIVE DIRECTOR

Rana Adib  
REN21

## FOREWORD

In addition to the global development and climate deterioration, the global energy crisis experienced in 2021-2022 has highlighted the critical importance of securing a reliable and stable energy supply. In this context, policy makers as well as energy consumers have turned more attention to renewable energy. As shifting to renewables becomes a global necessity, a pressing question remains: How do we ensure that we have enough of them to support a prosperous economy, foster social equity, and achieve sustainable development? And how can we provide secure and stable energy supply globally?

Renewable power experienced record-breaking growth in 2022, but this progress alone does not capture the full picture of the transition. The current growth rate of renewable power is still insufficient, and it overshadows some critical bottlenecks, such as slow permitting processes and insufficient grid infrastructure – as I write, over 1 terawatt of renewable power capacity is waiting to be constructed or connected to the grid. Renewable heat and fuels also lag - heat and fuels provide nearly 80% of global energy supply but are still largely depending on fossil fuel. To shield us from future crises, policymakers need to pay greater attention to diversifying the sources and technologies of renewables.

In addition, they need to focus on building an economy that has renewables as its backbone. This means putting in place structures to enable the sustainable growth of the renewables industry, including ramping up manufacturing capacities, securing necessary supply chains and developing skilled labour.

The *Renewables 2023 Global Status Report – Energy Supply Module* delves into the intricacies of renewable energy progress, examining the distribution of energy among carriers and addressing critical obstacles. It is the second in a five-piece collection released this year and represents the collaborative efforts of hundreds of contributors who share the ambition of providing irrefutable and unbiased facts and knowledge to propel the global wave of change. I hope that in this module, you will find the essential elements and tools to support your analysis and work towards a swift transition to renewable energy.

Thank you to the REN21 team, authors, special advisors, and contributors who have dedicated their knowledge, time, and effort to produce this report. Their insights, passion, and commitment are instrumental in creating these crowd-sourced and peer-reviewed reports. I am confident that this publication will serve as a valuable resource for policymakers, industry leaders, and stakeholders, informing their decision-making and driving the transition to a sustainable energy future for all.

Sincerely,



**Rana Adib**  
Executive Director, REN21

# TABLE OF CONTENTS

Foreword .....	03
Acknowledgements .....	09
Photo Credits and Impressum .....	88

## RENEWABLES IN ENERGY SUPPLY: Global Trends

Module Overview .....	13
Policy .....	21
Investment .....	26

## MARKET TRENDS

Bioenergy .....	35
Geothermal Power and Heat .....	42
Heat Pumps .....	46
Hydrogen .....	50
Hydropower .....	54
Ocean Power .....	59
Solar Photovoltaics (PV) .....	62
Concentrated Solar Power (CSP) .....	69
Solar Thermal Heating .....	71
Wind Power .....	77
Challenges and Opportunities .....	86



## REPORT CITATION

REN21. 2023.  
*Renewables 2023 Global Status Report collection,  
Renewables in Energy Supply*  
(Paris: REN21 Secretariat).

**ISBN 978-3-948393-08-3**

Comments and questions are welcome  
and can be sent to [gsr@ren21.net](mailto:gsr@ren21.net).

## LINKS TO MICROSITE

- Energy Units and Conversion Factors
- Data Collection and Validation
- Methodological Notes
- Glossary
- List of Abbreviations

Reference Tables can be accessed through the  
GSR 2023 Energy Supply Data Pack at  
→ <http://www.ren21.net/gsr2023-data-pack/supply>



## FIGURES

<b>Figure 1.</b>	Renewables in Energy Supply	12
<b>Figure 2.</b>	Share of Renewable Energy in Electricity Generation, by Energy Source 2012 and 2022	14
<b>Figure 3.</b>	Share of Renewable Heat Production, by Energy Source, 2010 and 2020	15
<b>Figure 4.</b>	Renewable Share of Electricity Generation, by Region, 2012 and 2022	16
<b>Figure 5.</b>	Renewable Power Total Installed Capacity and Annual Additions, by Technology, 2022	17
<b>Figure 6.</b>	Renewable Power Capacity Annual Additions by Technology, 2017-2022, and Increases Required by 2030 to Achieve the IEA's Net Zero Scenario	18
<b>Figure 7.</b>	Technology-Specific Targets for Installed Renewable Power Capacity, 2022	21
<b>Figure 8.</b>	Renewable Energy Feed-in Tariffs and Net Metering Policies, 2022	22
<b>Figure 9.</b>	Global Investment in Renewable Power and Fuels by Technology, 2018-2022	26
<b>Figure 10.</b>	Global Investment in RE Power and Fuels by Country and Region, 2013-2022	27
<b>Figure 11.</b>	Global Investment in New Power Capacity, by Type, 2022	31
<b>Figure 12.</b>	Range of Annual Renewable Energy Investment Needed in Climate Change Mitigation Scenarios, Compared to Recent Investments	32
<b>Figure 13.</b>	Share of Bioenergy in Total Final Energy Consumption, 2020	36
<b>Figure 14.</b>	Global Production of Ethanol, Biodiesel and HVO/HEFA Fuel, by Energy Content, 2011-2021	37
<b>Figure 15.</b>	Global Bioelectricity Installed Capacity, by Region, 2012-2022	40
<b>Figure 16.</b>	Global Wood Pellet Production, by Region, 2012-2021	41
<b>Figure 17.</b>	Geothermal Power Capacity and Additions, Top 10 Countries and Rest of World, 2022	43
<b>Figure 18.</b>	Geothermal Direct Use, Estimates for Top 4 Countries and Rest of World, 2022	44
<b>Figure 19.</b>	National Heat Pump Markets with the Largest Growth in 2022	47
<b>Figure 20.</b>	Sales of Heat Pumps and Additions of Solar PV in Poland, 2012-2022	48
<b>Figure 21.</b>	Hydrogen Strategies and Roadmaps in Selected Countries, as of End-2022	51
<b>Figure 22.</b>	Hydropower Global Capacity, Shares of Top 10 Countries and Rest of World, 2022	55

<b>Figure 23.</b>	Hydropower Global Capacity and Additions, Shares of Top 10 Countries, 2022	55
<b>Figure 24.</b>	Solar PV Global Capacity and Annual Additions, 2012-2022	63
<b>Figure 25.</b>	Solar PV Global Capacity, by Country and Region, 2012-2022	63
<b>Figure 26.</b>	Solar PV Capacity and Additions, Top 10 Countries for Capacity Added, 2022	64
<b>Figure 27.</b>	Solar PV Global Capacity Additions, Shares of Top 10 Countries and Rest of World, 2022	65
<b>Figure 28.</b>	Concentrating Solar Thermal Power Global Capacity, by Country and Region, 2012-2022	70
<b>Figure 29.</b>	Solar Water Heating Collectors Global Capacity, 2012-2022	72
<b>Figure 30.</b>	Solar Water Heating Collector Additions, Top 20 Countries for Capacity Added, 2022	72
<b>Figure 31.</b>	Wind Power Global Capacity and Annual Additions, 2012-2022	78
<b>Figure 32.</b>	Wind Power Capacity and Additions, Top 10 Countries, 2022	79

## TABLES

<b>Table 1.</b>	Top Five Countries, 2022	19
-----------------	--------------------------	----

## SIDEBARS

<b>Sidebar 1.</b>	Permitting and Grid Updates for Renewable Energy	33
<b>Sidebar 2.</b>	Standardising Sustainability in the Hydropower Sector	56

## SNAPSHOTS

<b>Poland</b>	48
<b>Chile</b>	53
<b>Japan</b>	83

For further details and access to the report, references and endnotes, visit [www.ren21.net/gsr-2023/](http://www.ren21.net/gsr-2023/)





# RENEWABLE ENERGY POLICY NETWORK FOR THE 21<sup>ST</sup> CENTURY

REN21 is the only global community of actors from science, governments, NGOs and industry **working collectively** to drive the rapid uptake of renewables – now!



REN21 works to build knowledge, shape dialogue and debate, and communicate these results to **inform decision makers** to strategically drive the deep transformations needed to make renewables the norm. We do this in close co-operation with the community, providing a platform for these stakeholders to engage and collaborate. REN21 also connects with non-energy players to grow the energy discourse, given the economic and social significance of energy.



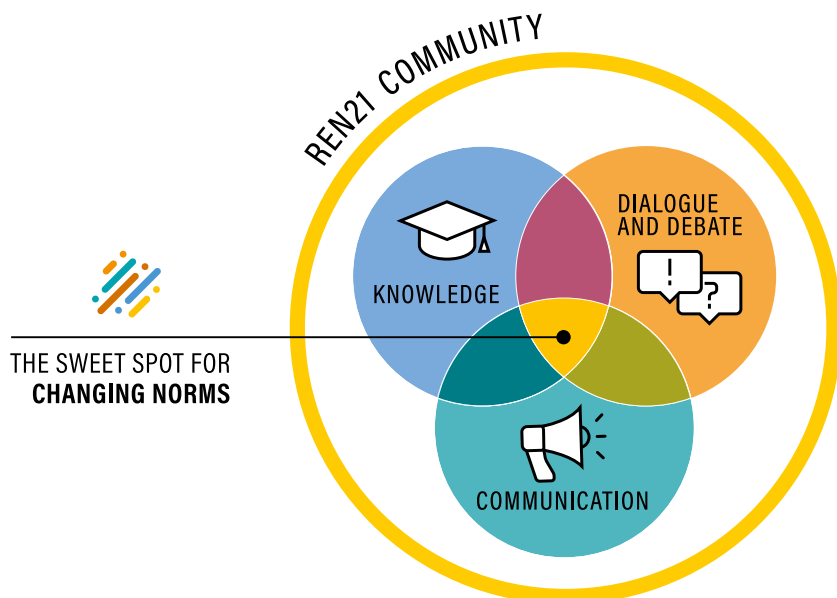
The most successful organisms, such as an octopus, have a **decentralised intelligence** and "sensing" function. This increases responsiveness to a changing environment. REN21 incarnates this approach.



Our more than **4,000 community members** guide our co-operative work. They reflect the vast array of backgrounds and perspectives in society. As REN21's eyes and ears, they collect information, share intelligence and make the renewable voice heard.



REN21 takes all this information to better understand the current thinking around renewables and change norms. **Our publications** are probably the world's most comprehensive crowd-sourced reports on renewables. Each is a truly collaborative process of co-authoring, data collection and peer reviewing.



# CROWD-SOURCED DATA AND KNOWLEDGE

REN21's data and knowledge collection method is built on a global multi-stakeholder community of experts. It is validated in a collaborative and transparent open peer-review process. It is made openly available to develop a shared language that shapes the sectoral, regional and global debate on the energy transition.



For more information, see the Methodological Notes section on data collection and validation.

## RENEWABLES GLOBAL STATUS REPORT 2023 COLLECTION

Since 2005, REN21's Renewables Global Status Report (GSR) has spotlighted ongoing developments and emerging trends that shape the future of renewables. It is a collaborative effort involving hundreds of experts.

This year's edition (18th) has evolved in design and structure to reflect the fundamental changes in the global energy landscape. The new structure is in the form of a collection of five publications. In addition to presenting the trends in renewable energy supply, it also dives into the energy demand sectors, with dedicated modules on

buildings, industry, transport and agriculture. It includes a publication on energy systems and infrastructure with renewables, as well as a publication on renewables for economic and social value creation, acknowledging the key role that energy plays across economies and societies. Collectively these five publications offer readers a systemic global overview of the current uptake of renewables.

This new structure makes the GSR a key tool in expanding the renewable energy discussion into key sectors and ecosystems, developing a shared language and driving a stronger integration of supply, demand, infrastructure, market and investment.





## 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.

The designations employed and the presentation of material in the maps in this report do not imply the expression of any opinion whatsoever concerning the legal status of any region, country, territory, city or area or of its authorities, and is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers or boundaries and to the name of any territory, city or area.



Supported by:



Federal Ministry  
for Economic Affairs  
and Climate Action

on the basis of a decision  
by the German Bundestag



Federal Ministry  
for Economic Cooperation  
and Development

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 Climate Action (BMWK) and the UN Environment Programme. A large share of the research for this report was conducted on a voluntary basis.



# ACKNOWLEDGEMENTS

## REN21 DATA AND KNOWLEDGE TEAM

Jad Baba  
Ana Díaz Vidal  
Yuko Komazawa  
Nathalie Ledanois  
Hend Yaqoob

## SPECIAL ADVISORS

Adam Brown  
Janet L. Sawin

## CHAPTER AUTHORS

Hagar Abdelnabi  
Hind Couzin  
Ahmed El Guindy  
Duncan Gibb  
Bharadwaj Kummamuru  
Kristin Seyboth  
Peter Stalter  
Freyr Sverrisson  
Glen Wright

## RESEARCH AND PROJECT SUPPORT (REN21 SECRETARIAT)

Thomas André  
Fayrouz Atrakouti  
Talia Contreras-Tapia  
Stefanie Gicquel  
Vibhushree Hamirwasia  
Jonas Reolon Kremer  
Borana Resulaj  
Andrea Wainer  
Laura E. Williamson

## COMMUNICATIONS SUPPORT (REN21 SECRETARIAT)

Yasmine Abd-El-Aziz  
Anna Abraham  
Mariela Lopez Hidalgo  
Hala Kilani  
Shiyao Zhang

## EDITING, DESIGN AND LAYOUT

Lisa Mastny (Editor)  
weeks.de Werbeagentur GmbH (Design)

## PRODUCTION

REN21 Secretariat, Paris, France

## DATA AND PYTHON PROGRAMMING

Nicolas Achury (independent consultant)

## LEAD TOPICAL CONTRIBUTORS

### BIOENERGY

Takanobu Aikawa (Renewable Energy Institute); Pharoah Le Feuvre (Enegas); Christian Rakos (Propellets Austria)

### HEAT PUMPS

Yannick Monschauer (International Energy Agency – IEA); Thomas Nowak (European Heat Pump Association); Jan Rosenow (Regulatory Assistance Project)

### HYDROPOWER

John Altomonte (Verne Energy Solutions, Corp.); Michael Barnard (CleanTechnica); Matteo Bianciotto; Alex Campbell; Rebecca Ellis; Debbie Gray; Lei Xie (International Hydropower Association (IHA)); Xizhou Zhou (S&P Global)

### INVESTMENT

James Ellis (Bloomberg NEF); Charlotte Gardes-Landolfini; Ali Izadi-Najafabadi (Bloomberg NFF); Ryan Wiser (Lawrence Berkeley National Laboratory)

### CSP

Richard Thonig (CSP.guru); David Trebolle (Protermo Solar)

### SOLAR THERMAL HEATING

Bärbel Epp (solrico); Monika Spörk-Dür; Werner Weiss (AEE – Institut für Nachhaltige Technologien); Pedro Dias (Solar Heat Europe)

### WIND

Feng Zhao (Global Wind Energy Council – GWEC); American Clean Power; Giuseppe Costanzo (WindEurope); Stefan Gsänger (World Wind Energy Association – WWEA)



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 topical contributors also participated in the Global Status Report (GSR) review and validation process.

## PEER REVIEWERS AND OTHER CONTRIBUTORS

Christian A. Sarikie (EndaSolar (T) Ltd);  
 Mussa Abbasi Mussa (Ministry of Energy  
 Tanzania); Mohammed Abdalghafoor  
 (United Nations Framework Convention  
 on Climate Change); Mahmoud Abou  
 Elenen (GE); Hassan Aboughalma  
 (Georenco); Abdenour Achour (Chalmers  
 University of Technology); Ayooluwa  
 Adewole (University College London);  
 Damilola Adeyanju (Enel Foundation);  
 Sujan Adhikari (International Renewable  
 Energy Agency – IRENA); Florencia  
 Agatiello; Gamze Akarsu (United Nations  
 Development Programme); Iqbal Akbar  
 (Honeywell International); Carolyn  
 Amon (Deloitte); Marlon Arraes Jardim  
 (Ministry of Mines and Energy Brazil);  
 Eros Artuso (Terra Consult Sarl); Patrick  
 Atouda Beyala (SOAS University of  
 London); Fadeke Ayoola (NET Africa);  
 Shakila Aziz (United International  
 University); Matthieu Ballu (European  
 Commission); Manjola Banja (European  
 Commission); Raju Barman; Marie  
 Blanche Ting (University of Sussex);  
 Rina Bohle Zeller (Vestas); Udochukwu  
 Bola Akuru (Tshwane University of  
 Technology); Elina Bosch (Becquerel  
 Institute); Gonzalo Bravo (Bariloche  
 Foundation); William Brent (Husk  
 Power Systems); Kirstin Bretthauer  
 (Deutsche Gesellschaft für Internationale  
 Zusammenarbeit – GIZ); Guy Brindley  
 (WindEurope); Thailys Campos  
 Magalhães; Anita Chebii (Serengeti  
 Energy); Sreenivas Chigullapalli (Indian  
 Institute of Technology Bombay); Chuck  
 Chuan Ng (Xiamen University Malaysia);  
 David Clark (Kinetic Energy Generation  
 Systems); Suani Coelho (University  
 of São Paulo); Ute Collier (IRENA);  
 Lanvin Concessao (World Resources  
 Institute); Alekhya Datta (KPMG India);  
 Elmien de Wet (Zero Carbon Charge);  
 Giles Dearden (Natural Power); Zuzana  
 Dobrotkova (World Bank); Julie Dulce  
 (Manila Electric Company); Sälma  
 El-Gamal (World Future Council);  
 Wemogar Elijah Borweh (University  
 of Liberia); Ben Elliston (University of  
 New South Wales); Yasemin Erboy  
 Ruff (CLASP); Gerardo Escamilla  
 (IRENA); Ammar Fadlallah (Lebanese  
 Center for Energy Conservation); Akif  
 Farooqui (TERI); Thomas Fees (Inti  
 Tech Solar); Juan Fernando Martín  
 (Fundación Renovables); David Ferrari  
 (Exemplary Energy, Melbourne);  
 Rafael Francisco (ABSOLAR); Ahmed  
 Garba (Blue Camel Energy Ltd);  
 Eduardo Garcia (ENERGY-W); Luis  
 García; Alfonso German (StripSteel);  
 Anastasia Grabco (Suma Capital);  
 Chris Greacen (University of San  
 Francisco); Paul H.Suding (Elsud);  
 Brad Heavner (California Solar &  
 Storage Association); John Hensley  
 (American Clean Power Association);  
 Gabriela Hernández-Luna (Autonomous  
 University of Morelos State – UAEM);  
 Rainer Hinrichs-Rahlwes (European  
 Renewable Energies Federation);  
 Anastasia Ioannou (University of  
 Glasgow); Sammy Jamar Chemengich  
 (CLASP); Rod Janssen (Energy in  
 Demand); Ario Jati; Bernardo Joel Carrillo  
 Castillo; Danielle Johann (ABRASOL);  
 Wim Jonker Klunne (Household Solar  
 Funders Group); Manuel José Espinosa  
 (The Phoenix Group); Maria José Linders  
 (Statistics Netherlands); József Kádár  
 (Arava Institute for Environmental  
 Studies); Christos Kalyvas (University  
 of Hertfordshire); Chisakula Kaputu  
 (Sustainable Energy & Environment  
 LTD); Phubalan Karunakaran (WWF  
 Malaysia); Panayiotis Kastanias (Cyprus  
 Union of Solar Thermal Industrialists);  
 Chisakula Kaputu (Sustainable Energy &  
 Environment LTD); Shorai Kavu (Ministry  
 of Energy and Power Development,  
 Zimbabwe); Kamil Kaygusuz (Karadeniz  
 Technical University); Mohamed  
 Khalifa (Khartoum Refinery Company  
 Ltd); M. Khalil Elahee (University of  
 Mauritius); Kennedy Khusi; Birol Kilikis  
 (OSTIM Technical University); Siir Kilikis  
 (Scientific and Technical Research  
 Council of Türkiye); Shigeki Kobayashi  
 (Transport Institute of Central Japan);  
 Bozhil Kondev; Assem Korayem (Total  
 Eren); Deepak Kumar (State University of  
 New York at Albany); Sivanappan Kumar  
 (Naresuan University); Maryse Labriet  
 (Eneris Consultants); Reshmi Ladwa  
 (GWEC); Elisa Lai (CLASP); Padmasai  
 Lakshmi Bhamidipati (United Nations  
 Environment Programme); Ferdinand  
 Larona (GIZ); George Lavidas (Delft  
 University of Technology); Andrew  
 Lawrence (Wits School of Governance);  
 Denis Lenardic; Detlef Loy (Loy Energy  
 Consulting); Andrea Lieson (BSW  
 Solar); Jose Luis Villate (TECNALIA);  
 Marissa Malahayati; Jaideep Malaviya  
 (Solar Thermal Federation of India  
 – STFI); Emile Martin (Wuppertal  
 Institute; Gonçalo Martins (Portuguese  
 Association of Renewable Energy –  
 APREN); Hironao Matsubara (Institute for  
 Sustainable Energy Policies); Leopoldo  
 Mico (Solar Heat Europe); Alan Miller;  
 Emi Mizuno (Sustainable Energy for All);  
 Alireza Mollasalehi; Mohammadreza  
 Mollasalehi (Berroz Fanavar e  
 Beinolmelal Co.); Antonio Moreno-  
 Munoz (University of Cordoba); Wolfgang  
 Mostert; Sabatha Mthwecu (Solar  
 Rais); Julia Muench (LDES Council);  
 Mweetwa Mundia Sikamikami (Bitpop  
 Engineering); Abubakar Musa Magaga  
 (Nigerian institute of Transportation  
 Technology); Amon Mwadime (Africa  
 Minigrid Developers Association); Nurzat  
 Myrsaliev (United Nations Industrial  
 Development Organization – UNIDO);  
 Paul Nduhuura (Makerere University  
 Business School); Tuan Nguyen (RINA  
 Consulting); Marjan Nikolov (Center  
 for Economic Analyses); Jesse Nyokabi  
 (Quaise Energy Africa); Solomon Ojoawo  
 (Memorial University of Newfoundland);  
 Peta Olesen (Department of Climate  
 Change, Energy, the Environment  
 and Water); Saverio Papa (Solar Heat  
 Europe); Arghya Paul; Tomasz Pawelec  
 (UNIDO); Lotta Pirttimaa (Ocean Energy  
 Europe); Pascual Polo (Asociación de la  
 Industria Solar Térmica – ASIT); Ramesh  
 Poluru (INCLEN Trust International);  
 Debora Pontes (Zypho®); Edwige  
 Porcheyre (Enerplan); Joana Portugal  
 Pereira (Federal University of Rio de  
 Janeiro); Pedro R. Dias (Solar Heat  
 Europe/ESTIF); Uwe R. Fritsche (IINAS  
 & IEA Bioenergy); Swasti Raizada

(International Institute for Sustainable Development); Daya Ram Nhuchhen (Government of Northwest Territories); Bard Rama (Prague Technical University); Atul Raturi (The University of the South Pacific); Shayan Razaghy (Circuit Energy Inc.); A. Ricardo J. Esparta (USP); Nkweauseh Reginald Longfor (Sophia University); Dave Renné (International Solar Energy Society); Juan Roberto Lozano-Maya (National Energy Control Center – CENACE); Heather Rosmarin (InterAmerican Clean Energy Institute); Martin Sabel (Bundesverband Wärmepumpe (BWP) e.V.); Tarek Safwat Kabel (University of Sadat City); Sanchit Saran Agarwal (The Energy and Resources Institute); Amit Saraogi (Oorja Development Solutions Limited); Miguel Schloss (Surinvest. Ltda.); Ali Shahhoseini (Qazvin Islamic

Azad University); Eli Shilton (Elsol); N. Shinde (UES Renewable Energy Pvt Ltd); Wilson Sierra (Universidad de la República Uruguay); Kamil Sobczak (fenixwing.com); Dosse Sossouga (Amis des Etrangers au Togo); Julia Souder (LDES Council); Laiz Souto (University of Bristol); Janusz Starościk (Association of Manufacturers and Importers of Heating Appliances – SPUIG); Alexandra Styles (Hamburg Institut); Jan Svoboda (AMO); Jin Tanaka (UNISC International); Michael Taylor (IRENA); Suani Teixeira Coelho (USP); Faruk Telemcioglu; Hannibal Tesfahunegn (Power for All); Costas Travasaros (Greek Solar Industry Association – EBHB); Daniel Trier (PlanEnergi); Ioannis Tspouridis (RED PRO Consultants); Kutay Ulke (Bural); Rodrigo Valdovinos (IDMA Chile Institut); Daniel Van Mosnenck (NemoRenSys);

Silvia Vera (Institute for Diversification and Energy Saving – IDAE); Ana Vieira (National Laboratory for Civil Engineering – LNEC); Patricia Villarroel Sáez (Regional Courts of Appeal, Chile); Marion Walker (ZSW); David Walwyn (Renewable Energy Generation); Moritz Weigel (African Energy Now); Tim Weis (University of Alberta); Harsha Wickramasinghe (Sri Lanka Sustainable Energy Authority); Amin Yahya Khotbehsara; Qazvin Islamic Azad University); Peter Yang (Case Western Reserve University); Nouredine Yassaa (Commissariat aux Energies Renouvelables et à l'Eff); Hameedullah Zaheb (Kabul University); Xia Zuzhang (Food and Agriculture Organization of the United Nations)

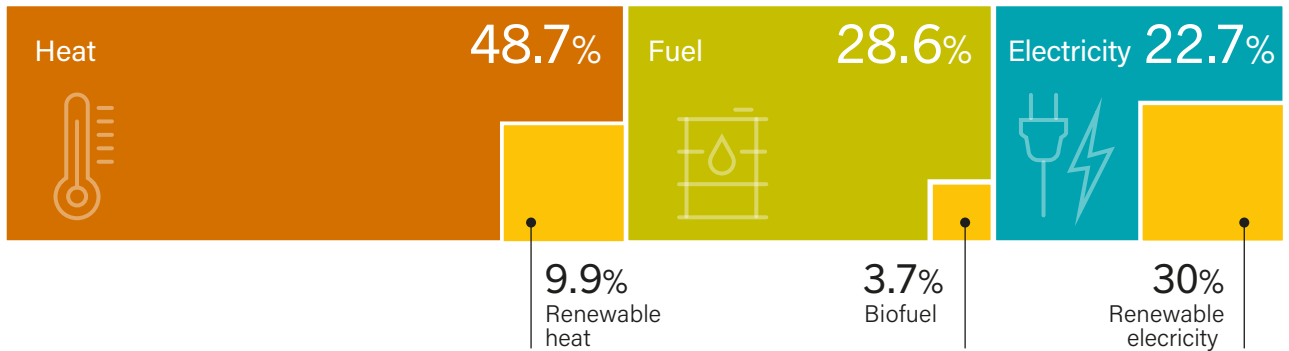


FIGURE 1.

# RENEWABLES IN ENERGY SUPPLY



Total Final Energy and Total Modern Renewable Energy Share, by Energy Carrier, 2020



**30%**  
of total electricity generation was supplied by renewables in 2022

**174** countries have renewable power targets, but only 37 have 100% targets

Only **3** countries announced new or revised renewable heating targets in 2022, for a total of 46 countries

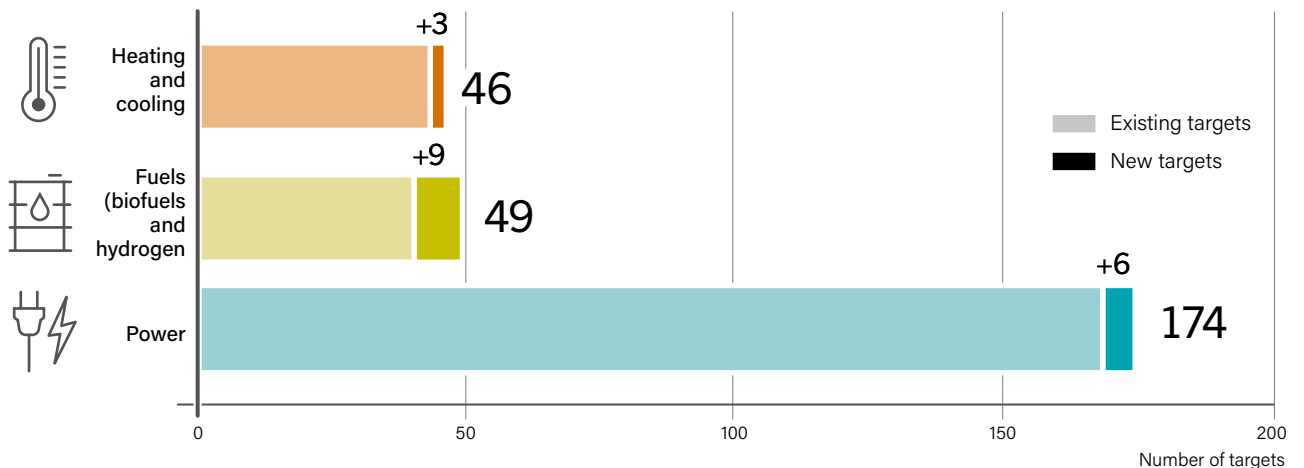
Investment in renewables grew **+17.2%** in 2022, but growth was uneven across technologies and geographies

Electricity accounts for **23%** of total final energy consumption

Newly installed renewable power capacity accounted for **348 GW** in 2022.



Renewable Power and Heating and Cooling Targets, 2022



Source: See endnote 6 for this section.

# RENEWABLES IN ENERGY SUPPLY

Module Overview | Policy | Investment

## MODULE OVERVIEW

The global energy crisis of 2021-2022, was sparked by the rapid economic rebound in the wake of the COVID-19 pandemic which led to tighter energy supply markets starting in October 2021.<sup>1</sup> The world's energy challenges were exacerbated in February 2022 following the Russian Federation's invasion of Ukraine.<sup>2</sup> The energy crisis contributed to high inflation and then became a global phenomenon during the year, even if the effects were less visible in Asia and some parts of the world.<sup>3</sup>

In response, governments have paid greater attention to the security of energy supply and have turned to renewables to counter inflation, supply disruptions and price volatility.<sup>4</sup> This is highlighted by the growth in energy-related policies such as the US Inflation Reduction Act (IRA), which includes subsidy packages aimed at boosting domestic manufacturing and deployment of renewable energy technologies and the European Union's (EU) REPowerEU, which aims to bridge the gap between regional energy supply and demand through renewables.<sup>5</sup>

The global energy crisis and associated challenges have prompted wide-ranging changes in the energy supply landscape. These include greater emphasis on energy security, expansion of domestic energy production and manufacturing, increased international cooperation and policy support for renewables highlighting the need for an accelerated shift to renewables in energy supply.



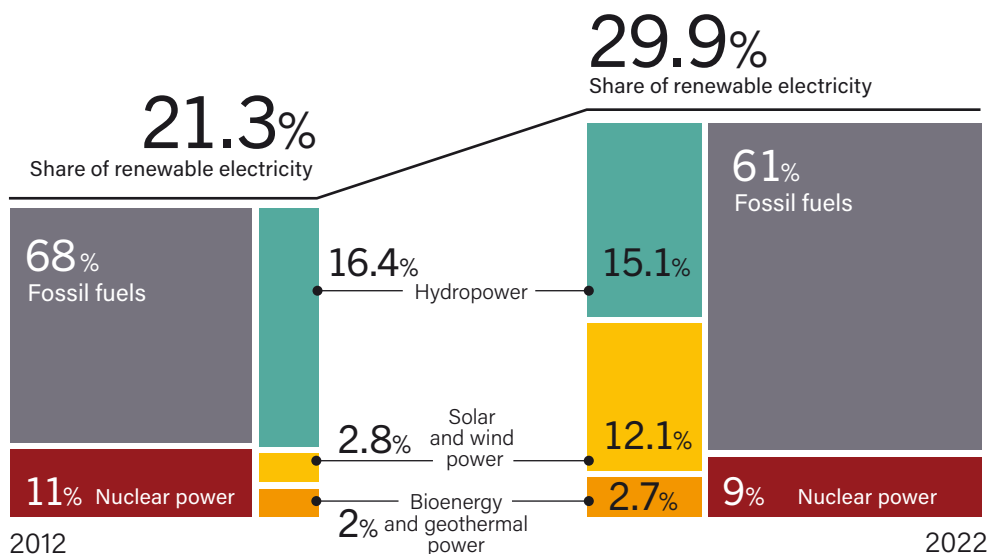
### RENEWABLE ELECTRICITY IS DRIVING THE SHIFT IN ENERGY SUPPLY

The distribution of the world's total final energy supply across – heat, fuel and electricity – reveals important insights about the status of the renewable energy transition. The majority of the world's energy is supplied in the form of direct heat<sup>i</sup>, which accounted for 48.7% of the total in 2020<sup>6</sup> (→ see *Figure 1*), followed by fuel – including liquid and gaseous fuels used for transport – which represented 29% of the total.<sup>7</sup> Meanwhile, the share of electricity (including for heat and transport) in the global energy supply has increased steadily, rising from 19% in 2010 to 23% in 2020.<sup>8</sup> This shift reflects the growing reliance on electricity to meet energy needs in all end-use sectors.

Reflecting this trend, most of the progress in increasing the share of renewables in the energy supply has been achieved in the power sector, with renewable energy contributing nearly one-third (30%) of global electricity production in 2022.<sup>9</sup> (→ See *Figure 2*.)

i This includes the direct heat supplied by/produced from fossil fuels, traditional biomass, modern bioenergy, solar thermal and geothermal sources.

**FIGURE 2.**  
Share of Renewable Electricity Generation, by Energy Source, 2012 and 2022



Renewable share of electricity generation increased by almost 9 percentage points in the past decade.



Source: See endnote 6 for this section.

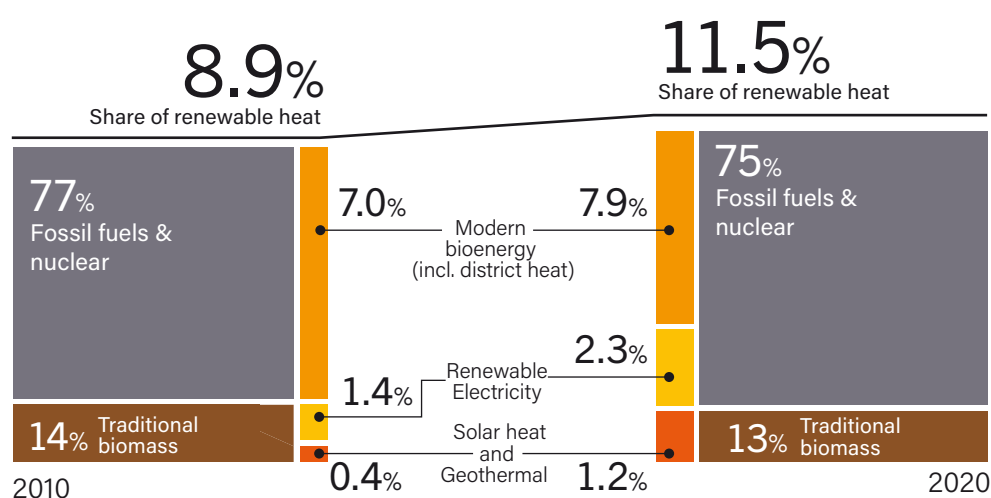
For **heat**, the progress has been relatively slower, with the share of modern renewables in the heat supply increasing 2.6% in the last decade, from 8.9% in 2010 to 11.5% (excluding traditional biomass) in 2020.<sup>10</sup> (→ See Figure 3.) Modern bioenergy continued to supply most of renewable heat, at 68%, while solar thermal supplied 6% and geothermal direct heat contributed 5% (the remaining 21% was supplied by renewable electricity).<sup>11</sup>

For **fuels**, biofuels represented nearly all renewable fuel and supplied 3.6% of the total fuel supply in 2020, up from 2.3% in 2010.<sup>12</sup> In absolute terms, biofuel production increased 60% during the decade.<sup>13</sup> Renewable hydrogen has been hailed as a potential game-changer for decarbonising energy intensive sectors, and in 2022 the number of electrolysis plants grew rapidly to reach around 1 gigawatt (GW) of capacity.<sup>14</sup> However, more than 95% of current hydrogen production is still based on fossil fuels.<sup>15</sup>

The development of renewable energy in the power sector is the result of increased policy attention to renewable power. As of 2022, as many as 174 countries had targets for renewable power shares (including 37 countries with targets for 100% renewable electricity), 49 countries had targets for biofuels, and 46 countries had targets for renewable heat, with only 9 and 3 new targets for biofuels and renewable heat, respectively, being announced in 2022. In contrast, more than 25 new targets for renewable power shares and installed capacity were announced in 2022.<sup>16</sup>



**FIGURE 3.**  
Share of Renewable Heat Production, by Energy Source, 2010 and 2020



Renewable share of heat generation increased by almost **2.6** percentage points in the past decade.



Source: See endnote 10 for this section.

### THE SHIFT TO RENEWABLE ENERGY SUPPLY IS UNEVEN ACROSS REGIONS

Globally, China continued to lead in new renewable energy investments in 2022, accounting for 55% of the total.<sup>17</sup> Europe followed with 11%, and the United States with 10%.<sup>18</sup> In contrast, Africa and the Middle East combined represented only 1.6% of global investment in renewables, indicating the high concentration of this investment in just a few regions.<sup>19</sup>

For **renewable heat**, Europe leads in the modern bioheat market, with a 24% share in 2020, followed by the United States with 13%.<sup>20</sup> China accounted for 73% of the solar water heating market, followed by Türkiye, the United States, Germany and Brazil.<sup>21</sup> The solar heat market contracted more than 9% in 2022 due largely to declining sales in China; however, some European markets, especially in response to the energy crisis, experienced double-digit growth, including Italy (up 43%), France (29%), Greece (nearly 17%), Germany and Poland (both 11%).<sup>22</sup> China is the world's fastest-growing geothermal heat market, and other key markets are Türkiye, Iceland and Japan; together, these four countries accounted for nearly 90% of global geothermal direct use in 2022. Overall, however, global capacity additions of geothermal power were one-third lower than in 2021, with only 0.2 GW added in 2022.<sup>23</sup>

In the case of **renewable fuels**, North America supplied 44% of the global total of renewable biofuels in 2020 (latest available data), followed by Latin America and the Caribbean with 25% and Europe with 18%.<sup>24</sup> Renewable fuel production has lagged in Asia and the Pacific (11%) and Africa (less than 1%).<sup>25</sup> Australia is an emerging leader in renewable based hydrogen and is set to have the largest number of renewable hydrogen plants worldwide.<sup>26</sup>

The share of **renewable electricity**, the share of renewables has been grown steadily in recent year. In 2022, global renewable electricity generation grew 8.1% up from a 5.5% growth in 2021.<sup>27</sup> **Latin America and the Caribbean** continued to have the highest share of renewables in the electricity mix among regions, at 61% in 2022 (up from 56% in 2012) (→ see Figure 4).<sup>28</sup> Hydropower dominates the region's electricity supply, contributing 45% of total production and 73% of renewable production.<sup>29</sup> In 2022, renewable electricity generation in Latin America and the Caribbean grew by 12%.<sup>30</sup>

**Oceania** showed the biggest increase in the share of renewables in the electricity mix, rising from 21% in 2012 to 40% in 2022, due mostly to developments in Australia, with 13% growth in renewable electricity generation in 2022 alone.<sup>31</sup> This is attributed mostly to the growing share of solar PV and wind energy, which rose from 4.1% to 22% in the region during the decade.<sup>32</sup>



In **Europe**, the share of renewables regional total electricity generation increased from 25% in 2012 to 36% in 2022.<sup>33</sup> Wind power represented 11% of Europe’s total generation in 2022 (up from 4% in 2012), and solar power represented 5% (up from 1.5% in 2012).<sup>34</sup> The region’s overall renewable electricity generation was stable reflecting opposing growth across technologies. Generation from hydropower, heavily affected by droughts and water scarcity, was down 11.5% compared to 2021, whereas generation from solar PV grew a record 21.6% and from power 11.2%.<sup>35</sup>

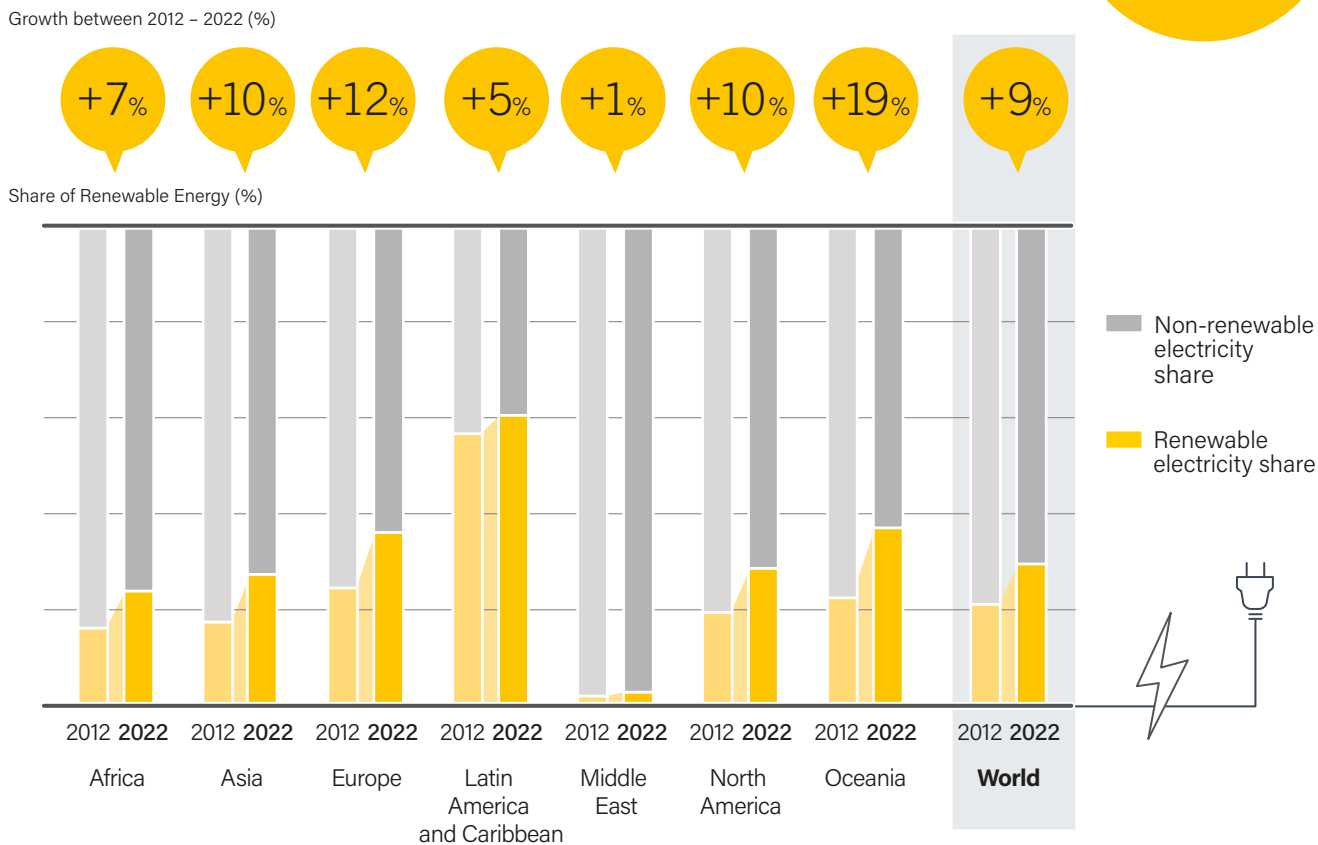
In **North America**, the share of renewables in the electricity mix rose from 19% in 2012 to 29% in 2022.<sup>36</sup> During the decade, wind power’s share of generation increased from 3.3% to 9.6%, and solar power’s share rose from 0.11% to 4.3%.<sup>37</sup> In 2022, renewable electricity generation in the region grew 9% up from 3% growth in 2021.<sup>38</sup>

The share of renewables in **Asia’s** electricity mix increased 10% during 2012-2022, rising from 17% to 27%.<sup>39</sup> This was due mainly to the increase in solar PV and wind generation, which supplied only 1.7% of Asia’s electricity in 2012 but reached an 11% share in 2022.<sup>40</sup> In 2022 alone, renewable electricity generation in the region grew 11%.<sup>41</sup>

In **Africa**, the renewable electricity share increased 7%, from 17% in 2012 to 24% in 2022.<sup>42</sup> Hydropower’s share of generation in the region rose from 16% to 19%, and solar and wind energy grew from 0.4% to 4.7% (2.7% for wind and 2% for solar).<sup>43</sup> In 2022, renewable electricity in Africa grew 11% compared to 5% increase in 2021.<sup>44</sup>

The **Middle East** had continued to lag other regions, with the share of renewables in electricity generation rising from 2.4% in 2012 to 3.4% in 2021 (comprising 1.7% hydropower, 1.4% solar energy and 0.2% wind energy).<sup>45</sup>

**FIGURE 4.**  
**Renewable Share of Electricity Generation, by Region, 2012 and 2022**



Source: See endnote 28 for this section.



**THE SHIFT IN RENEWABLE ENERGY SUPPLY IS BEING LED BY SPECIFIC TECHNOLOGIES**

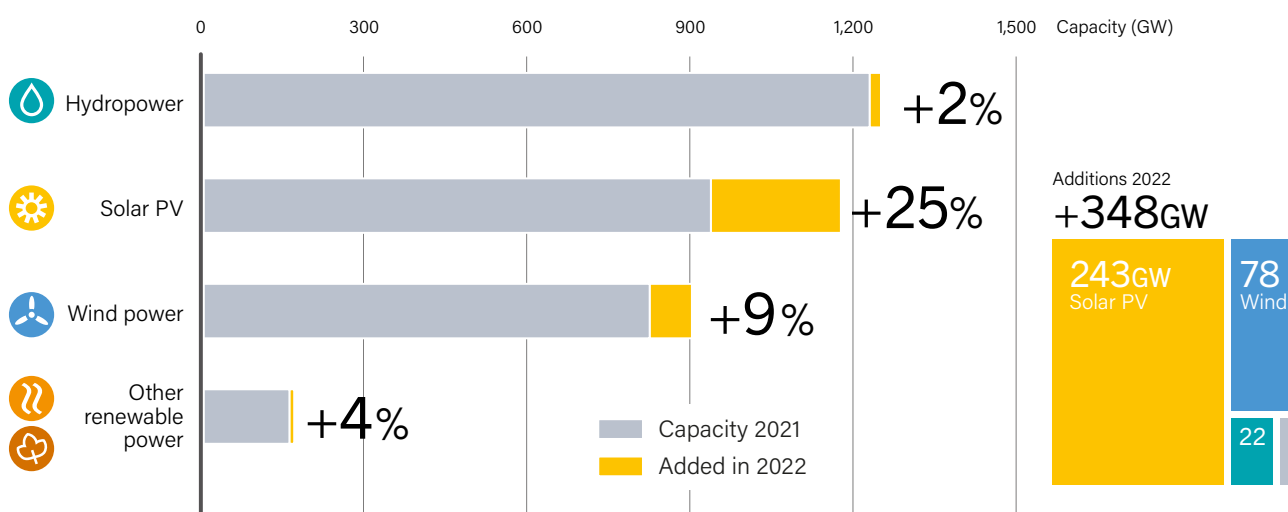
The energy transition has focused not only on power, but also on a few specific technologies in the power sector. In 2022, solar PV and wind power represented 92% of renewable power capacity (70% solar and 22% wind).<sup>46</sup> (→ See Figure 5.)

In total, 348 GW of renewable power capacity was added in 2022 (up 13% from the 306 GW added in 2021); however, this annual capacity addition would need to be accelerated by as much as 2.5 times to achieve the capacity growth required to achieve the

Solar PV and Wind accounted for **92%** of renewable power additions.



**FIGURE 5. Renewable Power Total Installed Capacity and Annual Additions, by Technology, 2022**



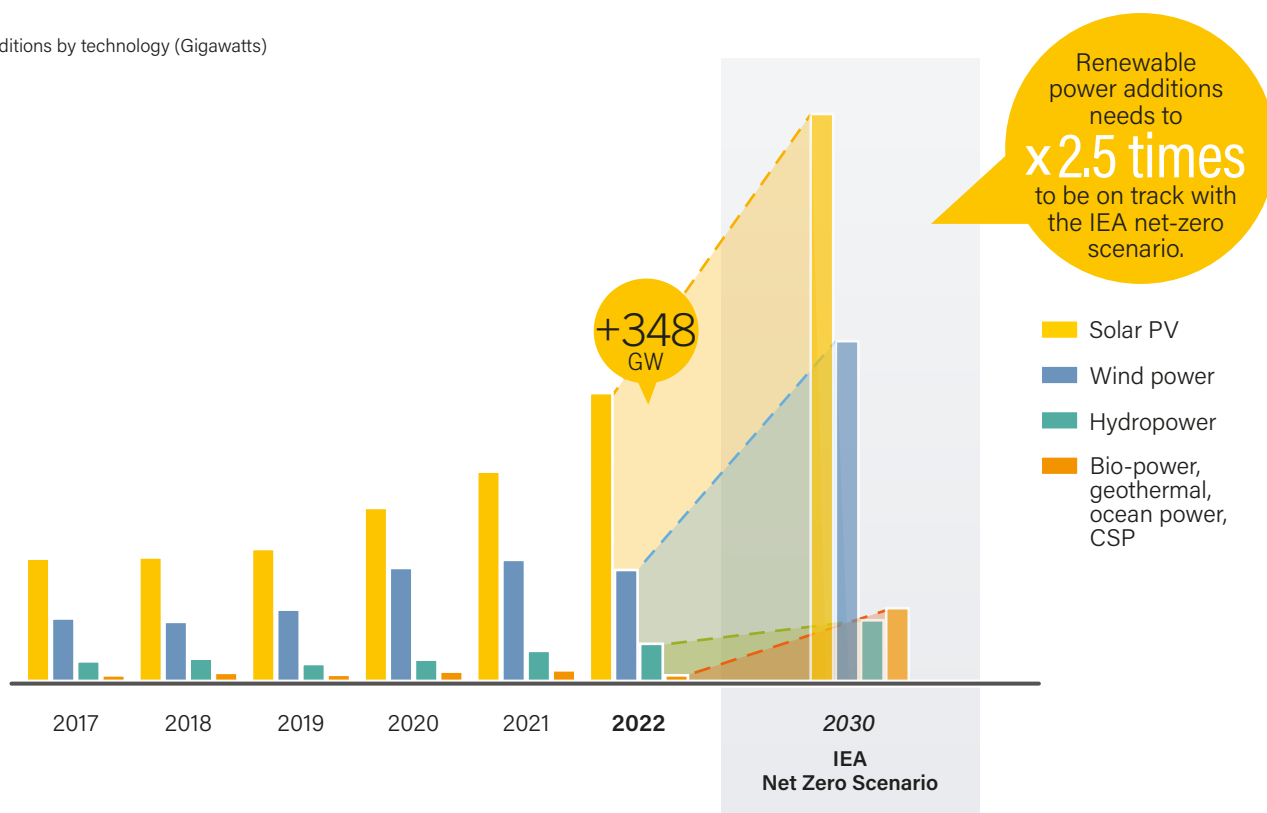
Source: See endnote 47 for this section.

International Energy Agency's (IEA) scenario for net zero emissions by 2030.<sup>47</sup> (→ See Figure 6.) Annual capacity additions for bio-power, geothermal, ocean power and concentrated solar thermal power (CSP) would need to grow 9.7 times to be on track with the IEA net zero targets.<sup>48</sup> For wind power, annual additions would need to increase 3.7 times to reach the IEA targets, particularly as additions slowed in 2022 as a result of supply chain interruption and

rising material costs (down 17% compared to 2021).<sup>49</sup> The wind sector especially is at critical juncture as the current new and announced manufacturing capacity falls short in meeting the IEA's net-zero scenario.<sup>50</sup> Meanwhile solar PV had another record year in 2022, with additions rising 37% compared to 2021 (up 25% for utility-scale solar PV and 54% for decentralised solar PV); however, to reach the IEA target, the current rate the annual installation needs to double in 2030.<sup>51</sup>

**FIGURE 6.**  
**Renewable Power Capacity Annual Additions by Technology, 2017-2022, and Increases Required by 2030 to Achieve the IEA's Net Zero Scenario**

Additions by technology (Gigawatts)



Source: See endnote 48 for this section.










 TABLE 1.  
Top Five Countries 2022

### Total Power Capacity as of end 2022

	1	2	3	4	5
<b>POWER</b>					
<b>Total renewable capacity</b>	China	United States	Brazil	India	Germany
<b>Total renewable capacity (no hydro)</b>	China	United States	Germany	India	Japan
<b>Total renewable capacity per capita (no hydro)</b>	Iceland	Denmark	Finland <b>(+16)</b> ▲	Belgium <b>(+8)</b> ▲	Greece <b>(+10)</b> ▲
 Biopower	China	Brazil	United States	India	Germany
 Geothermal	United States	Indonesia	Philippines	Türkiye	New Zealand
 Hydropower	China	Brazil	Canada	United States	Russian Federation
 Solar PV	China	United States	Japan	Germany <b>(+1)</b> ▲	India <b>(-1)</b> ▼
 CSP	Spain	United States	China	Morocco	South Africa
 Wind	China	United States	Germany	India	Spain
<b>HEAT</b>					
 Solar water heating collector capacity	China	Türkiye <b>(+1)</b> ▲	United States <b>(-1)</b> ▼	Germany	Brazil
 Geothermal heat output	China	Türkiye	Iceland	Japan	New Zealand

### Net Capacity Additions in 2022

	1	2	3	4	5
<b>TOTAL ADDITIONS PER TECHNOLOGY</b>					
 Biopower capacity	China	Japan <b>(+3)</b> ▲	Brazil	Indonesia <b>(+12)</b> ▲	Türkiye <b>(-1)</b> ▼
 Geothermal capacity	Kenya <b>(New)</b>	Indonesia	United States <b>(-2)</b> ▼	Türkiye <b>(-1)</b> ▼	Chile <b>(New)</b>
 Hydropower capacity	China	Lao PDR <b>(+3)</b> ▲	Canada <b>(-1)</b> ▼	France <b>(New)</b>	Ethiopia <b>(New)</b>
 Solar PV capacity	China	United States	India	Brazil <b>(+1)</b> ▲	Netherlands <b>(+8)</b> ▲
 Concentrated Solar Thermal Power (CSP) capacity	China <b>(New)</b>	United Arab Emirates <b>(New)</b>	-	-	-
 Wind capacity	China	United States	Brazil	United Kingdom <b>(+1)</b> ▲	Germany <b>(+2)</b> ▲
 Solar water heating capacity	China	Türkiye	Brazil	India	United States

Note: New = Country did not have a ranking in 2021.

**RENEWABLE ENERGY MANUFACTURING IS CONCENTRATED IN CHINA**

In 2022, manufacturing capacities for both renewables and enabling technologies had another year of strong growth for solar PV (up 39%), electrolysers (26%) and heat pumps (13%).<sup>52</sup> Wind energy manufacturing capacity grew by a more modest 2%.<sup>53</sup> In response to the energy crisis and associated challenges, multiple flagship policy packages – such as the US Inflation Reduction Act, the Net-zero Industry Act in Europe, Japan’s Green Transformation programme and India’s Production Linked Incentive scheme – have aimed to increase domestic manufacturing capacity of renewable energy and enabling technologies.<sup>54</sup>

The manufacturing of solar PV panels remained geographically concentrated in China, which dominated with more than 80% shares across all production stages in 2022.<sup>55</sup> The next largest countries with respect to manufacturing capacity are Vietnam and India, accounting for 5% and 3%, respectively, of the global capacity.<sup>56</sup> In 2022, 90% of the growth occurred in China and out of the top 10 largest solar PV announced manufacturing projects, only one (number 10) was in India. High costs continue to be a leading barrier to more widespread solar PV manufacturing; compared to China, costs are an estimate 10% higher in India, 20% higher in the United States and 35% higher in Europe.<sup>57</sup>

For wind energy, western manufacturers continued to face growing competition from Chinese turbine makers, which have actively pursued sales overseas.<sup>58</sup> In 2022, China accounted for over 60% of global manufacturing capacity, followed by the EU (just under 15%) and the United States (10%).<sup>59</sup>

Heat pump manufacturing capacity is more globally distributed. In 2022, 35% of global capacity was in China, followed by 25% in the United States, and close to 20% in the EU.<sup>60</sup> Similarly, electrolyser manufacturing is concentrated in China with around 40% of electrolyser manufacturing capacity, with the EU and the United States having shares of 20% each.<sup>61</sup>

In 2022, global manufacturing of renewable energy and enabling technologies grew by nearly **40%**.





POLICY

OVERALL CONTEXT

As policy makers around the world grapple with energy security concerns, they have prioritised measures that can ensure a steady and reliable energy supply while speeding decarbonisation of the sector.<sup>1</sup> This has led to the uptake of well-defined and specific policy measures.<sup>2</sup> Major announcements in 2022 that reshaped the policy landscape of renewables include the US Inflation Reduction Act, the European Union's (EU) Fit for 55 and RePowerEU packages, Australia's Climate Change Bill, Japan's GX Green Transformation and China's 14th Five-Year Plan.<sup>3</sup> In response to the ongoing energy crisis, governments also increased their spending on the energy transition.<sup>4</sup> However, meeting the decarbonisation target required to avert the worst effects of climatic change requires far greater effort. The policies discussed here offer a wide diversity of examples but are not exhaustive.

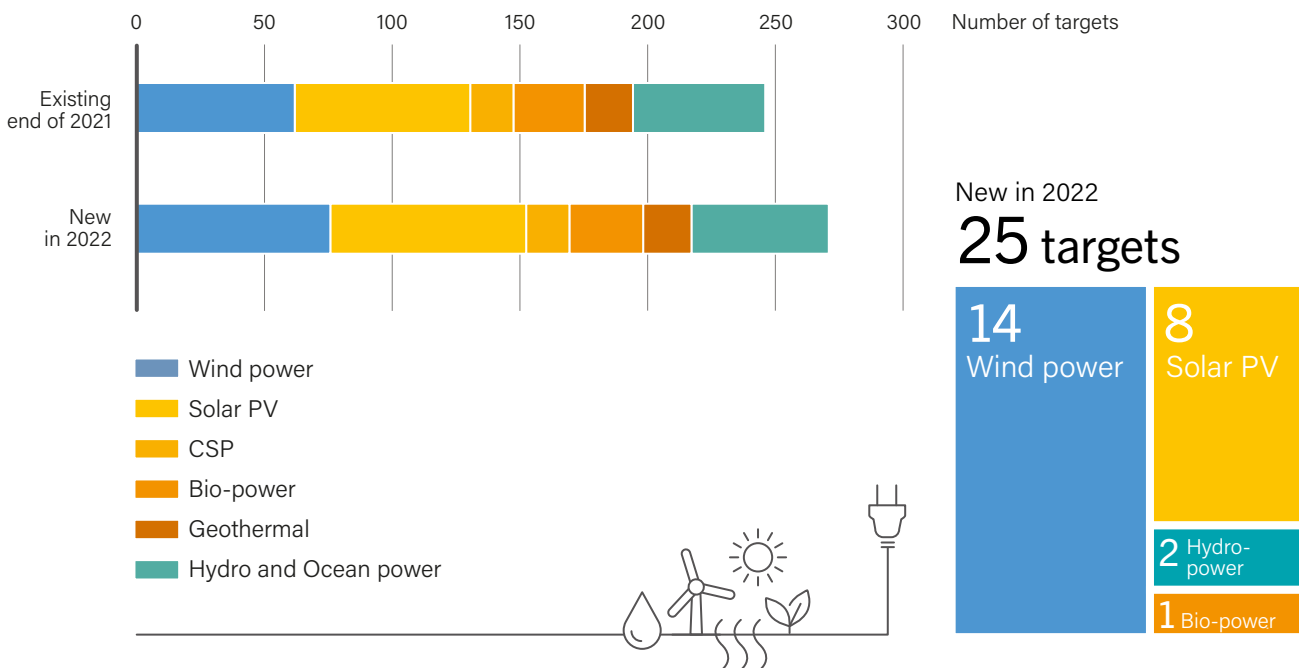
ELECTRICITY

Most countries have in place broad national renewable energy **targets** for the power sector.<sup>5</sup> In 2022, Bolivia, Chile, the EU and four sub-national jurisdictions in Canada announced new or revised targets for renewables in electricity generation, bringing the total number of jurisdictions with such targets to at least 174, up from 135 in 2021.<sup>6</sup> (→ See Figure 1 in Module Overview.) Although targets alone may not be enough to incentivise investment, they can indicate a region's dedication to the energy transition. Converting targets into concrete action requires implementing associated policies and regulations.<sup>7</sup>

Power policies focus primarily on solar PV and wind power capacity (→ see Figure 7), similar to the high levels of investment in solar and wind energy as compared to other renewable technologies.<sup>8</sup> During 2022, the EU and 20 national and sub-national jurisdictions added new targets for installed capacities of solar PV (7) and wind (13) power.<sup>9</sup> In total, more than 250 technology-specific power capacity targets were in place in 126 national and sub-national jurisdictions by year's end.<sup>10</sup>



FIGURE 7. Technology-Specific Targets for Installed Renewable Power Capacity, 2022



Source: See endnote 8 for this section.

Note: No new technology-specific targets were announced in 2022 for CSP, Geothermal power and Ocean power.

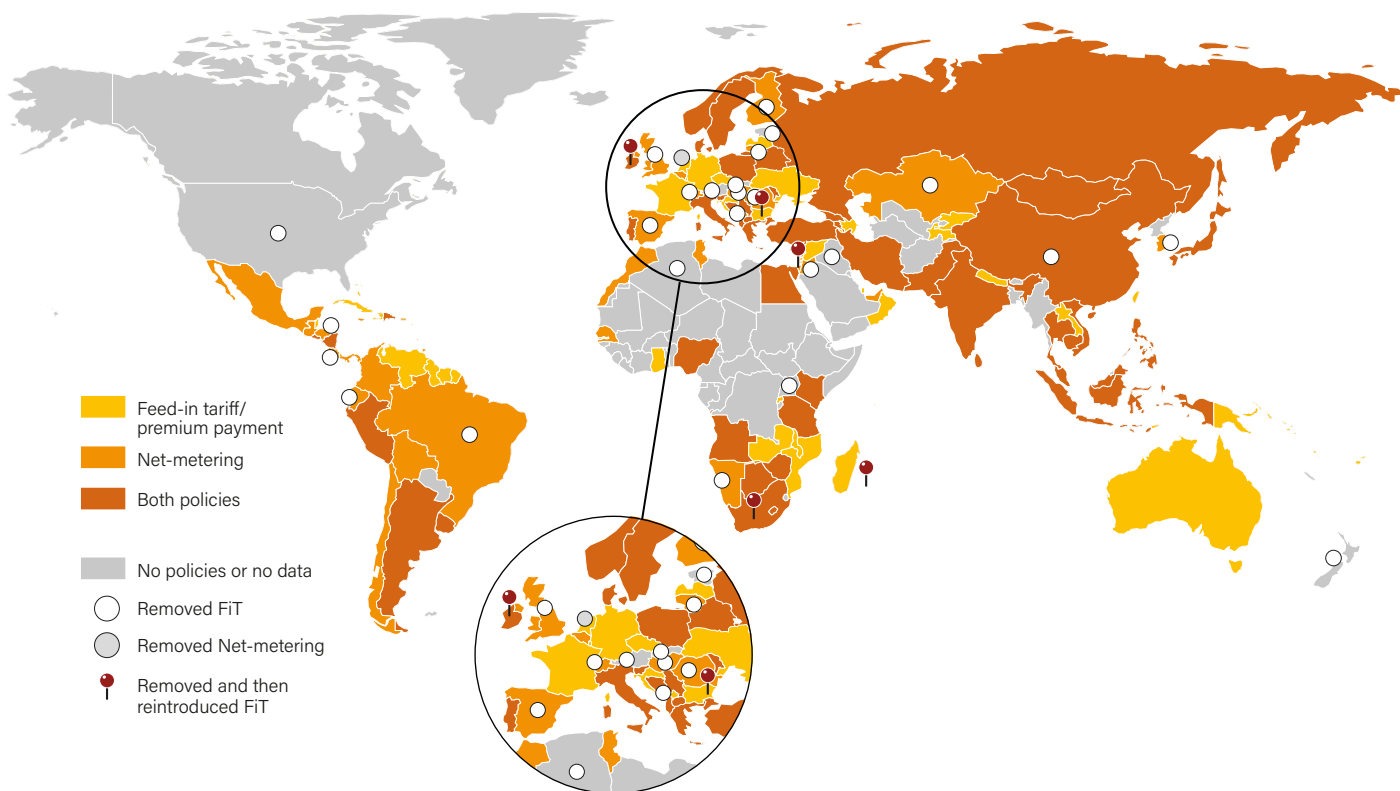
The number of countries with support **policies** for renewables in the power sector remained at 156 in 2022, the same as in 2021.<sup>11</sup> Although some countries adopted new policies, others removed policies (mainly feed-in tariff policies).<sup>12</sup> Most countries use a mix of policy instruments to support the uptake of renewables, which can differ based on the technology and size of the installation and on whether or not it is decentralised. Renewable energy policies in the power sector include targets, renewable portfolio standards (RPS), renewable energy certificates (RECs) or Guarantees of Origin (GOs), feed-in tariffs and premiums, auctions and tenders, net metering (and other policies that encourage self-consumption), and fiscal and financial incentives such as grants, rebates and tax credits.<sup>13</sup>

**Feed-in tariffs (FITs)** and feed-in premiums have been used widely to support the uptake of renewables within both large-scale grid systems and for decentralised power generation.<sup>14</sup> (→ See Figure 8.) In 2022 and early 2023, 15 countries and 5 sub-national jurisdictions (all in Australia) revised their feed-in tariff or premium payment policies.<sup>15</sup> By the end of 2022, 83 countries had in place feed-in tariff or premium payment policies.<sup>16</sup> FIT policies were removed in six countries (Austria, Costa Rica, Finland, New Zealand, Switzerland and Uganda) during the year and reintroduced in six countries (Bulgaria, China, Ireland, Mauritius and South Africa) after having previously been removed.<sup>17</sup>

Barbados revised down its FIT for smaller projects (below 1 megawatt, MW) and raised it for larger projects (10 MW and higher) in an effort to incentivise large projects.<sup>18</sup> Germany updated its Renewable Energy Act to give owners of rooftop solar photovoltaic (PV) systems (up to 750 kilowatts, kW) the option to either choose a reduced FIT but use part of the power they produce themselves, or feed in all of the electricity generated by rooftop systems and receive an additional payment on top of the standard FIT.<sup>19</sup> Mauritius included in its 2022-2023 budget provisions for a FIT for medium-scale systems.<sup>20</sup> South Africa announced the reintroduction of FITs for solar PV to tackle load shedding.<sup>21</sup> Thailand introduced a 25-year FIT for solar PV and solar-plus-storage, and Japan adopted provisional FITs for fiscal year 2023.<sup>22</sup>

By the end of 2022,  
**83 countries**  
 had in place feed-in tariff  
 or premium payment  
 policies.

**FIGURE 8.**  
**Renewable Energy Feed-in Tariffs and Net Metering Policies, 2022**



Source: See endnote 14 for this section.

Note: All countries with round circles have removed feed-in tariff policies except for the Netherlands where the net metering policy was removed after parliament voted to end the measure.

**Net metering** is still a popular policy used to incentivise households, commercial entities and industrial facilities to invest in their own renewable energy systems by enabling them to sell surplus electricity to the grid. In 2022, 10 countries and several US states revised their net metering policies, including Cyprus, Egypt, Finland, Ghana, the Philippines, Romania and Slovenia.<sup>23</sup> The Netherlands removed its net metering policy in 2022 after the parliament voted to end the measure.<sup>24</sup> By year's end, a total of 92 countries had net metering policies in place.<sup>25</sup>

Cyprus announced that it would expand funding for solar net metering by EUR 40 million (USD 43 million).<sup>26</sup> Finland, which has implemented net metering since early 2021, adopted a new centralised information system that enables many more solar PV systems to benefit from the scheme starting in 2023.<sup>27</sup> Egypt released updated net metering rules in Decree No. 6 of 2022, with increases to the maximum net metering capacity allowed.<sup>28</sup> Ghana's Public Utility Regulatory Commission approved net metering tariff guidelines, and the Philippines increased the size limit of energy systems eligible for net metering from 100 kW to 1 MW.<sup>29</sup>

However, some countries have phased down net metering, in some cases to indirectly encourage the installation of energy storage systems. The Dutch parliament's decision to phase out net metering was aimed largely at incentivising the use of storage and relieving pressure on the grid.<sup>30</sup> Poland is shifting from net metering to net billing.<sup>31</sup> At the sub-national level, US states that are reducing or shifting away from net metering schemes include California, Florida, Idaho, Indiana, Michigan and North Carolina.<sup>32</sup> In California, the third iteration of the Net Metering Program (NEM 3.0) entered into force in April 2023 and is less favourable than NEM 2.0.<sup>33</sup>

Between January and September 2022, the awarded renewable auction capacity increased 70% to reach 77 gigawatts (GW), primarily in solar PV and wind power, with China and Europe accounting for 75% of the total awarded capacity.<sup>34</sup> In 2022, several countries used **auctions and tenders** to attract private sector investment for large-scale renewable energy projects, increase the installed power capacity and diversify the energy mix to boost energy security. In Asia, India tendered 28 GW of variable renewable power capacity and Thailand launched a new round of auctions for biogas, wind, solar power as well as for energy storage capacity.<sup>35</sup> The Philippines announced a Green Energy Auction Programme for 2023 of a combined 2 GW for hydropower, solar, biomass and wind power capacity.<sup>36</sup>

In Europe, Germany issued tenders for installations above 750 kW, Greece launched a new round of tenders until 2024 (awarding over 530 MW in its first round), and Poland awarded 486 MW of solar PV in an auction.<sup>37</sup> South Africa concluded its sixth auction round by awarding 860 MW of solar power capacity.<sup>38</sup> At the subnational level, New South Wales in Australia launched its first-ever renewable energy auction, targeting 12 GW of renewables and storage by 2030 to replace retiring coal plants.<sup>39</sup>

In general, however, auctions and tenders were undersubscribed globally as countries (including France, Germany, Greece and Spain) struggled to adjust these measures to inflation and to the rising costs of renewable power components.<sup>40</sup> Across much of Europe, the United States and several other countries, permitting processes continue to be challenging and in lead to undersubscribed auctions.<sup>41</sup> To attract interest, Germany raised the price cap for wind and solar PV tenders.<sup>42</sup>

**Financial and fiscal policies** – such as tax exemptions, rebates, grants and loans – are popular instruments to incentivise the uptake of renewables.<sup>43</sup>

Such policies can target specific technologies and sectors or be technology-agnostic. In 2022, 61 jurisdictions – including Bulgaria, Canada, the EU, Kenya, South Africa and the United States – introduced or revised financial and fiscal policies for renewables, bringing the total number of countries with such policies to 138.<sup>44</sup> The US Inflation Reduction Act of 2022 allocates USD 391 billion in subsidies and tax credits for the clean energy transition, including technology-neutral tax credits from 2025 onwards for new electricity generation (including renewable), tax credits for the manufacture of clean energy technologies.<sup>45</sup> The credits are guaranteed for 10 years, helping to provide confidence to the market.<sup>46</sup>

Other countries announced financial and fiscal incentives. Through RePowerEU, the EU plans to ease access to tax credits for green investment.<sup>47</sup> Canada announced tax credits totalling USD 83 billion for clean electricity, clean technology manufacturing chains and clean hydrogen.<sup>48</sup> South Africa announced a ZAR 9 billion (USD 500 million) solar tax incentive for households and companies, and agreed to expand its renewable energy tax initiative to remove thresholds on generation and to enable investors to deduct the full cost of new renewable assets.<sup>49</sup> Bulgaria is allocating EUR 102 million (USD 112 million) for green energy and storage projects in the tourism sector.<sup>50</sup> As of January 2022, Kenya is granting a 50% tax exemption to power producers selling electricity that is generated fully off-grid, in a push for decentralised renewable energy solutions.<sup>51</sup>



i Net metering is a system that allows residential and commercial customers with solar panels or other renewable energy sources to receive credit for any excess electricity they generate and send back to the grid, which can be used to offset future electricity bills. Net billing, on the other hand, is a system in which customers are paid for the excess energy they generate at a fixed rate per kWh, which is typically lower than the retail rate they would pay for electricity.

By the end of 2022, 35 countries had in place **renewable portfolio standards** (RPS), which mandate utilities and private sector companies to install or use renewables. The Philippines amended its RPS to require a minimum of 2.5% renewable energy supplied to distribution utilities or direct buyers, up from 1% previously.<sup>52</sup> At the sub-national level, 36 US states and the District of Columbia had RPS as of November 2022 to support renewable energy generation.<sup>53</sup> The state of Maryland revised its RPS policies in place to no longer include waste incineration, factory farm gas, and wood biomass, as part of the Reclaim Renewable Energy Act.<sup>54</sup>

Mandates for **rooftop solar PV** require certain buildings or properties to install solar panels on their roofs.<sup>55</sup> Such policies made a comeback in 2022, with announcements of mandates in the Czech Republic and three sub-national jurisdictions in China (Guangzhou, Jiangxi and Shaanxi).<sup>56</sup> The EU released its Solar Energy Strategy and its proposed Performance for Building Directive, which require the installation of rooftop solar PV on all new public and commercial buildings with at least 250 square metres (m<sup>2</sup>) of surface by 2026, on all existing public and commercial buildings by 2027 and on all residential buildings by 2029.<sup>57</sup>

In France, new legislation makes it mandatory for parking lots of 80 spots or more to install solar PV systems within three to five years.<sup>58</sup> Greece's solar mandate, which took effect in 2023, requires solar PV on all new buildings with at least 50% non-residential use and more than 500 m<sup>2</sup> in area.<sup>59</sup> In Germany, 9 out of the 16 federal states have rooftop solar PV mandates, all of which took effect in January 2022.<sup>60</sup> At the sub-national level, Tokyo and Kawasaki City in Japan announced in 2022 that they are mandating solar PV on all new residential buildings as of 2025.<sup>61</sup>

**Community solar** enables individuals, businesses and communities to have a stake in renewable energy projects, such as community energy arrangements, shared ownership, self-consumption and virtual net metering. Such engagement helps to create a more positive public response to renewables and to increase project deployment. As of the end of 2022, 13 US states had formal community solar programmes, and several other states had utility-run programmes.<sup>62</sup> Among advancements during the year, California enacted legislation authorising regulators to define a new community programme for the state.<sup>63</sup> The US National Community Solar Partnership issued a roadmap for reaching 5 million community solar households by 2025.<sup>64</sup> The Australian Government, as part of its 2022 Climate Change Law, committed AUD 102.2 million (USD 70 million) to the Community Solar Banks Initiative.<sup>65</sup>

In 2022, Belgium, Denmark, Germany and the Netherlands collectively pledged to increase offshore **wind** capacity ten-fold by 2050.<sup>66</sup> Germany updated its target for offshore wind power capacity from 40 GW to 70 GW by 2040 under the Offshore Wind Energy Act.<sup>67</sup> Australia has developed regulations for offshore energy infrastructure to provide increased investment and regulation for the sector.<sup>68</sup>

Vietnam's Draft Power Development VIII includes targets for 16 GW of onshore and nearshore wind and 7 GW of offshore wind.<sup>69</sup> In 2023, nine European countries (Belgium, Denmark, France, Germany, Ireland, Luxembourg, the Netherlands, Norway and the United Kingdom) agreed to collective capacity targets



for offshore wind power, aiming to achieve a minimum 120 GW by 2030 and 300 GW by 2050.<sup>70</sup>

Other policy changes during the year could slow growth in wind power deployment. Denmark paused its well-established and efficient "open door" scheme for offshore wind, creating uncertainty for developers, while Poland voted to amend its strict wind power law to forbid siting wind turbines within 700 metres of residential buildings.<sup>71</sup> Ireland introduced a requirement that offshore wind power projects be built in (yet unidentified) Designated Marine Areas, effectively putting offshore development on hold.<sup>72</sup>

In 2022 and early 2023, the Slovak Republic, Türkiye and the United Kingdom announced national **renewable hydrogen** strategies and roadmaps, bringing the total number of countries' with such strategies to 45.<sup>73</sup> (→ See Figure 21 in Hydrogen section.) Fiscal and financial incentives supporting renewable hydrogen were in place in 14 countries, 7 sub-national jurisdictions and the EU as of end of 2022.<sup>74</sup>

Other policies and programmes include a measure setting up export-import corridors for renewable hydrogen between Chile and the Netherlands.<sup>75</sup> Countries are supporting renewable hydrogen because of its potential to reduce carbon emissions in hard-to-abate sectors, such as in some industries.<sup>76</sup>

Argentina launched a Green Hydrogen Strategy targeting 5 GW of renewable hydrogen by 2030.<sup>77</sup> South Africa issued its Hydrogen Society Roadmap, which aims for 500 kilotonnes of renewable hydrogen production by 2030 and 15 GW by 2040.<sup>78</sup> Austria, in its hydrogen strategy, is targeting 4 terawatt-hours of annual renewable hydrogen production and 1 GW of electrolysis capacity by 2030.<sup>79</sup> Uruguay announced a renewable hydrogen roadmap targeting 1 million tonnes of production annually by 2040 and requiring the installation of 20 GW of renewables.<sup>80</sup>

The US Inflation Reduction Act includes a tax credit for renewable hydrogen of USD 3 per kilogram.<sup>81</sup> In 2021, six countries (Egypt, Kenya, Mauritania, Morocco, Namibia and South Africa) launched the Africa Green Hydrogen Alliance in an effort to advance the uptake of renewable hydrogen in Africa.<sup>82</sup>



## HEATING AND COOLING

In 2022, only two countries (Germany and Serbia) and the EU updated their heating and cooling targets. (→ See Figure 1 in Module Overview.)

The EU is taking significant steps towards policy advancement in **solar thermal** energy. The Fit for 55 package aims to accelerate the deployment and uptake of renewables, including solar thermal, by setting higher overall targets for 2030 and more ambitious sub-sectoral targets in heating and cooling, buildings and industry.<sup>83</sup> The revised text focuses on accelerating permitting for renewable energy projects and ensuring the availability of a skilled workforce.<sup>84</sup>

Under the EU's Green Deal Industrial Plan, solar thermal energy is recognised as a strategic net zero industry, and the region plans to innovate and scale manufacturing capacity in net zero technologies.<sup>85</sup> Although the sector is currently able to supply around 90% of EU heat energy demand, the challenge is to expand this capacity to meet projected growth to 2030 and beyond.<sup>86</sup> The EU also is underpinning its leadership in the green transition and research and innovation investments in clean energy technologies by revamping the Strategic Energy Technology Plan; this is expected to benefit the European solar thermal sector by including renewable heating and cooling generation.<sup>87</sup>

Policies around **district heating** gained momentum in 2022, especially in the face of high energy prices during the year.<sup>88</sup> Germany is setting up a fund of EUR 3 billion (USD 3.3 billion) aimed at decarbonising the district heating sector and financing the construction of new heating networks with 75% renewables.<sup>89</sup> Denmark approved a new law that allows district heating companies to negotiate pricing with geothermal operators to put a cap on consumer costs.<sup>90</sup> The UK Net Zero Strategy allocates GBP 338 million (USD 421 million) for the Heat Network Transformation Programme, with a focus on low-carbon technologies.<sup>91</sup>

**Heat pumps** are considered a central solution for energy efficiency, and many countries have pushed for greater uptake. Governments in Europe, Japan and the United States introduced high-level policymaking efforts to encourage deployment of the devices.<sup>92</sup> Subsidies currently available for upfront costs of both air-to-air and air-to-water heat pumps are below those for gas boilers in some countries, including France and the United States.<sup>93</sup>

The RePowerEU policy targets the installation of 20 million heat pumps by 2026 and nearly 60 million by 2030.<sup>94</sup> The EU also announced an action plan to boost regional heat pump manufacturing and deployment.<sup>95</sup> In France, grant support for installing ground-source heat pumps was raised to EUR 5,000 (USD 5,500) per unit in early 2023.<sup>96</sup> Germany launched rebates of up to 40% for homeowners to install heat pumps.<sup>97</sup> The US Inflation Reduction Act offers rebates for low-income households that cover up to 100% of the cost of a heat pump and installation.<sup>98</sup>

China introduced an updated building energy law, its first binding energy efficiency standard for new buildings, that targets installing heat pumps for 2 million square metres of public and government buildings.<sup>99</sup> Canada announced an additional CAD 250 million (USD 185 million) to swap oil furnaces for heat pumps, and New York State invested USD 70 million to electrify public housing.<sup>100</sup> Such policies have resulted in rising heat pump sales and provided clear signals to the expanding heat pump industry.<sup>101</sup>

The RePowerEU policy targets the installation of

**20 million**

heat pumps by 2026 and nearly 60 million by 2030.





## INVESTMENT AND FINANCE

Global new investment in renewable power and fuels (not including hydropower projects larger than 50 megawatts, MW) reached a record high in 2022, at an estimated USD 495.4 billion<sup>i</sup>. Investment increased 17.2% from 2021, due largely to the global rise in solar photovoltaic (PV) installations.<sup>2</sup> These estimates do not include investment in renewable heating and cooling technologies, for which data are not collected systematically. Global investment in heat pumps<sup>ii</sup> reached USD 63.4 billion, up 9.6% from 2021.<sup>3</sup> (→ See *Buildings Module*.) Hydropower investment (including projects above 50 MW) has hovered at around USD 8 billion for the past several years, although data remain limited.<sup>4</sup>

The increase in renewable energy investment came amid drastic changes in the energy landscape in 2022, including the Russian Federation’s invasion of Ukraine, skyrocketing inflation and ongoing supply chain disruptions related to the COVID-19 pandemic. In Europe, the war in Ukraine and its implications for imports of Russian gas amplified calls for greater deployment of renewables and related investment.<sup>5</sup> Together, these factors prompted

sweeping government interventions to fast-track a clean energy transition, including the Inflation Reduction Act in the United States, the REPowerEU plan in Europe and the GX Green Transformation Programme in Japan.<sup>6</sup> (→ See *Policy* section.)

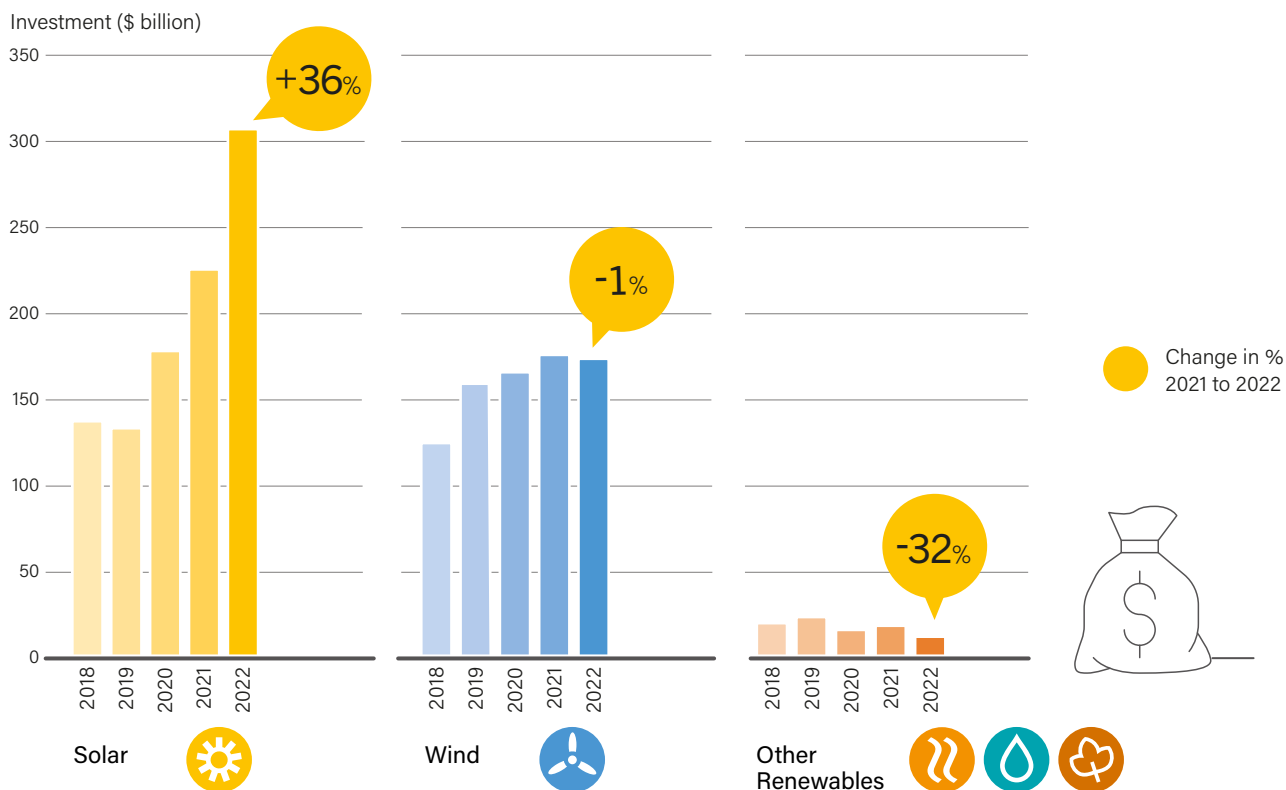
Inflation (of around 8%) played a role in the investment growth in renewables in 2022, contributing to higher costs for components, construction and financing.<sup>7</sup> However, inflation represented only a fraction of the overall investment increase, meaning that investment expanded well beyond the effects of inflation.<sup>8</sup> In general, the declining costs of renewables over the past decade have meant that a dollar invested today translates into higher capacity installed than it did in years past.<sup>9</sup> Without these cost reductions, much more investment would be needed to bring the same level of capacity online.<sup>10</sup>

Global new investment in renewable power and fuels reached a record high

**USD 495 billion** in 2022.

i Data are from Bloomberg NEF and include the following renewable energy projects: 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; all ocean energy projects; and all biofuel projects with an annual production capacity of 1 million litres or more.  
 ii Heat pumps, although not considered renewable energy technologies in this report, are energy-efficient heating and cooling systems.

**FIGURE 9.** Global Investment in Renewable Power and Fuels by Technology, 2018-2022



Source: See endnote 11 for this section.



### INVESTMENT BY TECHNOLOGY

Solar PV and wind power continued to dominate new investment in renewables, with solar PV accounting for 62% of the 2022 total and wind power for 35%.<sup>11</sup> (→ See Figure 9.) The strong growth in solar PV investment of 2021 expanded further in 2022, rising nearly 36% to reach USD 307.5 billion.<sup>12</sup> Wind power investment fell 1.3% to USD 174.5 billion, a reflection of policy uncertainties, long and complex permitting regulations in many countries, and high inflation in the costs of inputs.<sup>13</sup>

The private sector has been the primary source of global investments in renewable energy in recent years, although the balance between public and private investments varies depending on the technology and context.<sup>14</sup> In 2020, the most recent year for which data are available, private sources accounted for 69% of renewable energy investment, with most of this originating from commercial financial institutions and corporations.<sup>15</sup>

Private finance accounts for the vast majority of solar PV technologies (around 83% in 2020), as these technologies are commercially viable and highly competitive; in contrast, geothermal and hydropower technologies rely mostly on public finance, with private finance representing only around 32% and 3%, respectively.<sup>16</sup> Hydropower investments often need public finance because of the large upfront investments, the need for long-tenor loans (as construction can take more than a decade), high construction risks, complex and lengthy permitting procedures, and high social costs and environmental risks, all of which hamper private sector investments.<sup>17</sup>

### INVESTMENT BY ECONOMY

Investment in renewable power and fuels varied by region in 2022, rising in Brazil, China and India but falling in Europe and the United States.<sup>18</sup> (→ See Figure 10.) China continued to account for the largest share of global renewable energy investment (excluding hydropower larger than 50 MW), at 55%, followed by Europe (11.3%), Asia-Oceania (excluding China and India; 10.8%) and the United States (10.0%).<sup>19</sup> All other world regions accounted for 4% or less of the total.<sup>20</sup>

**China's** overall investment in renewables increased sharply in 2022, rising 56.2% to reach USD 274.4 billion.<sup>21</sup> This was due largely to continued growth in the country's solar PV capacity, which grew 78.9% to USD 164.5 billion.<sup>22</sup> Wind power investment also increased in China, rising 33.2% to reach USD 109.0 billion.<sup>23</sup> Investment in all other renewable energy technologies was only marginal by comparison.<sup>24</sup>

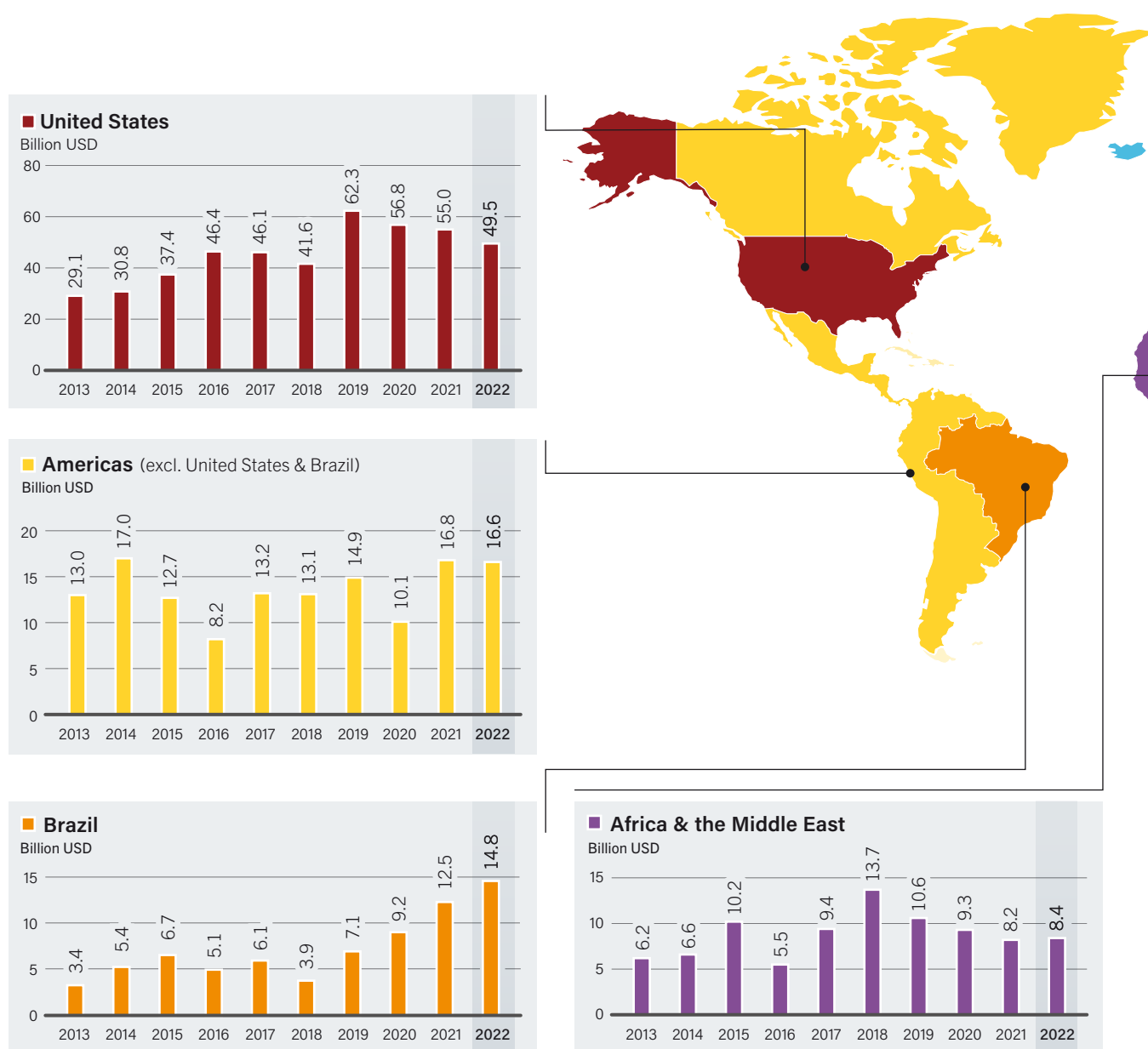
Renewable energy investment in China is driven in part by the country's long-term decarbonisation goals and by the growing demand for electricity compared with countries in the Organisation for Economic Co-operation and Development (OECD), where electricity demand is relatively stagnant or growing far more slowly.<sup>25</sup> Investment in solar PV has been supported by policies enacted by Chinese provincial and local governments, as well as by growing interest in distributed solar PV from commercial and industrial entities.<sup>26</sup> Although China has phased out direct subsidy support for wind power at the national level, provincial and local governments have continued to support project investments, particularly by facilitating land acquisition and other project logistics.<sup>27</sup>

In **Europe**, investment in renewable energy projects fell 26% to USD 55.9 billion in 2022.<sup>28</sup> This decline reflects inflation-related challenges (with costs rising at a higher rate than prospective revenues) as well as national interventions in electricity markets that set varying revenue caps for different technologies, shaking investor confidence.<sup>29</sup> Despite these challenges, some European countries showed remarkable investment growth:

in Italy, renewable energy investment increased 53.2% to USD 3.69 billion, and in Spain it grew 36.3% to USD 10.5 billion.<sup>30</sup> Bulgaria, Estonia and Romania also showed notable growth, although starting from a much smaller base.<sup>31</sup>

Other countries saw significant drops in investment. In France, investment fell 35.6% to USD 4.4 billion, in Germany it was

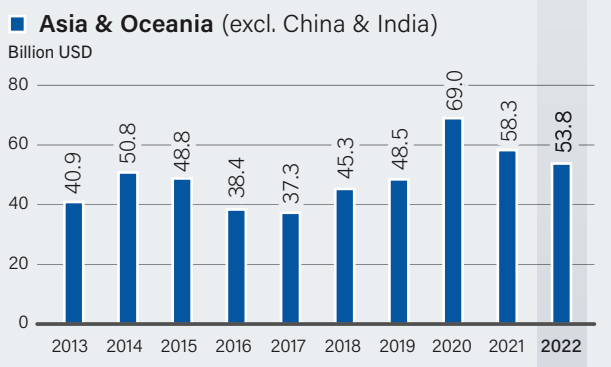
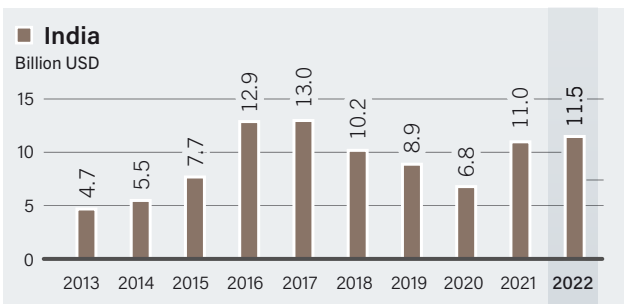
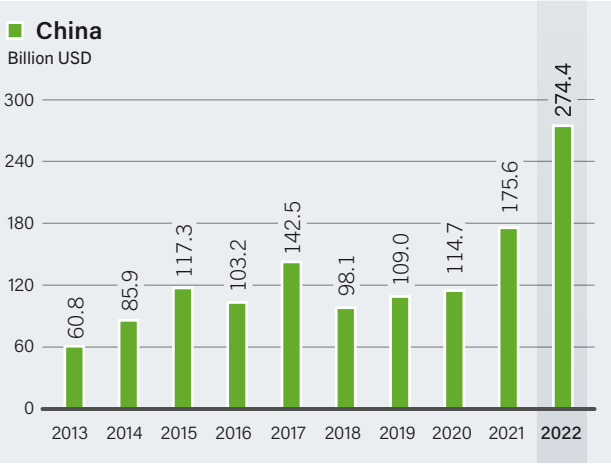
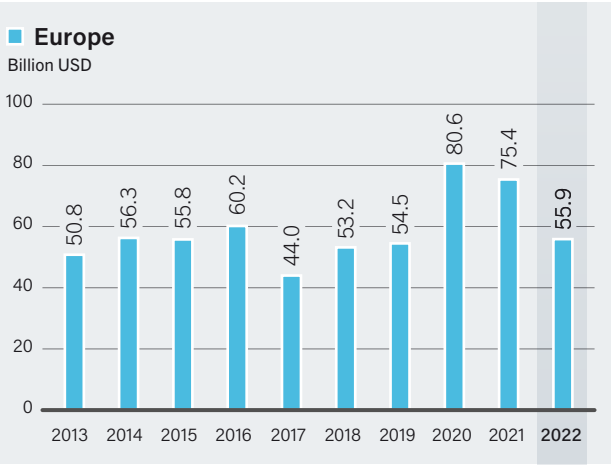
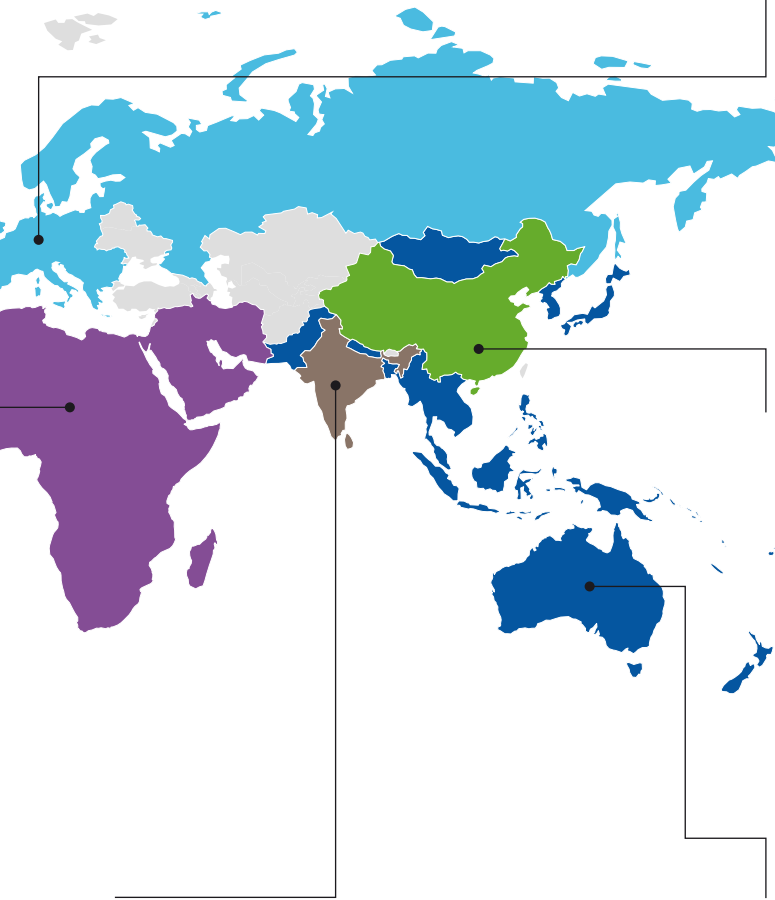
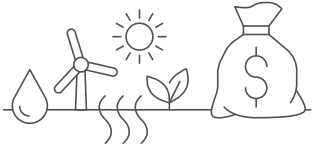
**FIGURE 10.**  
Global Investment in Renewable Power and Fuels, by Country and Region, 2013-2022



Note: Figure does not include investment in hydropower projects larger than 50 MW.  
Reference: Bloomberg NEF, Energy Transition Investment Trends 2023  
Source: See endnote 70 for this chapter.

down 32.8% to USD 8.8 billion, and in the United Kingdom it plummeted 81.4% to USD 2.2 billion.<sup>32</sup> The dramatic drop in UK investment reflects policies that have banned solar PV from farmland (citing food security concerns) as well as planning laws that have blocked onshore wind farms.<sup>33</sup> In the regional ranking, Spain again took the lead in renewable energy investment, followed by Germany and Poland.<sup>34</sup>

China accounted for **55%** of global investment in renewables.



In **Asia-Oceania** (excluding China and India), investment in renewables fell 7.7% to USD 53.7 billion.<sup>35</sup> This decline reflects decreases in Japan (down 29.4% to USD 12.5 billion) and the Republic of Korea (down USD 4.2% to USD 6.7 billion).<sup>36</sup> Although investment in solar PV in the region grew slightly (3.4% to USD 39.8 billion) in 2022, it was nowhere near the levels seen in 2020.<sup>37</sup> A contributing factor was the ongoing decline in solar PV investment in Vietnam, the region's largest solar PV market, following the discontinuation of the country's feed-in tariff at the end of 2020.<sup>38</sup>

Investment in wind power in Asia-Oceania fell 15.9% to USD 12.1 billion, attributed in part to difficulties in acquiring grid connections, a common problem in the region.<sup>39</sup> Investment in biofuels increased markedly during the year, up 239.6% to USD 0.18 billion.<sup>40</sup> The increase is due largely to incentives that Indonesia and Malaysia put in place to support the local palm oil industry, after the European Union (EU) imposed sustainability restrictions on palm oil imports.<sup>41</sup>

The **United States** attracted the most renewable energy investment among developed economies, although investment continued its decline of recent years, falling 10% to USD 49.5 billion.<sup>42</sup> Investment fell in both solar PV (down 16.1% to USD 25.5 billion) and wind power (down 24.6% to USD 15.2 billion).<sup>43</sup> The US investment decline continued to reflect the challenges seen in 2021: difficulties with supply chains, road blocks in permitting and grid connection, the fall-off in available federal tax credits (which was reversed during the year), and continued uncertainty about tariffs and other trade measures that impact module imports.<sup>44</sup>

In **India**, total new investment in renewables increased 4.4% to USD 11.5 billion in 2022.<sup>45</sup> Investment in solar PV rose 19%

to USD 8.6 billion.<sup>46</sup> Biofuel investment grew marginally, and investment in all other renewable technologies, including wind power, fell during the year.<sup>47</sup> Although auctions continue to support investment in both solar PV and wind power in India, the scalable nature of solar PV (which allows it to be deployed more quickly with fewer complications for grid connection) has given it a great advantage over wind power, explaining in part the large difference in investment between the technologies.<sup>48</sup> Wind power investment in India has not yet recovered to its 2016 peak, due largely to difficulties with procuring land for new projects in areas with strong wind resources or near transmission networks, but also because of the national shift from feed-in tariffs to tendering.<sup>49</sup>

**Brazil's** total investment in renewables was up 18.3% to USD 14.8 billion.<sup>50</sup> Continuing the growth of 2021, investment in solar PV increased 23.7% in 2022 and in wind power increased 14.5%, whereas investment in all other renewable energy technologies either stagnated or declined.<sup>51</sup> The flurry of investment in rooftop solar PV continued, in advance of revised legislation that will gradually introduce grid-access charges for residential and commercial system owners beginning in June 2023.<sup>52</sup>

Wind power investment reached a new high in Brazil and is increasingly being supported by power purchase agreements that are not connected with government-run auctions.<sup>53</sup> This demonstrates the rise in unregulated electricity market shares coupled with growing corporate demand for clean energy.<sup>54</sup>

Although the shares of biomass in Brazil's total renewable power investment are decreasing, dependable sugarcane feedstocks and ongoing government auctions targeting biomass-generated electricity have helped to ensure ongoing investment in the technology.<sup>55</sup>



Outside Brazil and the United States, renewable energy investment in the **Americas** totalled USD 16.6 billion, down slightly from 2021.<sup>56</sup> Solar PV investment in the region increased 16% to USD 11.8 billion, whereas investment fell in all other technologies, including wind power, which was down 9.6% to USD 4.8 billion.<sup>57</sup> Biofuel investment dropped 100% to only USD 1.1 billion.<sup>58</sup> Investment in renewables was impacted by inflation, the discontinuation of COVID-19 stimulus packages, weak local currencies and slow economic growth.<sup>59</sup>

In Argentina, new renewable energy investment has fallen sharply due mainly to economic and financial turmoil, as well as to bottlenecks in the transmission infrastructure that have greatly slowed the integration of additional variable electricity supplies.<sup>60</sup> Chile remains a key destination for new renewable energy investment in the region, despite relatively lower levels spent in 2022, and Colombia has emerged as an important new market for wind and solar power investment.<sup>61</sup> To enable greater grid integration of variable renewables, both countries have taken steps to support utility-scale battery capacity<sup>i</sup>, which is only beginning to be deployed in the region at scale.<sup>62</sup>

Investment in renewables in the **Middle East and Africa** was up 3.0% to reach USD 8.4 billion in 2022.<sup>63</sup> Regional investment leaders included South Africa (up 45.4% to USD 2.2 billion), Egypt (up 669.2% to USD 1.8 billion) and Israel (up 9.2% to USD 0.99 billion).<sup>64</sup> At least some of South Africa's remarkable growth in renewable energy investment may be in response to

the November 2021 announcement of dedicated finance (initially USD 8.5 billion) for decommissioning coal-fired power plants and deploying renewables.<sup>65</sup> Partners in this Just Energy Transition Investment Plan for the country include France, Germany, the United Kingdom, the United States and the EU.<sup>66</sup>

Many developing and emerging economies face unique challenges in financing renewable energy projects, compared to the developed world. Investment in these countries may be complicated by political instability, macroeconomic uncertainty (related to inflation and exchange rates), policy and regulatory issues (such as poorly designed or implemented processes for obtaining licences, permits, rights and other approvals to build), institutional weaknesses and a lack of transparency.<sup>67</sup> (→ See *Sidebar 1*) Country related risks and underdeveloped local financial systems also can directly affect the cost of capital.<sup>68</sup> Nominal financing costs can be up to seven times higher in emerging and developing countries than in developed countries, such as the United States and countries in Europe.<sup>69</sup>

**RENEWABLE ENERGY INVESTMENT IN PERSPECTIVE**

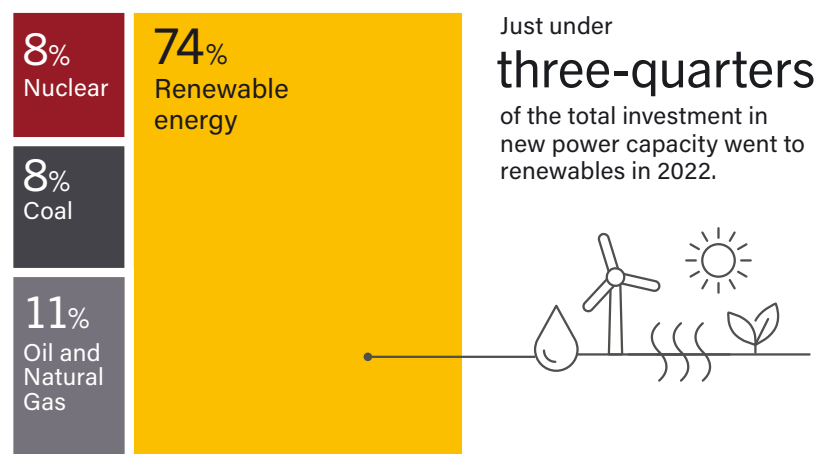
Renewable power installations continued to attract far more investment in 2022 than did fossil-fuel based or nuclear generating power plants.<sup>70</sup> Investment in new renewable power capacity accounted for 74% of the total investment committed to new power generating capacity (including fossil fuels and nuclear).<sup>71</sup> (→ See *Figure 11*).

i Investment in utility-scale battery capacity is not included in the investment totals for renewable power and fuels presented earlier in the paragraph.

**FIGURE 11.**  
Global Investment in New Power Capacity, by Type, 2022

640

USD billion invested in 2022



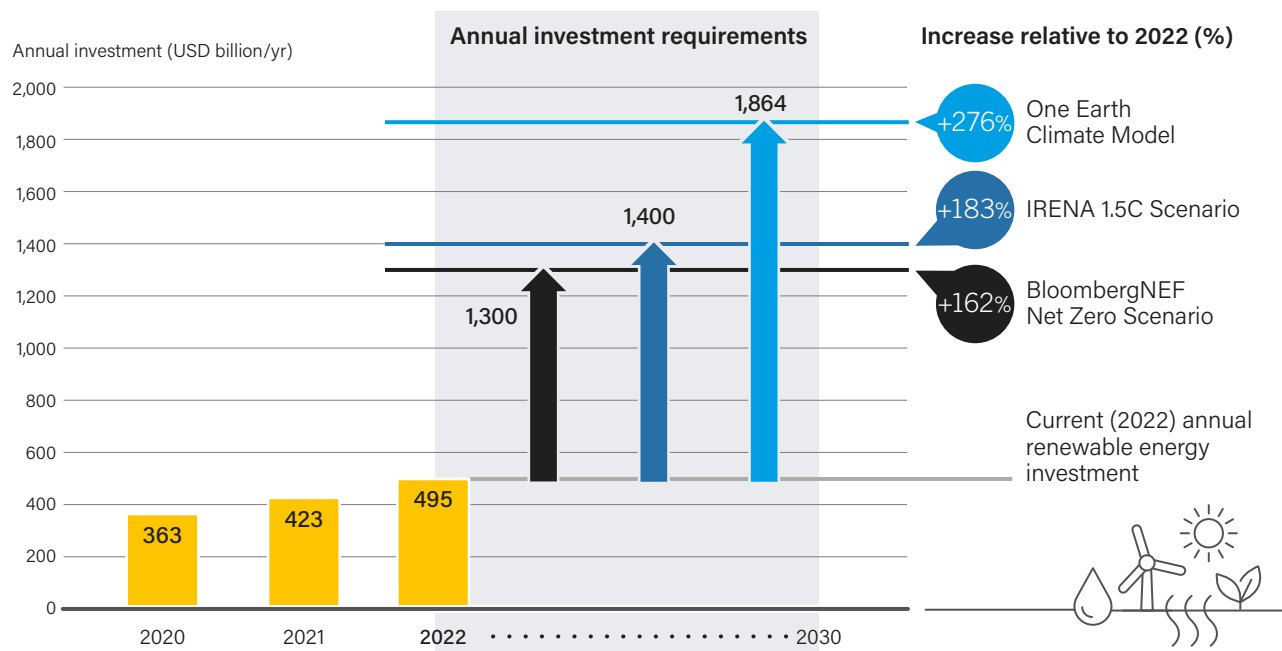
Source: See endnote 70 for this section.



Most scenarios that limit the increase in the global mean temperature are accompanied by a near-complete phase-out of fossil fuel power generation (without carbon capture and storage) by 2100.<sup>72</sup> The Paris Agreement (in Article 2.1c) highlights the need to make finance flows consistent with the goal of limiting global temperature rise to 1.5 degrees Celsius.<sup>73</sup> Achieving this goal would require large growth in overall renewable energy investment compared to the last decade. Estimates of the annual investment in renewable power needed by 2030 to achieve the Paris Agreement goals are in the range of USD 1,300–1,400 billion.<sup>74</sup> (→ See Figure 12.)

Annual investment in renewable energy needs to increase by more than an **150%**.

**FIGURE 12.** Range of Annual Renewable Energy Investment Needed in Climate Change Mitigation Scenarios, Compared to Recent Investments



Source: See endnote 74 for this section.

Note: These scenarios quantify renewable energy differently than the Bloomberg NEF historical basis used in this chapter. These scenario estimates are for renewable power only, while the historical basis includes power and renewable fuels.



## SIDEBAR 1. Permitting and Grid Updates for Renewable Energy

Interest in renewable energy increased globally in 2022 in light of the severe energy crisis triggered by the Russian Federation's invasion of Ukraine. More countries and companies are seeking the opportunity to increase their installed capacity as renewables are seen as providing cleaner, cheaper and more stable energy than fossil fuels. In 2022, global renewable energy capacity grew 13%, adding 348 GW to reach a total of 3,481 GW.

However, a key constraint for the implementation of renewables is the required permitting to enable connection to the electrical grid. In most places, the current grid capacity is insufficient to transmit the power generated from renewable sources. The United States has more than 900 GW of renewable energy projects waiting to be constructed and connected, yet many have been unable to connect to the grid, delaying decarbonisation in the world's second largest emitter of greenhouse gases. The conventional grid was built to accommodate a centralised power system fed by a relatively small number of large power plants. Investments in grid updates have been inadequate, resulting in more than 1,200 GW of renewable energy projects in US awaiting connection as of 2022.

This challenge is being witnessed globally. Greece, a country that fully covered its electricity demand with renewables for the first time in 2022, has 11.5 GW of projects waiting to be connected to the grid. In the United Kingdom, around 600 projects with a combined capacity of 176 GW are in the queue for connection, with a projected waiting time for some projects extending into 2036.



Financial and environmental variables can greatly complicate grid upgrading, and the cost can sometimes be prohibitive for utility companies. In 2020, Pine Gate Renewables in the US state of North Carolina terminated its solar PV project due to the estimated grid connection cost of USD 5 million. Germany, which plans to add 12,000 kilometres of electricity lines, faces an anticipated cost of EUR 55 billion (USD 58.7 billion) to expand high-voltage lines by 2030. Globally, an estimated USD 21.4 trillion in grid investment would be needed to achieve net zero emissions by 2050.

The process of upgrading grids needs to be transparent to local communities and sensitive to environmental concerns. This can be time consuming for companies that are hoping to realise projects as quickly as possible to recoup initial investments. In the United States, the median approval time for connecting a new power project to the grid in 2021 was 2.8 years, double the approval time in 2015. In Germany, farmers have protested grid expansions, citing the potentially serious impacts that underground cables could bring to farmlands.

Many governments are well aware of the potential bottleneck of grid connection for the energy transition. In 2022, the government of Greece implemented stricter standards for connecting renewable energy to grids, to prevent inexperienced utility companies from preoccupying the grid by taking long lead times to realise projects. The US government launched a Better Grid Initiative to develop new and upgraded high-capacity transmission lines in the country, identifying areas of greatest need. In addition, the federal government will provide more than USD 20 billion to support transmission infrastructure.

Given that grid expansion takes time, the Japanese government has developed a scheme to use the existing grid more flexibly, requiring companies to agree to "non-firm connection" whereby projects must suspend operations when required to secure grid stability. To accelerate permitting, Spain temporarily abolished its requirement to carry out environmental impact assessments for renewables projects, which could halve the development time. In the United States, a bill to similarly overhaul the environmental process was proposed but rejected. Meanwhile, UK renewable energy developers have asked for regulatory reforms that prioritise renewable energy projects with short lead-times that are ready to proceed, in place of the current "first come, first served" approach.

<sup>i</sup> An individual, household or small business that not only consumes energy but also produces it. Prosumers may play an active role in energy storage and demand-side management.

Source: See endnote 75 for this section.



Total global installed renewable power capacity reached **3,481 Gigawatt** in 2022.

Almost **10%** of the total installed renewable power capacity was added in 2022.

Renewables cover **30%** of global electricity generation with solar PV and wind power representing 12%.

China, the United States, India, Brazil, and Spain installed **66%** of the new Solar PV capacity in 2022.

As of end-of 2022, announced **hydrogen projects** would lead to an installed electrolyser capacity of 134-240GW by 2030.



# MARKET DEVELOPMENTS



## KEY FACTS BIOENERGY

- Bioenergy (including traditional use of biomass) is the largest renewable energy source, accounting for 12.6% of overall energy consumption in 2020.
- Globally, most of the use of bioenergy was for heating.
- Global production of liquid biofuels totalled 162 billion litres in 2021, providing 3.6% of the overall energy use in the transport sector.
- In 2022, 672 terawatt-hours (TWh) of electricity was generated from a wide variety of biomass feedstock, with the share in overall electricity generation at 2.4%.
- Total installed biopower capacity was 149 gigawatts (GW) in 2022.



Bioenergy, or energy derived from biomass, is a versatile renewable energy source with a multitude of feedstocks, technological pathways and end-uses.<sup>1</sup> Predominant feedstocks include residues from forest harvesting and processing (e.g., fuelwood, wood chips, sawdust), energy crops, wastes and residues from the agriculture sector (e.g., paddy straw, rice husk, animal waste) and the renewable share of municipal solid waste.<sup>2</sup> This feedstock can be converted through a variety of biological, chemical and thermal processes to produce electricity, heat, cooling, and transport fuels, as well as materials and chemicals.<sup>3</sup>

The use of biomass for energy can be broadly classified into traditional and modern bioenergy. Traditional bioenergy typically

involves the direct combustion of biomass such as wood, charcoal, cow dung and crop waste in inefficient appliances such as open-fired cook stoves. Such use occurs mainly in developing countries and produces household air pollution that is harmful to human health.<sup>4</sup> However, modern sustainable bioenergy – the use of improved fuels (e.g., pellets, wood chips, ethanol, biogas, biomethane, etc.) in modern equipment – will play an important role in mitigating climate change.<sup>5</sup>

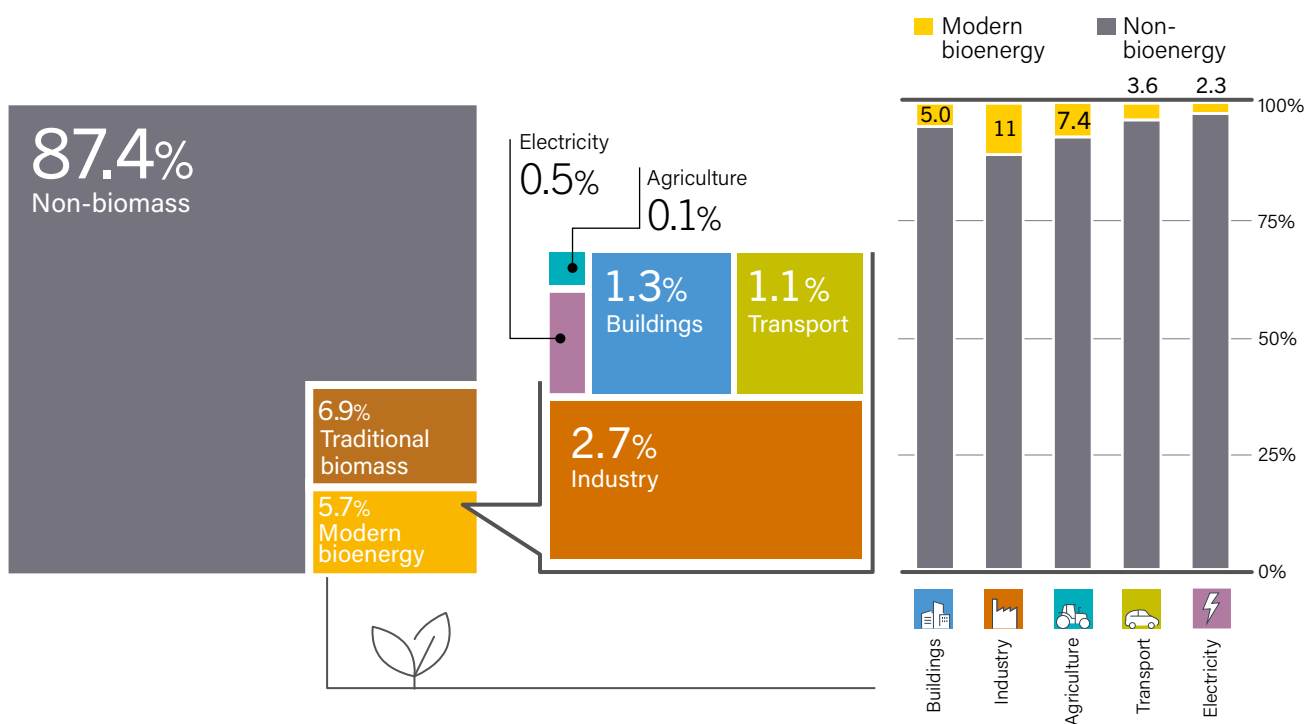
Bioenergy is the largest renewable energy source globally, as it provides heat, electricity and fuels for transport.<sup>6</sup> In 2020 (latest data available), the gross final energy consumption of bioenergy was 45.6 exajoules (EJ), accounting for 12.6% of total energy consumption.<sup>7</sup> The use of modern bioenergy for industry, buildings, transport, agriculture and power was 20.6 EJ, representing 5.7% of total energy consumption.<sup>8</sup> (→ See Figure 13.)

Globally, most bioenergy is used for heat. In 2020, modern bioenergy provided 14.9 EJ of heat (industry 66%, buildings 31% and agriculture 3%), which accounted for 23.4% of all heat consumption.<sup>9</sup> In transport, consumption of liquid and gaseous biofuels was 3.8 EJ, providing 3.6% of all renewable energy in the transport sector.<sup>10</sup> The electricity sector consumed 1.9 EJ of biomass, or 2.3% of energy use in that sector.<sup>11</sup>

Overall, bioenergy represented a renewable energy share of around 45% in global total final energy consumption in 2020, down from 54% in 2010.<sup>12</sup> During 2010-2020, the global final energy consumption of bioenergy increased from 29 EJ to 45 EJ, rising 4.4% annually.<sup>13</sup>



**FIGURE 13.** Share of Bioenergy in Total Final Energy Consumption, 2020



Source: See endnote 8 for this section.

**BIOHEAT**

Globally, **traditional use of biomass** accounts for more than half of all bioenergy use, mainly in emerging economies in Asia and Africa where it is used largely for cooking and indoor heating.<sup>14</sup> Under scenarios for net zero greenhouse gas emissions, the use of traditional biomass would need to be phased out by 2030.<sup>15</sup> Renewable alternatives include modern bioenergy technologies such as biogas, ethanol and processed biomass such as pellets and briquettes.<sup>16</sup>

In 2020, modern forms of bioenergy produced 1.2 EJ of **derived heat**, for example in combined heat and power (CHP) plants and heat-only plants.<sup>17</sup> Half of this production was from solid biomass sources such as wood chips and wood pellets, while waste-to-energy accounted for around 45% and biogas for 4.3%.<sup>18</sup> Heat production from solid biomass nearly tripled globally during 2010-2020.<sup>19</sup>

The **buildings sector** used an estimated 29 EJ of bioenergy in 2020 out of which 4.9 EJ of modern biomass for energy (including district heating networks); this accounted for 5% of total final energy consumption.<sup>20</sup> (→ See Figure 13.) In **industry**, biomass provided 9.9 EJ of renewable heat, or 11% of the overall heat demand.<sup>21</sup> The use of bioheat in industry increased 36% between 2010 and 2020.<sup>22</sup> Industries such as consumer goods, breweries, pharmaceuticals and bakeries are replacing their use of fossil fuels (mainly coal and natural gas) for producing

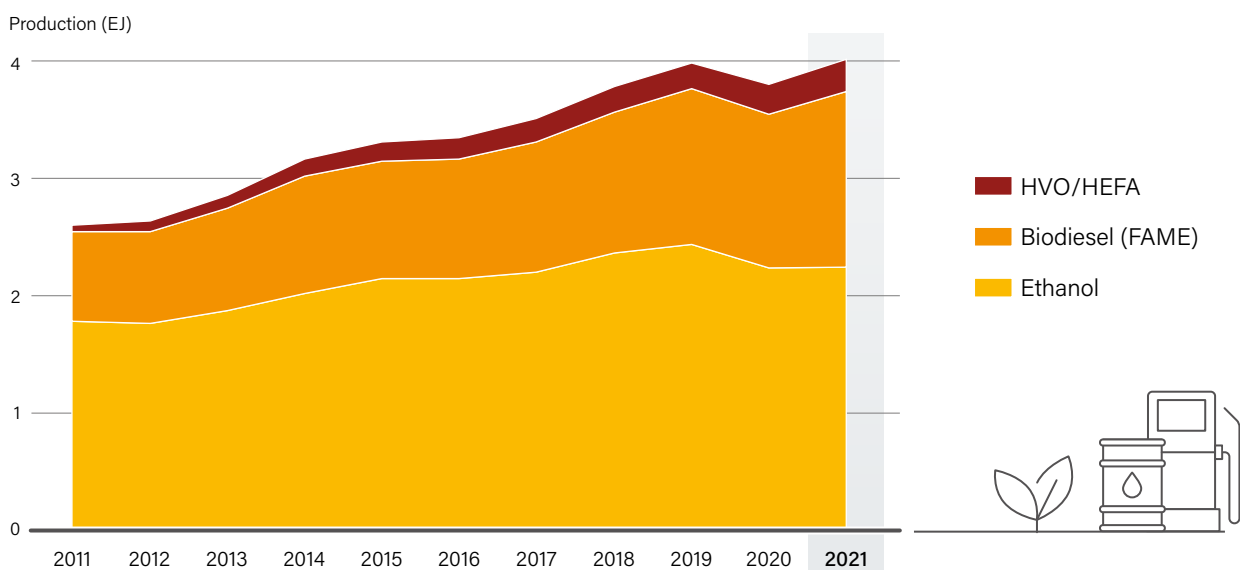
hot water and steam with renewables such as biogas, pellets and briquettes.<sup>23</sup> In 2022, Heineken opened the largest biomass plant in Cambodia to provide thermal energy to its brewery in Phnom Penh.<sup>24</sup>

Primary energy supply of bioenergy increased by **17%** during 2010 – 2020.

**District heating** is an efficient way to transfer heat around the clock from a large central plant to domestic and commercial establishments via underground pipes, leading to improved energy efficiency, reduced emissions, fuel flexibility and reduced costs.<sup>25</sup> District heating accounted for 8% of overall heat demand in 2021.<sup>26</sup> However, more than 90% of the district heating was from fossil fuels, mainly coal in China and natural gas in the Russian Federation.<sup>27</sup> In Europe, waste feedstock was used for most district heating, with Denmark, Sweden, Estonia, Lithuania and Latvia leading the way.<sup>28</sup>

In Vilnius, Lithuania, a new CHP plant using municipal waste and biomass will be able to provide 40% of the required heat for the city while reduce heating costs by 20%.<sup>29</sup> In Sweden, district heating in buildings amounted to 43.1 terawatt-hours (TWh) (0.16 EJ) in 2020, accounting for 58% of all energy consumption

**FIGURE 14.** Global Production of Ethanol, Biodiesel and HVO/HEFA Fuel, by Energy Content, 2011-2021



Source: See endnote 50 for this section.

in residential and commercial buildings.<sup>30</sup> As much as 80% of Sweden’s district heat production in CHP plants was from biomass sources, including wood briquettes and pellets, wood chips, sawdust, biogas and municipal waste.<sup>31</sup> In 2022, Egypt announced plans for the country’s first waste-to-energy plant.<sup>32</sup>

**Europe** accounts for 90% of all bioheat produced from municipal waste, solid biofuels and biogas.<sup>33</sup> In 2021, the region produced 0.55 EJ of bioheat from solid biofuels; 61% of this was in highly efficient CHP plants and the rest in heat-only plants.<sup>34</sup> Bioheat demand in Europe grew 16% in 2021.<sup>35</sup> Sweden, Finland and Denmark accounted for 50% of the heat production from biomass in Europe that year.<sup>36</sup> Renewable municipal waste provided 0.13 EJ of heat, mainly in CHP plants, with Germany and Sweden accounting for half of this production.<sup>37</sup> For biogas, gross heat production totalled 0.04 EJ, and one-third of this heat blended into natural gas grids.<sup>38</sup> Italy and Germany accounted for 63% of the biogas heat, with Germany producing 70% of all biogas heat in gas grids.<sup>39</sup>

A critical end-use for bioenergy is **clean cooking**. As of 2020, around 3 billion people (30% of the global population) did not have access to clean cooking solutions and relied on traditional biomass use in inefficient cook stoves (in Sub-Saharan Africa, access is even lower, at 17%).<sup>40</sup> Modern and renewable solutions include bottled ethanol, distributed solar, pellet gasifiers and electric pressure cookers.<sup>41</sup> The share of people with access to clean cooking solutions increased 9 percentage points during 2010-2020.<sup>42</sup> In 2020, according to an industry survey of 60 companies, sales of biomass stoves (including biogas) accounted for 90% of the total clean cooking sales revenue.<sup>43</sup> At an estimated USD 26 million, this was well below the USD 8 billion per year required for universal access to clean cooking.<sup>44</sup>



## TRANSPORT BIOFUELS

**Liquid biofuels** offer a solution to replacing fossil oil in the transport sector.<sup>45</sup> In 2020, biofuels accounted for 3.6% of total energy use in the sector.<sup>46</sup> Transport biofuels are produced mainly from sugar or starch crops such as sugar cane, maize, cassava and cereals; oil crops such as rapeseed, soybean and oil palm; and, more recently, used cooking oil and animal fats. Through various production pathways, these feedstocks can be converted to bioethanol, biodiesel, hydrogenated vegetable oil (HVO) and fuels for maritime transport and aviation (sustainable aviation fuels, or SAF). Gaseous fuels such as biomethane, produced by upgrading biogas, are also used in road transport.<sup>47</sup>

The biofuels are typically **blended** with petrol or diesel when used in road transport. Current blends typically range from E5 (5% ethanol in petrol) and B7 (7% biodiesel in diesel) to ambitions for E20 (India) and B35 (Indonesia).<sup>48</sup> Higher blends also are possible with existing ED95 and B100, which are typically used in heavy-duty transport and with a modified diesel engine.<sup>49</sup>

In 2021, global **production** of liquid biofuels totalled 162 billion litres (4.06 EJ).<sup>50</sup> (→ See Figure 14.) Bioethanol production totalled an estimated 106 billion litres (2.24 EJ), accounting for two-thirds of global biofuel production.<sup>51</sup> Biodiesel accounted for 28% of global production, at 45.7 billion litres (1.49 EJ), followed by HVO (renewable diesel) at almost 10 billion litres (0.33 EJ).<sup>52</sup> Despite intense focus and significant opportunities, biojet (SAF) production remains at an early stage of market development, with 150 million litres produced in 2022.<sup>53</sup>

Demand for liquid biofuels grew 4.6% in 2021 as transport restrictions related to the COVID-19 pandemic were eased, leading to a massive increase in fuel demand for all end-use sectors, especially aviation.<sup>54</sup> Biodiesel production increased 4.3%, followed by bioethanol production at a modest rate of 2.2%.<sup>55</sup> Renewable diesel production grew 44%, and biojet production doubled in 2021.<sup>56</sup>

**Ethanol** is the largest biofuel produced globally and accounted for 66% of total biofuel production in 2021.<sup>57</sup> The United States is world’s largest ethanol producer, followed by Brazil; together, they produced more than 80% of the global total in 2021.<sup>58</sup> The primary ethanol feedstock in the United States is corn (maize), while in Brazil it is sugar cane. The most common US blend is E10, which is available in every state, and efforts are under way to increase the blend to E15 in certain midwestern states such as Iowa, Illinois and Minnesota.<sup>59</sup> In Brazil, the current blending mandate is 27%, and policies such as Renovabio aim to further expand the use of biofuels to reduce the carbon intensity of transport.<sup>60</sup>

In the European Union (EU), the share of ethanol in transport was 6.8% by volume in 2021, with E5 contributing to the bulk of the petrol market (although E10 is increasing gradually).<sup>61</sup> Major hurdles for the expansion of liquid biofuels in the region include recent legislation that curtails the qualification of crop biofuels for renewable energy targets; declining petrol demand; and discussions surrounding the phase-out of internal combustion engines.<sup>62</sup>

In Asia, China is one of the largest producers of ethanol, with estimated production of 12 billion litres in 2022, mainly via maize and rice kernels.<sup>63</sup> A planned nationwide blending mandate of 10% by 2020 was not met, with the blend rate reaching only 1.8%

as of 2022.<sup>64</sup> In India, in contrast, implementation of the Ethanol Blended Petrol programme led to the achievement of E10 in 2022.<sup>65</sup> The Indian government has announced a target of E20 to be achieved by 2025.<sup>66</sup>

Apart from crop-based biofuels, ethanol can be produced from cellulosic sources such as wheat straw. Commercialisation of cellulosic ethanol facilities is ongoing, although major projects have faced technical, supply chain and economic issues.<sup>67</sup> Even so, there is renewed interest, with new projects being announced in Brazil, India and Romania.<sup>68</sup>

Conventional **biodiesel**, commonly referred to as FAME (fatty acid methyl ester) biodiesel, uses common vegetable oils (palm, soy, peanut, rapeseed) for conversion via transesterification to produce a renewable substitute to diesel in road transport. In 2021, biodiesel represented 28% of total biofuel production.<sup>69</sup> The EU is a leader in FAME biodiesel – producing an estimated 12 billion litres in 2021 – and accounts for 7.8% of the diesel demand, with rapeseed being the dominant feedstock.<sup>70</sup> France, German and Spain contribute 62% of the region’s FAME biodiesel production.<sup>71</sup>

Asia has experienced rapid growth in biodiesel production, driven mainly by expanding mandates in Southeast Asian countries. Indonesia, the world’s top palm oil producer, announced plans to increase its biodiesel blending mandate to B35 starting in 2023.<sup>72</sup> In 2020, Malaysia announced a goal of B20, but the roll-out was delayed due to issues related to the COVID-19 pandemic and to an uncertain political situation.<sup>73</sup> Thailand postponed its proposed B10 mandate and is instead focusing on B7 due to surging feedstock prices.<sup>74</sup>

**Hydrogenated vegetable oil (HVO)**, or renewable diesel, relies on similar feedstock as biodiesel, although there is a marked difference in the production technology and product characteristics.<sup>75</sup> HVO is produced via hydro processing of oils and fats, resulting in a drop-in fuel that is fully compatible with existing fossil fuel infrastructure.<sup>76</sup> Neste accounts for an estimated 40% of all production globally, with refineries in Finland, the Netherlands, and Singapore, and other major oil companies such as BP, Eni and Total also are investing in HVO.<sup>77</sup>

**Biomethane** (upgraded biogas) is another option for decarbonising transport and other sectors via injection into natural gas grids. Promising markets include the EU, the United States and an emerging sector in Brazil.<sup>78</sup> In Sweden, 281 plants produced 2.3 TWh of biogas in 2021, out of which 67% was upgraded to biomethane.<sup>79</sup> Seventy percent of it was used for transport.<sup>80</sup> Total global biomethane production in 2020 was around 5 billion cubic metres, accounting for 0.1% of global natural gas consumption.<sup>81</sup> Incentives in the US Inflation Reduction Act as well as the EU target of producing 35 billion cubic metres of biomethane by 2030 are expected to further increase production.<sup>82</sup>

Production of HVO or renewable diesel increased by **66 times** during 2010 – 2020.

**Aviation** is expected to be a significant market for biofuels consumption. Due to limited other options for replacing fossil fuels (such as electrification), especially for long-haul flights, sustainable liquid biofuels offer a potential solution.<sup>83</sup> International agreements in the aviation sector target reducing greenhouse gas emissions 50% by 2050.<sup>84</sup> However, current SAF production levels are very low, at an estimated 150 million litres in 2022, representing only 0.03% of global jet fuel demand.<sup>85</sup> Although numerous pathways exist for producing SAF – such as alcohol-to-jet, gasification, Fischer-Tropsch, pyrolysis oil and power-to-liquid – there is currently only one commercial production route (HEFA).<sup>86</sup>

The main challenges for commercial SAF production are supply chains and higher production costs relative to fossil jet fuel; however, recent legislation such as the US Inflation Reduction Act could drive major growth in the sector.<sup>87</sup> The Inflation Reduction Act aims to produce 3 billion gallons of SAF by 2030 and offers tax credits for SAF biofuels.<sup>88</sup> The EU also has introduced SAF targets via the REFuelEU initiative.<sup>89</sup>

**Maritime transport** accounts for 2-3% of global greenhouse gas emissions and for 80% of the international trade of goods.<sup>90</sup> In 2018, the International Maritime Organization announced targets for reducing the carbon intensity of the sector 40% by 2030 and 70% by 2050, as well as limits on the sulphur content of the fuels used.<sup>91</sup> Compared to the aviation sector, which faces strict fuel regulations due to safety, the maritime sector has several options including electrification and biofuels. In 2020, global production of biofuels in the sector totalled an estimated 30,000 tonnes of used cooking oil, biofuels, and biogas, supplying roughly 0.01% of global maritime fuel consumption.<sup>92</sup> Critical barriers to growth include pricing, sustainability and supply chain infrastructure.<sup>93</sup>



### BIOPOWER

Biopower involves the production of electricity from biomass feedstock. The capacities vary from large-scale stand-alone power facilities of more than 100 megawatts (MW) to small-scale biomass plants of around 100 kilowatts (kW).<sup>94</sup> In 2022, 672 TWh of electricity was generated from a wide variety of feedstocks.<sup>95</sup> Production of electricity from biomass grew slightly at 0.8%, while the share in overall electricity generation remained the same at 2.4%.<sup>96</sup>

As of 2020, 70% of the electricity was produced from solid biomass sources from both forest and agriculture sectors, such as wood pellets, wood chips and sugarcane bagasse.<sup>97</sup> Urban municipal and industrial waste generated 113 TWh (16%) of electricity, while biogas generated 90 TWh (13%).<sup>98</sup>

Installed biopower capacity reached an estimated 149 GW in 2022, or just over 4% of total renewable power capacity.<sup>99</sup> Biopower capacity increased 5% in 2022, one of its slowest rates of year-on-year growth in the last decade.<sup>100</sup> (→ See Figure 15.) China had the largest installed biopower capacity, with 34 GW, followed by Brazil (17 GW), the United States (11 GW) and India (10 GW).<sup>101</sup>

China alone accounts for more than one-quarter (26%) of the global electricity production from biomass, with generation of 172 TWh in 2022 – mainly from forest and agricultural biomass as well as municipal solid waste.<sup>102</sup> In Brazil, the bioenergy

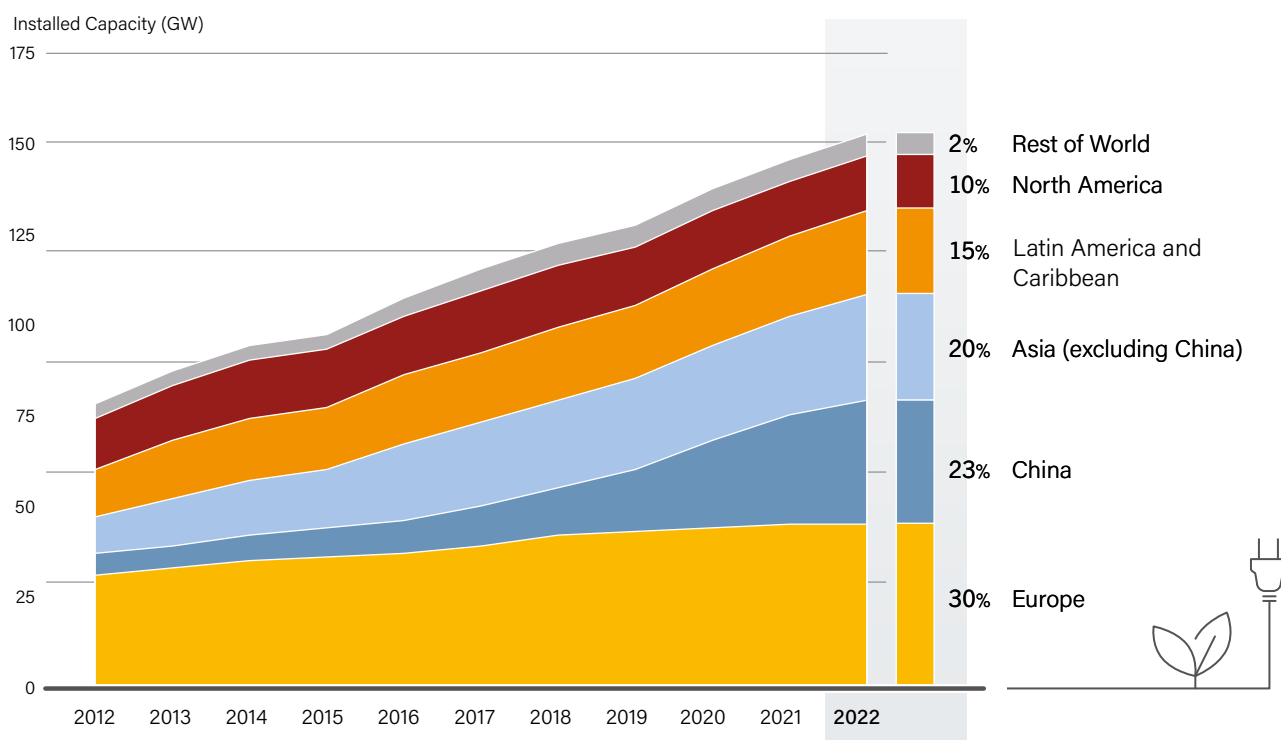
share (mainly from sugarcane bagasse) in electricity generation reached an estimated 8.6% in 2022.<sup>103</sup>

During 2022, electricity generation from biomass increased in Asian countries such as Japan (up 19%), the Republic of Korea (up 24%) and India (up 3%), driven by incentives such as feed-in tariffs, renewable energy certificates and mandates for co-firing biomass with coal.<sup>104</sup> India is expected to be a major player in biomass electricity generation due to an upcoming policy to co-fire 5% (and higher) of biomass in thermal power plants.<sup>105</sup> Although India used only 83,066 tonnes in 2022, financial incentives for processing biomass could generate new supply to meet this demand.<sup>106</sup> Biomass electricity generation fell 10% in the United Kingdom, reflecting outages at some key installations.<sup>107</sup>

In Europe, biopower generation from solid biofuels (excluding charcoal) grew 12% in 2021 to reach 93 TWh.<sup>108</sup> Crucially, 87% of the power generated was compliant with the sustainability criteria laid out in EU regulations, and most of the solid biomass used (96.5%) was of European origin.<sup>109</sup> In 2021, Finland, Sweden and Germany were the region’s top producers, accounting for 37% of production.<sup>110</sup>

However, debates have arisen around the revision of the EU Renewable Energy Directive (RED 3) and the inclusion of primary woody biomass feedstocks in subsidies and targets

**FIGURE 15.**  
Global Bioelectricity Installed Capacity, by Region, 2012-2022



Source: See endnote 100 for this section.



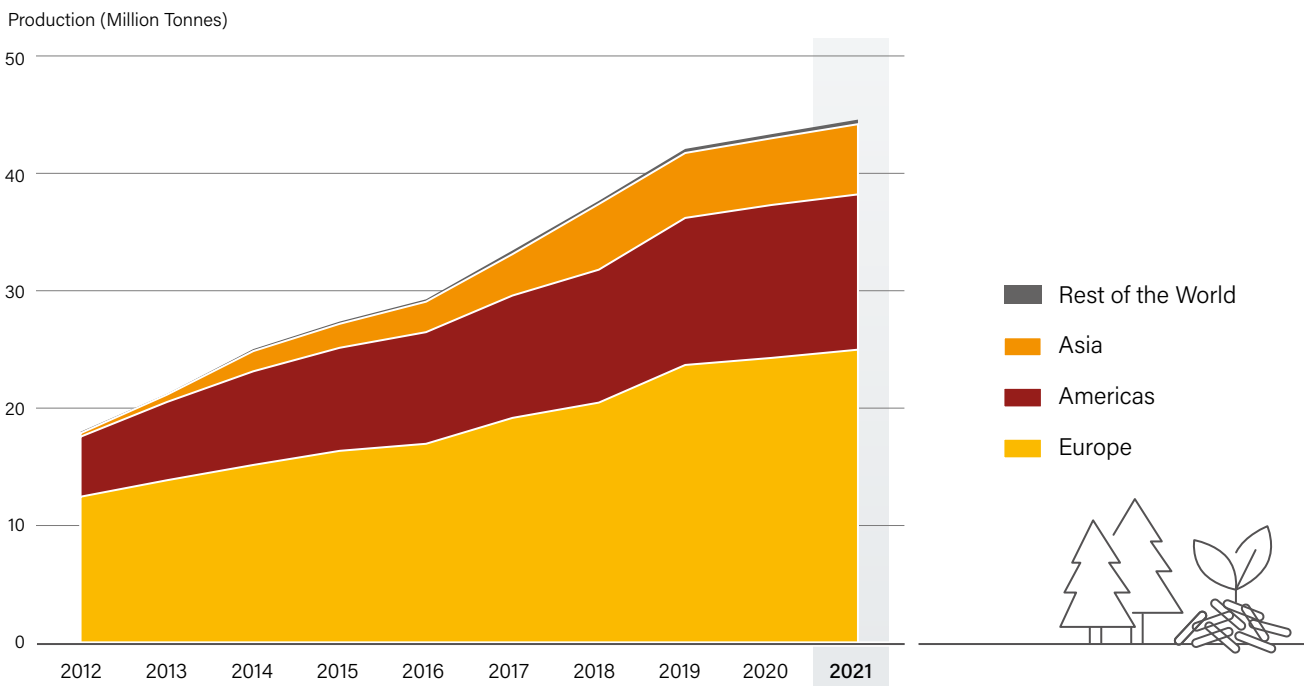


Bioelectricity and bioheat **increased** by 90% and 70% respectively between 2010 and 2020.

for renewables.<sup>111</sup> In recent discussions, the renewable energy target was raised to at least 42.5% by 2030, while strengthening the biomass sustainability criteria in line with EU climate and biodiversity ambitions.<sup>112</sup>

One of the most prominent and fastest growing biomass commodities is wood pellets. In 2022, global production totalled 44 million tonnes.<sup>113</sup> (→ See Figure 16.) The largest producer was the United States, followed by Vietnam, which recently took second place.<sup>114</sup> Despite the loss of pellet supply from the Russian Federation and Belarus due to the war in Ukraine, the international market is expected to expand globally due to proposed upgrades of US plants and new facilities in Southeast Asia and South America.<sup>115</sup> Major consumers include the EU (both commercial power generation and domestic heating) and Japan (mainly power).<sup>116</sup>

**FIGURE 16.**  
Global Wood Pellet Production, by Region, 2012-2021



Source: See endnote 113 for this section.



## KEY FACTS GEOTHERMAL POWER AND HEAT

- New geothermal power generating capacity of 0.2 GW came online in 2022, bringing the cumulative global total to around 14.6 GW.
- Global geothermal power capacity additions were one-third lower in 2022 than in 2021, and well below the five-year average of 0.5 GW since 2017.
- Geothermal power capacity was added in Indonesia, Japan, Kenya, Nicaragua, the Philippines, and the United States, with most countries adding only single, small units.
- Geothermal direct-use (excluding heat pumps) grew nearly an estimated 10% in 2022, to around 155 TWh (560 petajoules, PJ).
- China is the world’s fastest-growing geothermal heat market, and other key markets are Türkiye, Iceland and Japan. Together, these four countries are estimated to account for nearly 90% of global geothermal direct use in 2022.

Geothermal energy has a somewhat unique place among renewable energy technologies. On one hand, it represents a tiny fraction of the global energy balance and is dwarfed by other renewable energy sources. On the other hand, it can represent a valuable and even critical component of the energy mix in a relatively few locations around the world. While geothermal energy<sup>i</sup> is theoretically ubiquitous, it can be hard to reach in most places other than where the Earth’s lithospheric plates meet. New technologies are being developed to make this energy source more economically accessible in more locations.

Geothermal energy is derived from thermal and pressure differentials in the Earth’s crust, providing direct thermal energy or electricity by use of steam turbines. In 2022, geothermal electricity generation totalled an estimated 101 TWh, and direct useful thermal energy supply totalled an estimated 155 TWh (560 PJ).<sup>1</sup> In some instances, geothermal plants produce both electricity and heat for thermal applications (co-generation), but this option depends on location-specific thermal demand coinciding with the geothermal resource.<sup>2</sup>

### GEOTHERMAL POWER

For electricity generation, new geothermal power capacity introduced in 2022 was 0.2 GW<sup>ii</sup>, bringing the global total to around 14.6 GW.<sup>3</sup> This was one-third less than the additions in 2021 and well below the five-year average of 0.5 GW since 2017.<sup>4</sup> Capacity was added in Indonesia, Japan, Kenya, Nicaragua, the Philippines and the United States.<sup>5</sup> (→ See Figure 17)

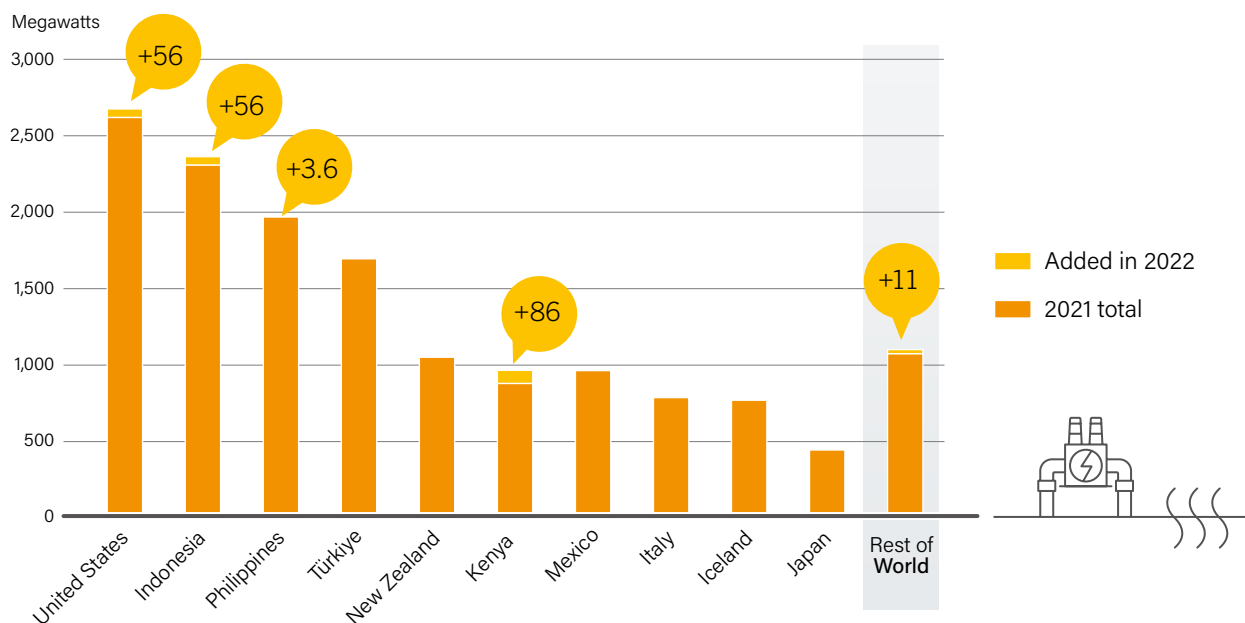
The top 10 countries for geothermal power capacity at the end of 2022 were the United States, Indonesia, the Philippines, Türkiye, New Zealand, Kenya, Mexico, Italy, Iceland and Japan.<sup>6</sup> However, capacity values are subject to high uncertainty due to a lack of standardised reporting criteria.<sup>7</sup>

**Kenya** had the largest geothermal power capacity addition in 2022 as it completed the 86 MW Unit 6 at the Olkaria I complex.<sup>8</sup> The addition raised the country’s geothermal capacity to 0.95 GW, representing 42% of Kenya’s total generating capacity.<sup>9</sup> Kenya is also pursuing upgrades to existing generating units, including the original three units (45 MW) at Olkaria I, which was the first geothermal power capacity commissioned in Africa, in 1980.<sup>10</sup> Total planned upgrades are expected to increase capacity by another 123 MW.<sup>11</sup>

i Here, the term refers mostly to energy derived from medium-to-high enthalpy (>100 degrees Celsius (°C)) hydrothermal and hot dry-rock resources, and typically at significant depth. Specifically, it does not include the renewable final energy output of near-surface, ground-source (or ground-coupled) heat pumps, sometimes referred to as “geothermal heat pumps”. (→ See Heat Pumps section.)

ii Net additions tend to be lower than the sum of new plants due to decommissioning or de-rating of existing capacity.

**FIGURE 17.**  
**Geothermal Power Capacity and Additions, Top 10 Countries and Rest of World, 2022**



Source: See endnote 5 for this section.

The **United States** remains the global leader in installed geothermal capacity, although annual capacity additions in recent years have mostly just maintained overall output.<sup>12</sup> During the five-year period of 2016-2021, net capacity increased 3.2% while generation grew less than 1%.<sup>13</sup> Three projects were completed in 2022, including the addition of 13 MW (net) at the Ormat Technologies (United States) Tungsten Mountain facility in Nevada.<sup>14</sup> In California, Ormat also completed the 30 MW (17 MW net) Casa Diablo-IV.<sup>15</sup> Geothermal power in the United States continues to supply around 0.4% of US net electricity generation, as much as 17 TWh<sup>i</sup> in 2022.<sup>16</sup> In early 2023, a US government study determined that large-scale expansion of geothermal power in the country would depend on large future cost reductions of enhanced geothermal systems<sup>ii</sup> (EGS).<sup>17</sup>

**Indonesia** completed three projects in 2022, adding 55.5 MW.<sup>18</sup> On the island of Flores, the first 5 MW unit of the Sokoria development was inaugurated, followed by the 50 MW Unit 3 at the Sorik Marapi project on North Sumatra.<sup>19</sup> On the North Sulawesi site of the 120 MW Lahendong complex (developed in stages from 2001 through 2016), a 0.5 MW binary-cycle<sup>iii</sup> unit was installed.<sup>20</sup>

During the five-year period 2017-2022, geothermal capacity in Indonesia grew nearly 30% (average of 106 MW annually), from 1.8 GW to more than 2.3 GW.<sup>21</sup> In 2021, geothermal power generation was 15.9 TWh, or 5.5% of the country's total grid supply.<sup>22</sup> With significant coal reserves, Indonesia's 6.8 GW of total new power capacity (9.1% growth to 81.2 GW in 2022) continued to be dominated by fossil thermal plants.<sup>23</sup> The government hopes to reverse that pattern and see renewable capacity outpace other sources this decade.<sup>24</sup>

In late 2022, **Nicaragua** saw the commissioning of a 10.4 MW (net) binary-cycle unit at the existing San Jacinto Geothermal Project.<sup>25</sup> Originally built to 10 MW in 2005, the San Jacinto facility was later expanded to 72 MW in 2012 (operating at 65 MW in 2022).<sup>26</sup>

**The Philippines** ranks third globally for total installed geothermal power capacity at 1.9 GW (1.8 GW of net dependable capacity).<sup>27</sup> No capacity had been added since 2018 until a small 3.6 MW binary-cycle unit was added in 2022 at the Mount Apo geothermal facility in Mindanao.<sup>28</sup> The new unit utilises residual thermal energy contained in the geothermal brine from the existing 103 MW plant, producing incremental electricity without the need for additional drilling, similar to the smallest new unit in Indonesia.<sup>29</sup>

i Generation data for geothermal power in the United States, as first reported, tend to be revised downward by the following year.

ii While conventional hydrothermal systems rely on sufficient heat, permeability and fluid to deliver energy to the surface, enhanced geothermal systems can be implemented where fluid and permeability are lacking. In an EGS, injecting fluid into the hot rock at great pressure creates fractures that allow fluid pathways to form, which can be used for an induced hydrothermal cycle.

iii In a binary-cycle plant, which has become the most common design at plants built in recent years, the geothermal fluid heats and vaporises a separate working fluid (with a lower boiling point than water) that drives a turbine to generate electricity. 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. Organic Rankine Cycle (ORC) binary geothermal plants use an organic working fluid, and the Kalina Cycle uses a non-organic working fluid. Conversely, geothermal steam can be used directly to drive the turbine, but this is more typical for higher-enthalpy applications.

In an effort to invigorate investment in geothermal energy, the Philippines government opened the sector up to full foreign project ownership in 2020 – a provision still denied to other renewable energy technologies.<sup>30</sup> Incremental resource development is made more difficult by high costs and exploration risks, while some potential projects face permitting hurdles on account of impacts on both ecologically sensitive areas and rural populations.<sup>31</sup>

**Japan** was the only other country to add capacity in 2022, installing a 150 kW binary-cycle power module at a thermal bath facility in the Kumamoto region.<sup>32</sup> Mimicking a nearby unit in operation since 2020, the module taps the 110°C well supply to generate electricity before the geothermal waters are utilised for bathing.<sup>33</sup>

Despite being the most active geothermal market over the last decade, **Türkiye** added no new geothermal power plants in 2022, although its stated installed capacity (1.7 GW) was 15 MW higher than at the end of 2021.<sup>34</sup> In the 11 years from 2008 through 2019, capacity grew from 30 MW to 1.5 GW, with the bulk of that coming online since 2015 (1.1 GW).<sup>35</sup> Annual additions then contracted to 99 MW in 2020 and 63 MW in 2021.<sup>36</sup>

Türkiye’s geothermal industry attributes the stagnation to the lack of government support, specifically a weakened feed-in tariff (FIT) that is no longer pegged to the US dollar since 2021, but also the currency risk of weakening Turkish lira.<sup>37</sup> In early 2023, the Turkish government indicated pending revisions to the FIT that would reflect current conditions.<sup>38</sup>

### GEOTHERMAL HEAT

Worldwide, the capacity for geothermal direct use<sup>i</sup> – direct extraction of geothermal energy for thermal applications – totalled an estimated 38 gigawatts-thermal (GW<sub>th</sub>) in 2022.<sup>39</sup> Based on reported values for 2019 and the preceding five-year growth rate, the estimated annual capacity increase in 2022 was 2.7 GW<sub>th</sub>.<sup>40</sup> By the same estimation, geothermal energy use for thermal applications is likely to have grown by 14 TWh during 2022 to an estimated 155 TWh (560 PJ).<sup>41</sup>

The top countries for geothermal direct use in 2022 were (in descending order) China, Türkiye, Iceland and Japan.<sup>42</sup> (→ See Figure 18.)

Geothermal direct use is highly concentrated in those four key markets (estimated to represent 87% of the global total in 2022) and is further localised within each country.<sup>43</sup> Direct use in other countries includes (in descending order) New Zealand, Hungary, the Russian Federation, Italy, the United States and Brazil.<sup>44</sup>

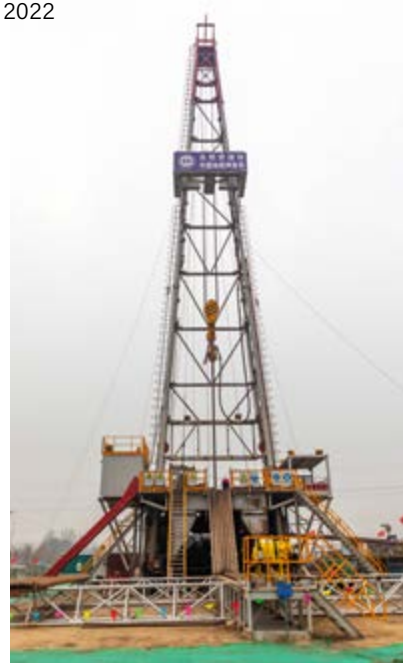
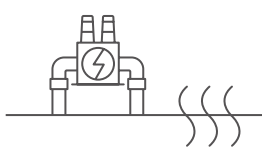
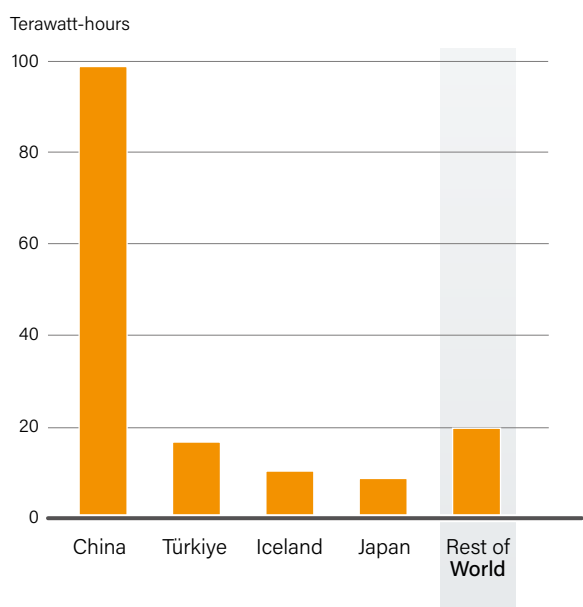
The top 4 countries represent

**90%**

of the global geothermal heat market.

<sup>i</sup> Direct use refers here to deep geothermal resources, irrespective of scale, that use geothermal fluid directly (i.e., direct use) or by direct transfer via heat exchangers. It does not include the use of shallow geothermal resources, specifically those tapped with ground-source heat pumps. (→ See Heat Pumps section.)

**FIGURE 18.**  
**Geothermal Direct Use, Estimates for Top 4 Countries and Rest of World, 2022**



Source: See endnote 42 for this section.

**China** is the world's fastest-growing geothermal heat market, with annual growth exceeding 21% during 2015-2019.<sup>45</sup> Based on this trend, China's use of geothermal heat has likely grown from a reported 197 PJ in 2019 to around 355 PJ in 2022, which would represent nearly two-thirds of the estimated current global use.<sup>46</sup> In 2022, China's 14th Five-Year Plan for energy efficiency and green building development emphasised continued expansion of geothermal energy use for space heating.<sup>47</sup>

In **Türkiye**, reported geothermal heat use grew 3.8% annually on average during 2015-2019, and at that rate it may have reached at least 61 PJ in 2022.<sup>48</sup> For space heating alone, installed capacity grew from just over 1 GW in 2019 to 1.5 GW in 2020, suggesting even more robust growth recently.<sup>49</sup>

**Iceland** ranks third globally in the use of geothermal heat.<sup>50</sup> As of 2021, annual geothermal heat consumption was around 35 PJ, from an installed capacity of around 2.5 GW<sub>th</sub>.<sup>51</sup> Direct geothermal supply meets 90% of space heating demand in Iceland.<sup>52</sup> Available geothermal resources for direct use far exceed current utilisation.<sup>53</sup> Therefore, incremental use will be determined by population growth and increases in economic activity, with the exception of any new resources found in less geothermally active parts of the country where populations have relied on electricity for space heating (either geothermal or hydropower) or even fossil fuels.<sup>54</sup>

Geothermal heat developments in continental Europe are concentrated in a few areas where deep heat reservoirs exist. These include, in particular, southern regions of Germany (Bavaria), the Paris region of France and various locations in Hungary, Italy, the Netherlands and Poland. Project exploration and development continued in 2022 in many locations.

In the **Netherlands**, the production of geothermal heat increased 6% in 2022, with 31 geothermal project locations with an annual production capacity of 6.4 PJ.<sup>55</sup> Even though new boreholes are added each year, the local geothermal industry considers progress to be slow, hampered by permit processing, the rigors of the drilling process, and a lack of adequate heat distribution networks to households and greenhouses.<sup>56</sup> Political, financial and social barriers also limit project development, with public acceptance becoming a more pressing concern.<sup>57</sup> As of late 2022, 70 projects were in various stages of development, with 19 advancing towards commencing heat production.<sup>58</sup> By early

2023, a new Mining Act was expected to support geothermal activities, allowing a state-owned enterprise to financially participate in projects as a non-operating partner.<sup>59</sup>

Development of direct-use facilities in **France** continues in the Paris region (Île-de-France), as well as to the southwest in Aquitaine and to the east in Alsace.<sup>60</sup> Following the completion of three new geothermal facilities in the Paris suburbs in 2021, a new project was announced in 2022 for the municipality of Meudon. The plan is to displace 83% of the current gas-fired supply by 2026, to heat the equivalent of 7,600 homes.<sup>61</sup> The local distribution network also will be upgraded for greater efficiency and to accommodate the lower geothermal supply temperatures.<sup>62</sup>

In **Germany**, no new geothermal plants came online in 2022.<sup>63</sup> However, the national government laid out a roadmap for achieving a 10-fold increase in geothermal heat utilisation by 2030 (10 TWh per year), which would entail building 100 additional geothermal projects in that time frame.<sup>64</sup> In Bavaria, local authorities outlined plans to meet one-quarter of heat demand in buildings with geothermal supply by 2050, expanding district heat networks as needed to connect thermal loads with expanding production areas.<sup>65</sup> Understanding the resource availability is critical to further development, and to that end, estimates of heat reservoirs in Germany were updated, indicating 20% higher heat flow than previously understood.<sup>66</sup> Work was under way during the year to expand geothermal heat supply and distribution networks in the Munich area.<sup>67</sup>

In Vienna, **Austria**, the culmination of extensive research on the subsoil under the city paved the way for plans to commence exploratory drilling in 2023.<sup>68</sup> The city anticipates that the completion of its first geothermal plant in 2026 (estimated at 20 megawatts-thermal) would supply heat to 125,000 households.<sup>69</sup>

The high risk of failure in geothermal exploration led to some projects being put on hold. In **Switzerland**, drilling had begun at Lavey-les-Bains early in 2022 with hopes of completing the country's first hydrothermal project to produce both electricity and heat by 2023. While the technically challenging drilling was a success, it did not find sufficient flow of geothermal fluid to make the project viable.<sup>70</sup> In addition, two German projects met critical setbacks when drilling failed to find enough permeability and flow for commercial utilisation.<sup>71</sup>



Geothermal energy use can expand significantly, provided that dramatic cost reductions are achieved.



## KEY FACTS HEAT PUMPS

- Heat pumps are an established technology and met around 10% of the world's heating needs in buildings in 2022.
- Sales of heat pumps grew 11% globally in 2022, notably in Europe where they increased 38%, driven in part by the Russian Federation's invasion of Ukraine. In the United States, annual sales of heat pumps eclipsed fossil gas furnaces for the first time.
- Many countries experienced reductions in the upfront cost of heat pumps, which remains a significant barrier to deployment.
- In 2022, more than EUR 5 billion (USD 5.4 billion) of investment was announced in heat pump manufacturing facilities in Europe, while the United States earmarked USD 10 billion in tax credits for manufacturing, for which heat pumps are eligible.
- Poland is one of the world's fastest growing markets for heat pumps and solar photovoltaics (PV). Heat pump sales grew 120% in 2022, and Poland became the third largest solar PV market in the European Union.

Heat pumps are widely used to meet heating and cooling demands in residential, commercial and industrial applications. On an appliance level, heat pumps can provide heat more efficiently than conventional heating technologies.<sup>1</sup> This is because, rather than “producing” thermal energy (for example, through combustion), heat pumps use a refrigeration cycle to draw heat from a lower-temperature ambient source to a higher-temperature destination. Heat pumps use an external energy source, typically electricity, to drive this cycle, “pumping” around 3-4 units of heat per unit of electricity.<sup>2</sup>

Common sources of ambient energy include the outside air, the ground and bodies of water. **Air-source heat pumps** are the most widespread, accounting for around 85% of the heat pumps in buildings worldwide.<sup>3</sup>

Whether or not heat pumps are a “renewable” technology is under debate. On the one hand, they always harness a source of renewable energy, whether it is the ambient air, water or even waste heat. However, the energy that powers the units, typically electricity, is not necessarily renewable and is frequently based on fossil fuels. The ratio of renewable heating and cooling provided by heat pumps is therefore limited by the auxiliary energy; if this energy is renewable, so is the full output of the heat pump.

In markets such as Japan and the EU, and to some extent the Republic of Korea, heat supplied by heat pumps is credited as renewable, making the units eligible for support under certain renewable energy policy schemes.<sup>4</sup> In 2022, China classified heat pumps as a renewable energy technology at the national level for the first time.<sup>5</sup>

Although heat pumps are widely available and have been a common technology for decades, they represent only a small share of the global heating market. In 2021, heat pumps accounted for less than 10% of heating equipment sales globally, whereas fossil fuel-based devices represented 45% of sales.<sup>6</sup>

### ANNUAL ADDITIONS AND LEADING COUNTRIES

The global market for heat pumps is concentrated mainly in countries with colder climates, such as China, Japan, the United States and parts of Europe. However, countries with warmer climates also install heat pumps, given that the units can be reversible, moving heat from the interior to the exterior rather than vice versa. Because heat pumps also can provide cooling, their growing global deployment is attributed in part to rising demand for space cooling.<sup>7</sup> Worldwide, the heat pump market grew an estimated 11% in 2022, the second consecutive year of double-digit growth.<sup>8</sup>

**China** is the world's leading installer of heat pumps. Its heat pump market remained largely stable in 2022 as the country continued to grapple with economic recovery from the COVID-19 pandemic.<sup>9</sup> Increasingly, **ground-source heat pumps** are being deployed in China to replace coal-fired furnaces.<sup>10</sup>

The **United States** also is a large heat pump market. Air-air systems are most common in the country, with buildings often using ductwork to distribute the heat from the device to the targeted space. In 2022, the US heat pump market grew 11% to reach a record 4.3 million units shipped.(→ See Figure 19.)<sup>11</sup> For the first time, US annual heat

pump sales eclipsed annual sales of gas boilers, although sales of both devices have been rising.<sup>12</sup> State and local policies have driven heat pump sales, even before federal legislation came into force.<sup>13</sup>

Heat pump sales in **Europe** also have risen dramatically. In 2022, sales increased 38% to reach a record 3 million units.<sup>14</sup> This was on top of a 34% market increase in 2021, vastly exceeding the roughly 10% growth of prior years.<sup>15</sup> France was again Europe's leading market, with sales of around 600,000 units corresponding to a market growth of 20%.<sup>16</sup> Sales grew 37% in Italy and 58% in Germany, the region's two other large markets.<sup>17</sup>

Notable growth also occurred in Europe's emerging markets. Poland experienced the largest overall expansion globally (first in percentage growth and second in absolute sales) with more than 200,000 units sold in 2022.<sup>18</sup> (→ See *Snapshot: Poland*.) Markets doubled in Belgium and the Czech Republic, although starting from a much smaller base.<sup>19</sup> **Air-to-water heat pumps** are most common in Europe, comprising around half of all units sold.<sup>20</sup>

In Europe, the Russian Federation's invasion of Ukraine was a key driver of heat pump uptake in 2022. A dramatic rise in energy prices, notably fossil gas for heating, led many consumers to look towards heat pumps to reduce their gas demand.<sup>21</sup> Also contributing to market expansion was the growing number of countries with policies mandating the phase-out or restriction of fossil fuel heating in buildings, with the expectation that an EU Directive would eventually require this.<sup>22</sup> Mandates restricting fossil fuel use in new buildings are increasingly common in the United States as well, although they have faced backlash.<sup>23</sup>

### HEAT PUMP APPLICATIONS AND TRENDS

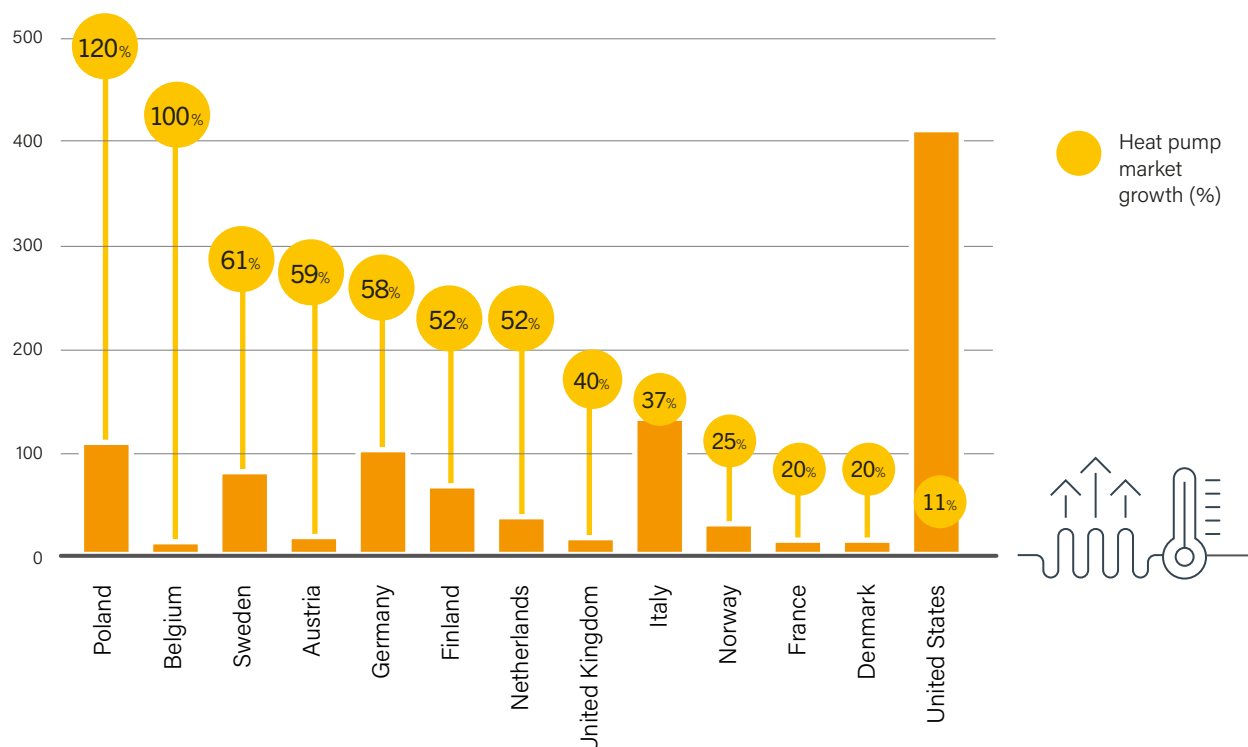
Heat pumps are most commonly deployed in buildings to heat space and water. As of 2021, heat pumps met an estimated 10% of the world's heating demand in buildings.<sup>24</sup>

In addition to providing direct heat in buildings, heat pumps are increasingly used to meet low-temperature needs in industrial processing. Heat pumps provide energy for various purposes in food and beverage production, paper manufacturing, and chemical production, typically supplying process heat up to 100°C.<sup>25</sup> In some industries, commercial applications have achieved temperatures of 140-160°C, and as of 2022 high-temperature industrial heat pumps reaching 200°C were in the precommercial stage.<sup>26</sup> In Europe and the United States, industries have turned increasingly to heat pumps to reduce dependence on fossil fuels.<sup>27</sup> Manufacturers have announced massive models of up to 120 MW in capacity to generate process steam for the chemical industry.<sup>28</sup>

Heat pumps also supply thermal energy for district heating networks.<sup>29</sup> Unlike for household applications, the most common systems for district heating are water-source and ground-source heat pumps, drawing on wastewater or industrial waste heat as the energy source.<sup>30</sup> In 2022, large-scale heat pumps advanced in Austria (based on wastewater), Finland (wastewater and seawater), Germany (river water from the Rhine; Europe's largest heat pump at 40 MW), the Netherlands (wastewater) and Sweden.<sup>31</sup> Two projects under discussion in Serbia would use heat pumps based on wastewater to heat district energy networks.<sup>32</sup>

**FIGURE 19.**  
**National Heat Pump Markets with the Largest Growth in 2022**

Annual growth in heat pump sales (additional units sold in thousands)



Source: See endnote 11 for this section.

# SNAPSHOT POLAND



## Heat Pumps Grew Rapidly in Poland in 2022

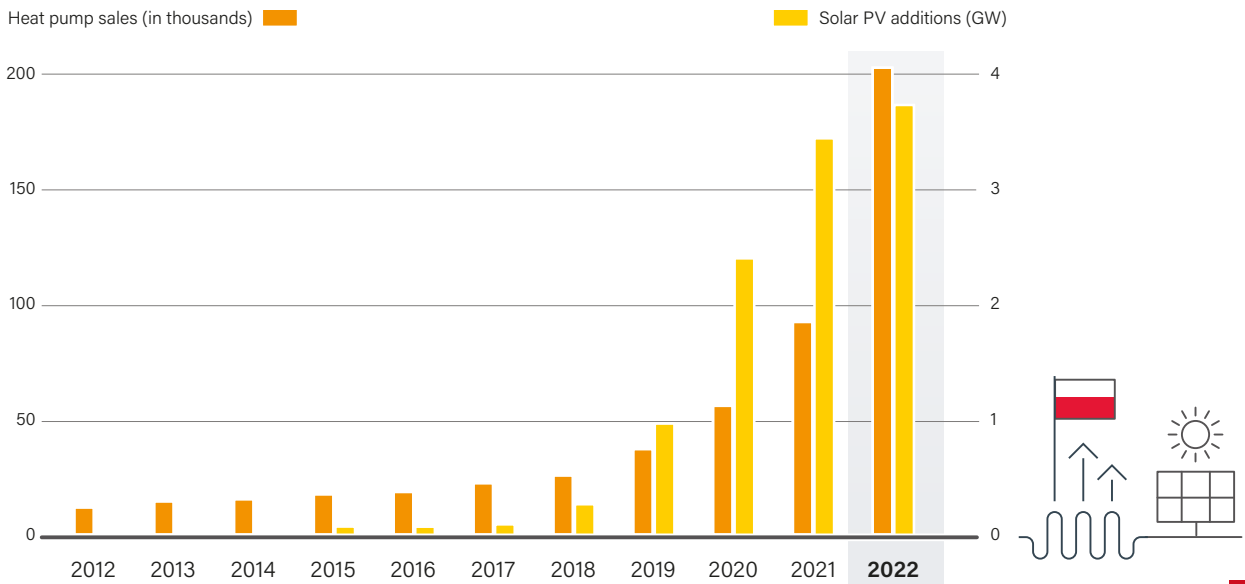
Amid a surging European heat pump market, Poland experienced the world's fastest growth in heat pumps in 2022. Sales of heat pumps in Poland grew 120% compared to 2021. Nearly a third of all new heating systems in Poland were heat pumps in 2022, and the country became the EU's fifth largest market in absolute terms.

Poland's heat pump market has been on the upswing for several years. The number of units sold has increased from around 12,000 in 2012 to more than 200,000 in 2022. The rapid market growth began in 2018 following the reform of an air pollution law that increased financial support for heat pumps to replace coal-fired heating systems. Notably, Poland is one of the only European countries to provide renewable heating subsidies adjusted to household income.

Heat pumps are not the only energy technology to experience rapid growth in Poland. Solar PV markets also have skyrocketed, with Poland becoming the EU's third largest market in 2022. (→ See Figure 20.) The Russian Federation's invasion of Ukraine also resulted in support for solar PV in 2022, with natural gas and coal prices increasing substantially and consumers eager to avoid buying Russian gas.



**FIGURE 20.**  
Sales of Heat Pumps and Additions of Solar PV in Poland, 2012-2022



Source: See endnote 18 for this section.



Notable trends in the **heat pump industry** in 2022 included significant investments in manufacturing spurred by the global energy crisis and the Russian invasion of Ukraine, more competitive costs, use of operating heat pumps as a source of flexibility, and efforts to lower the life-cycle emissions of units.

Numerous firms across the heat pump value chain announced new manufacturing facilities during 2022. Most of these projects are in Europe and are expected to be completed by 2025, boosting the region's heat pump production capacity; in total, projects representing more than EUR 5.5 billion (USD 5.9 billion) were announced.<sup>33</sup> Daikin Europe accounted for more than a quarter of this sum, investing around EUR 1.2 billion (USD 1.3 billion) in its European sites.<sup>34</sup> Vaillant announced an investment of EUR 130 million (USD 139 million) in 2022 and opened a new factory in early 2023 that can produce more than 500,000 heat pumps annually.<sup>35</sup> Stiebel Eltron announced an investment of EUR 600 million (USD 640 million) to triple its production by 2025.<sup>36</sup>

Additional investment announcements came from BDR Thermea, Bosch, Ecoforest, Groupe Atlantic, Hoval, NIBE, Midea Group and Panasonic.<sup>37</sup> Many heat pump component manufacturers also pledged new investments.<sup>38</sup> The US Inflation Reduction Act of 2022 earmarked USD 10 billion in tax credits for clean energy manufacturing as well as USD 500 million in grants for manufacturing facilities.<sup>39</sup> In early 2023, LG Electronics announced that it would open its first heat pump manufacturing facility in the United States.<sup>40</sup>

The **cost of heating** with a heat pump depends on both upfront and ongoing costs. In most markets, the upfront costs for equipment and installation remain a barrier to adoption. Depending on the region, installing a heat pump can be much more expensive than installing a fossil-based heating technology.<sup>41</sup> Despite this, many countries have seen reductions in the upfront costs of heat pumps.<sup>42</sup> Policies to reduce such costs, especially for low-income households, are important for wider adoption of the technology.<sup>43</sup>

The operational costs of heat pumps vary by country, and their competitiveness with fossil fuel technologies depends on an array of factors. In jurisdictions where fossil gas and oil are much cheaper than electricity, even the high efficiency of heat pumps cannot compensate for ongoing costs.<sup>44</sup> This is often exacerbated by energy taxation regimes that place heavy burdens on electricity.<sup>45</sup> Denmark, Germany, the Netherlands and the United Kingdom have begun reforming their tax regimes to favour electric heating, especially with heat pumps.<sup>46</sup> Other countries have reformed tariffs to further incentivise heat pumps.<sup>47</sup>

Despite ongoing cost barriers, many households that switched to heat pumps from existing fossil fuel boilers saw savings on their energy bills.<sup>48</sup> In Canada, Germany, the Republic of Korea, and the United Kingdom, the levelised cost of heating was competitive with a fossil gas boiler alternative during 2022.<sup>49</sup>

Switching to heat pumps typically reduces greenhouse gas emissions, but the use of conventional refrigerants (fluorinated gases, or f-gases) in these systems can contribute potent greenhouse gases if released to the atmosphere.<sup>50</sup> In Europe, efforts to phase out these refrigerants have led to discussions on alternatives with lower global warming potentials, such as propane or carbon dioxide (CO<sub>2</sub>). However, some alternatives may have environmental hazards and complicated or expensive operating and installation conditions that hamper their use.<sup>51</sup>

In early 2023, the European Parliament adopted a proposal to phase out f-gases by 2050, and while the heat pump industry supports the goal, it has expressed concerns about proposed short-term bans affecting production capacity.<sup>52</sup> Previous international environmental agreements, such as the Kigali Amendment to the Montreal Protocol, fostered the transition to many refrigerants with lower global warming potentials that are currently in use. As the heat pump industry evolves, the biggest competitive challenge will be the ongoing use of relatively inexpensive fossil fuels for heating.<sup>53</sup>

In many countries,  
operating a heat pump  
is already

**cheaper**

than a fossil fuel heating  
system.



i These declines can largely be attributed to economies of scale in both manufacturing and installation due in part to widespread uptake and technology improvements. See endnote 42 for this section.



## KEY FACTS HYDROGEN

- Despite the rapid scale-up of electrolysis plants to 510 MW by the end of 2021 – up by 210 MW or 70% relative to 2020 – the demand for hydrogen is still being met almost entirely (around 95%) by hydrogen produced from fossil fuels.
- More than 393 deals related to hydrogen were closed in 2022, up significantly from the 277 deals registered in 2021.
- Realisation of all of the projects in the hydrogen pipeline could lead to an installed electrolyser capacity of 134-240 GW by 2030, with the lower end of the range similar to the total installed renewable capacity in Germany and the upper end similar to the capacity in all of Latin America.
- Australia has the largest number of announced renewable hydrogen plants among countries.
- Governments continue to consider hydrogen a pillar of their energy sector strategies, with around 30 countries having national hydrogen strategies as of 2022.

Renewable (often referred to as green) hydrogen is rapidly emerging as a key enabling technology with significant potential to decarbonise various sectors, in line with global efforts to meet net zero emission targets. Renewable hydrogen is hydrogen produced using renewable energy sources<sup>i</sup> via electrolysis, a process that splits water molecules into hydrogen and oxygen. The hydrogen can be stored<sup>ii</sup>, transported, or used on-site as a clean and flexible fuel for a wide range of applications. Interest has grown in using renewable hydrogen as a means to reduce emissions in hard-to-abate sectors such as heavy industry.

The potential uses of renewable hydrogen are diverse, ranging from fuel for long-haul trucking and shipping, to feedstock for industrial processes such as steel and cement production, to serving as a carrier for electricity generation.<sup>1</sup> However, renewable hydrogen faces several key challenges that hinder its rapid upscaling. These include high conversion losses (with 20-30% of the energy lost through electrolysis), high upfront production costs and the need for significant investments in infrastructure such as pipelines and storage facilities.<sup>2</sup> Nevertheless, governments and industries are increasingly recognising the potential of renewable hydrogen and committing large resources to its development.<sup>3</sup>

### RENEWABLE HYDROGEN PRODUCTION FACILITIES

Currently, the global demand for hydrogen is met almost entirely (around 95%) with hydrogen produced from fossil fuels.<sup>4</sup> In 2022, despite the slowing global economy, worldwide hydrogen production capacity exceeded an estimated 100 million tonnes, up from 94 million tonnes in 2021 and 91 million tonnes in 2019.<sup>5</sup> Renewable hydrogen production, however, totalled only 109 kilotonnes in 2022, although this was a 44% increase from the 2021 level (35 kilotonnes).

Enabling the growth in hydrogen production was the rapid scale-up of electrolysis plants to 510 MW in 2021, an increase of 210 MW, or 70%, compared to 2020.<sup>6</sup> Electrolyser manufacturing capacity doubled between 2017 and 2022 to nearly 8 GW, as successful pilot and demonstration projects advanced to commercial-scale projects.<sup>7</sup> The average size of new electrolysers in 2021 was 5 MW, but this could reach 260 MW in 2025 and in the GW-scale by 2030.<sup>8</sup>

In 2022, more than 112 million tonnes of new low-carbon hydrogen capacity was announced, mainly in the United States, Denmark, Egypt, Canada and Portugal.<sup>9</sup> In total, more than 393 deals related to hydrogen were closed, up from 277 deals in 2021, showing an upward trend in low-carbon hydrogen market development.<sup>10</sup> **Australia** had the largest number of announced renewable hydrogen plants worldwide as of 2022; due to its abundant solar and wind resources, the country is expected to see some of the lowest levelised costs for producing renewable hydrogen by 2050.<sup>11</sup>

i The definition of renewable energy sources is still under debate. For example, France is pressing the EU to acknowledge nuclear as a renewable energy source, given the dominance of nuclear power in the country's energy mix.

ii Hydrogen is an energy carrier, not an energy source, and can deliver or store a tremendous amount of energy. Hydrogen can be used in fuel cells to generate electricity, or power and heat.

In 2022, higher costs for key elements of renewable hydrogen projects resulted in part from global supply chain issues (related to geopolitical instability in Europe) and from rising global demand for solar PV and electrolyzers.<sup>12</sup> At this early development stage of the clean hydrogen industry globally, costs of renewable hydrogen production vary depending on the scale and size of the project as well as on how nearby the production is to where the hydrogen will be used. In 2022, hydrogen produced through electrolysis using renewable power cost an estimated USD 5-10 per kilogram.<sup>13</sup>

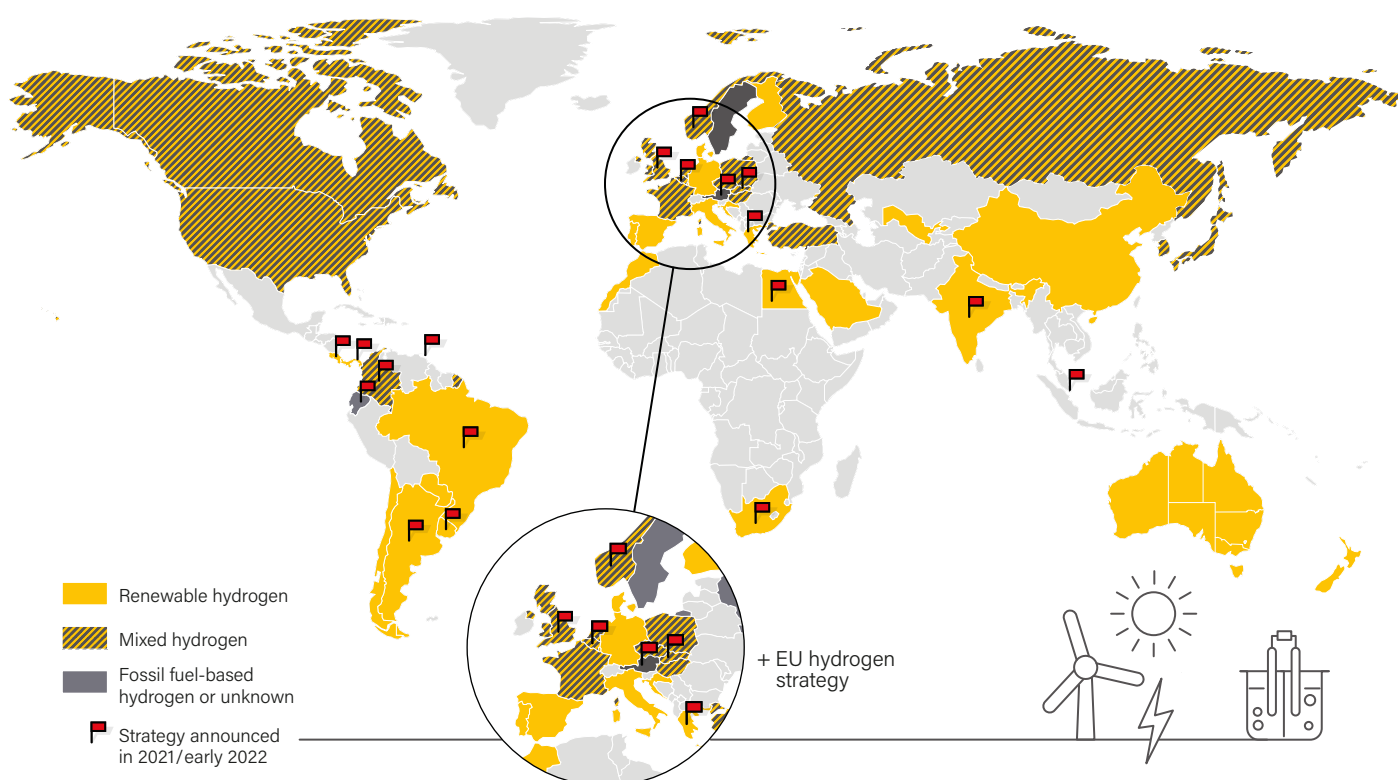
Hydrogen strategies are being developed and implemented worldwide, with leading players in Asia, North America, Australia and the EU.<sup>14</sup> (→ See Figure 21.) Each region has its unique approach to hydrogen deployment, depending on factors such as national energy policies, natural resources and infrastructure.

**Japan** was the first country globally to formulate a national hydrogen strategy, in 2017, as part of its ambition to become the world's first "hydrogen society" by adopting green hydrogen across all sectors.<sup>15</sup> A key pillar in the strategy is developing

long-term supply agreements to import hydrogen from overseas, given Japan's shortage of the natural resources necessary to deploy wind and solar energy at scale. Despite its ambitious and visionary plan, Japan has performed far below its goal of increasing uptake of hydrogen fuel cells and fuel cell vehicles, and the hydrogen stations built across the country have seen little use.<sup>16</sup> As of early 2023, Japan faced challenges in scaling up hydrogen production and use due to high costs and lack of infrastructure.<sup>17</sup>

**China** was the largest producer of hydrogen in 2022, at around 25 million tonnes, and is exploring the production and use of lower-emission hydrogen to help meet energy needs and spur industrial development while also addressing climate concerns.<sup>18</sup> The Chinese government has laid out a medium- and long-term development plan for hydrogen (2021-2035), with the goals of bringing 50,000 fuel cell electric vehicles on the road by 2025; producing green hydrogen using renewables to reach 100,000 to 200,000 tonnes annually by 2025; and using clean hydrogen in energy storage, electricity generation and industry.<sup>19</sup>

**FIGURE 21.**  
Hydrogen Strategies and Roadmaps in Selected Countries, as of End-2022



Source: See endnote 14 for this section.

Note: The type of hydrogen (renewable, mixed, fossil fuel-based) is unknown for Austria, Ecuador, Sweden, and Trinidad and Tobago. The Russian Federation plans to produce hydrogen from nuclear and renewable sources, but currently natural gas is the main source for hydrogen production. Mixed refers to hydrogen produced from both renewable and non-renewable energy sources. Austria, Singapore, Türkiye and Uruguay's hydrogen strategies are currently in preparation. Type of hydrogen production in Austria, Ecuador, Sweden, and Trinidad and Tobago is unknown.

In **India**, the prime minister has stated that renewable hydrogen could enable a “quantum leap” towards energy independence for the country by 2047.<sup>20</sup> In 2021, India announced a National Hydrogen Energy Mission to develop a roadmap for using hydrogen as an energy source; the aims are to create a global hub for the manufacturing of hydrogen technologies; to facilitate demand creation in industry (such as fertilisers, steel and petrochemicals); and to demonstrate the use of hydrogen in transport applications.<sup>21</sup>

In 2020, the **European Commission** adopted its overarching “hydrogen strategy for a climate-neutral Europe”.<sup>22</sup> The strategy aims to support the deployment of clean hydrogen in various sectors, including industry, transport, and power generation, as part of EU efforts to achieve climate neutrality by 2050.<sup>23</sup> A key aspect of the EU strategy is leveraging partnerships and collaboration at the regional and global levels, as illustrated in 2022-2023 through the Mediterranean hydrogen pipeline project and the Japan-EU partnership for the exchange of information and research.<sup>24</sup> In 2023, the EU (with 28%) and Japan (24%) were the global leaders in patent filings related to hydrogen.<sup>25</sup>

**Germany’s** National Hydrogen Strategy intends to expand the role of hydrogen to decrease national dependence on coal.<sup>26</sup> The government plans to invest USD 7.5 billion to achieve a hydrogen production capacity of 5 GW by 2030 and another 5 GW during 2035-2040, allowing exemption from the green power surcharge (EEG levy); it will also leverage partnerships with 31 potential net exporters and across the EU through a USD 2.1 billion fund to establish international trade partnerships.<sup>27</sup> In 2022-2023, Germany signed a landmark agreement with Denmark, the largest deal of its kind to date, to build a 1 GW electrolysis plant in Denmark that will produce green hydrogen using offshore wind power, at a total project cost of USD 32.6 billion.<sup>28</sup>

In 2020, **France** announced its strategy for the development of decarbonised hydrogen, aiming to invest USD 7.5 billion in green hydrogen production and infrastructure, with the goal of reducing greenhouse gas emissions 6 million tonnes by 2030.<sup>29</sup> Given the contribution of nuclear power plants to France’s energy mix, the country has been pushing for the EU to recognise low-carbon hydrogen produced from nuclear power in its renewable energy rules; however, some EU Member States worry that this would undermine efforts to rapidly scale up wind and solar.<sup>30</sup>

**Spain** released a strategy in 2020 that provides a vision for developing a favourable environment for the supply and demand of renewable hydrogen.<sup>31</sup> Key milestones of the strategy are commissioning 300-600 MW of electrolyzers by 2024 and 4 GW by 2030, and reducing 4.6 million tonnes of CO<sub>2</sub> emissions, through mobilising USD 9.6 billion of investments.<sup>32</sup> In February 2022, four grant programmes totalling USD 267 million were deployed to address innovation in the hydrogen value chain. This included USD 108 million for large electrolyzers, USD 86 million for piloting fuel cell electric vehicles, USD 43 million for industrial and experimental research, and USD 32 million for capacity building. Spain is expected to become a key player in hydrogen economy in the short- and medium-term, considering the country’s industry investment, collaboration with Mediterranean countries and ample solar resource for producing green hydrogen.<sup>33</sup>

In North America, the **United States** released its draft National Clean Hydrogen Strategy Roadmap in late 2022. The plan sets out three key priorities: targeting strategic, high-impact uses of hydrogen; reducing the cost of clean hydrogen to USD 1 per kilogram by 2031; and deploying at least four regional clean hydrogen hubs through an unprecedented USD 7 billion in funding.<sup>34</sup> The United States is the world’s second biggest producer and consumer of hydrogen after China, accounting for 13% of global demand.<sup>35</sup> The Infrastructure Investment and Jobs Act of 2021 contained a USD 9.5 billion budget to boost clean hydrogen development, and the subsequent Hydrogen Earthshot programme, through its “111 goal”, aims to cut the cost of clean hydrogen to USD 1 per 1 kilogram in 1 decade.<sup>36</sup>

**Australia** released its green hydrogen strategy in 2019, laying out a comprehensive plan to position the country as a major global player in the hydrogen industry by 2030. The strategy aims to develop a clean, innovative, safe and competitive hydrogen industry that delivers significant economic, social, and environmental benefits, with a set of ambitious targets. Gigawatt-scale project ambition is on the rise in Australia, with 11 GW-scale hydrogen projects in the pipeline in 2022 and 9 more announced (either new or existing projects).<sup>37</sup> The Australian government is providing USD 526 million (AUS 800 million) towards the establishment of eight hydrogen hubs through the Regional Hydrogen Hubs programme and other commitments, including nine feasibility studies to support potential future hydrogen hubs.<sup>38</sup>

As of 2022, almost  
**95%**  
of global hydrogen  
production was from  
fossil fuels.



**Brazil** published a resolution in 2022 establishing the National Hydrogen Program (PNH2), which aims to promote the development of a competitive hydrogen market in the country.<sup>39</sup> The programme seeks to encourage the production, distribution and use of hydrogen as a clean energy source, with a focus on renewable hydrogen. The renewable hydrogen segment in Brazil started to grow in 2022 with the installation of the country's first industrial-scale renewable hydrogen production plant, completed in May by Unigel.<sup>40</sup> The system includes three 20 MW electrolyzers supplied by Thyssenrupp Nucera, with a second phase expected to expand the project's capacity beyond 100 MW.<sup>41</sup>

**Chile's** national strategy was released in 2020 and has three main strategic pillars: commissioning 5 GW of electrolysis by 2025, ensuring the most competitively priced green hydrogen in the world by 2030 and becoming among the world's top exporter of green hydrogen by 2040.<sup>42</sup> The Haru Oni project, led by the company Highly Innovative Fuels, was successfully commissioned in 2022 and entails building a hydrogen-based fuel production plant in Magallanes, South

Chile.<sup>43</sup> The project will produce hydrogen, e-methanol and e-petrol powered by 3.4 MW wind turbines.<sup>44</sup> Expected annual production is 350 tonnes of crude methanol, 130,000 litres of petrol and 16 tonnes of carbon-neutral liquefied gas.<sup>45</sup>

### HYDROGEN TRADE ROUTES

As the global demand for green hydrogen continues to rise, an expanding network of hydrogen trade routes, plans and agreements is taking shape, fostering international collaboration and highlighting key importers and exporters.<sup>46</sup> Main importing regions, such as Europe, Japan, and the Republic of Korea, are driven by ambitious climate goals, industrial requirements, and limited domestic renewable energy sources to meet their green hydrogen needs. On the other hand, countries with abundant renewable energy potential – such as Australia, Chile (→ see *Snapshot: Chile*), and countries in the Middle East and North Africa – are emerging as potential key exporters, aiming to capitalise on the growing hydrogen market.<sup>47</sup>



## SNAPSHOT CHILE

### A Hidden Hydrogen Champion is Awakening

A notable player in the emerging global hydrogen trade is Chile, which is focusing on public-private partnerships as a key mechanism to accelerate the country's energy transition. Chile has signed several international agreements with foreign countries to strengthen its hydrogen industry. In 2021, Chile signed a joint agreement with Germany with the aim of enhancing co-operation in green hydrogen project development. The two countries will exchange experience and knowledge through the creation of a working group, and will also establish a regulatory framework. A further aim is to develop low-carbon certification systems.

A joint agreement between Chile and the Netherlands aims to establish green hydrogen import-export corridors. It also seeks to align the investment agenda and to improve the collaboration of private companies. In addition, Chile signed a memorandum of understanding with Belgium to enhance green hydrogen production in co-operation with the ports of Antwerp and Zeebrugge, which aim to become the main hubs for hydrogen imports to Europe. In Asia, Chile signed a memorandum of understanding with the Republic of Korea to expand co-operation in the low-carbon hydrogen sector and to exchange technologies for producing, storing, transporting and using clean hydrogen.

Source: See endnote 47 for this section.





 KEY FACTS  
**HYDROPOWER**

- Global installed hydropower capacity reached 1,220 GW in 2022, up 22.2 GW from 2021.
- China grew its lead in installed hydropower capacity, bringing the total to 368 GW in 2022, more than in Brazil, Canada, the United States and the Russian Federation combined.
- Hydropower generation reached 4,429 TWh in 2022, half of it produced by only four countries (China, Brazil, Canada and the United States).
- European hydropower production dropped 19% in 2022 due to extreme drought.
- Hydropower provides crucial services including load following, grid support and caseload electricity; in areas where hydroelectric production has declined due to drought, in some cases coal has been used to supplement these services.

Global hydropower markets added at least 22.2 GW in 2022, for a total installed capacity of 1,220 GW.<sup>1</sup> Generation increased 5% over 2021 to reach 4,429 TWh.<sup>2</sup> However, as in 2021, the capacity added in 2022 was well below the estimated 30 GW of hydropower additions that are needed annually to keep global temperature rise below 2°C by 2050.<sup>3</sup> In 2022, hydropower represented 37% of the world’s total installed renewable energy capacity and added 2% of the total capacity of all renewables.<sup>4</sup>

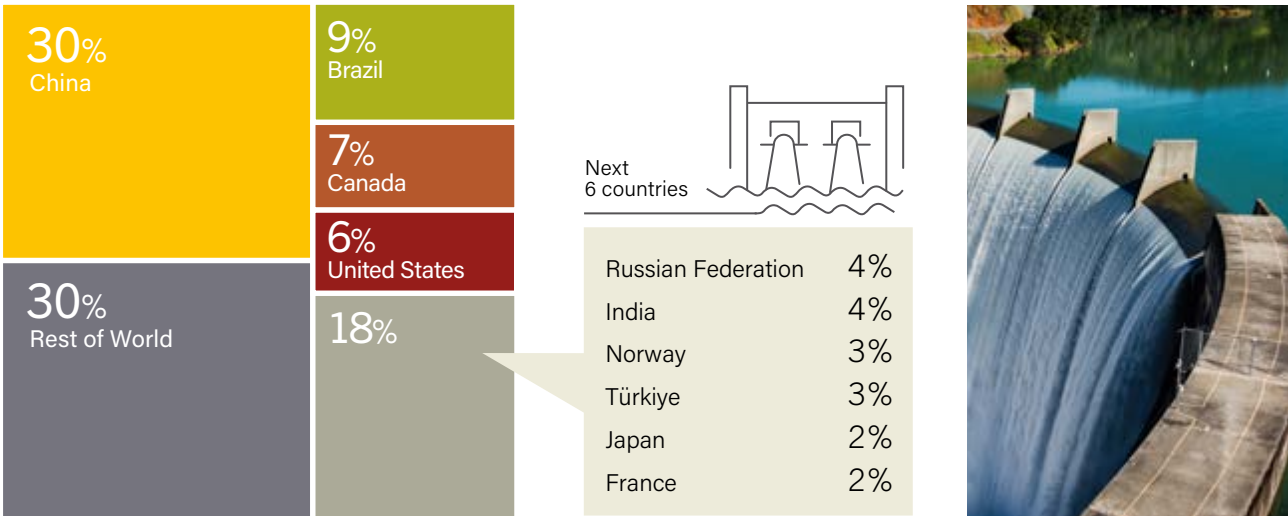
Fluctuating water levels, related in part to climate change, have raised concerns about hydropower infrastructure and the development of future facilities and storage. Africa, Asia, Europe and North America all experienced severe droughts in 2022, reducing water supplies and the capacity use of plants.<sup>5</sup> In the Zambezi river basin between Zambia and Zimbabwe, the 2.13 GW Kariba reservoir (the world’s largest) dropped to 0.97% of its usable storage in December 2022, leading to power rationing and outages.<sup>6</sup> Many drought-stricken areas have turned to coal to supplement power needs.<sup>7</sup> Climate change also could alter seasonal production, causing snowy regions to produce more hydropower in winter as rain replaces snow, and less power in spring and summer due to reduced snowmelt.<sup>8</sup> (→ See Sidebar 2.)

As with solar PV and wind, China dominated the global hydropower market in 2022, with a total installed capacity exceeding that of the next four leading countries combined (Brazil, the United States, Canada and the Russian Federation).<sup>9</sup> (→ See Figures 22 and 23). The top four countries in hydropower generation (China, Brazil, Canada and the United States) produced more than the rest of the world combined.<sup>10</sup> Developing countries continued to lead in shares of hydropower in the energy mix, with Costa Rica generating 73% of its electricity from hydropower, and Venezuela, the world’s tenth largest producer, generating 68 TWh.<sup>11</sup>



i Hydropower capacities exclude pumped storage, which serves as energy storage, not as an energy source.

**FIGURE 22.**  
Hydropower Global Capacity, Shares of Top 10 Countries and Rest of World, 2022

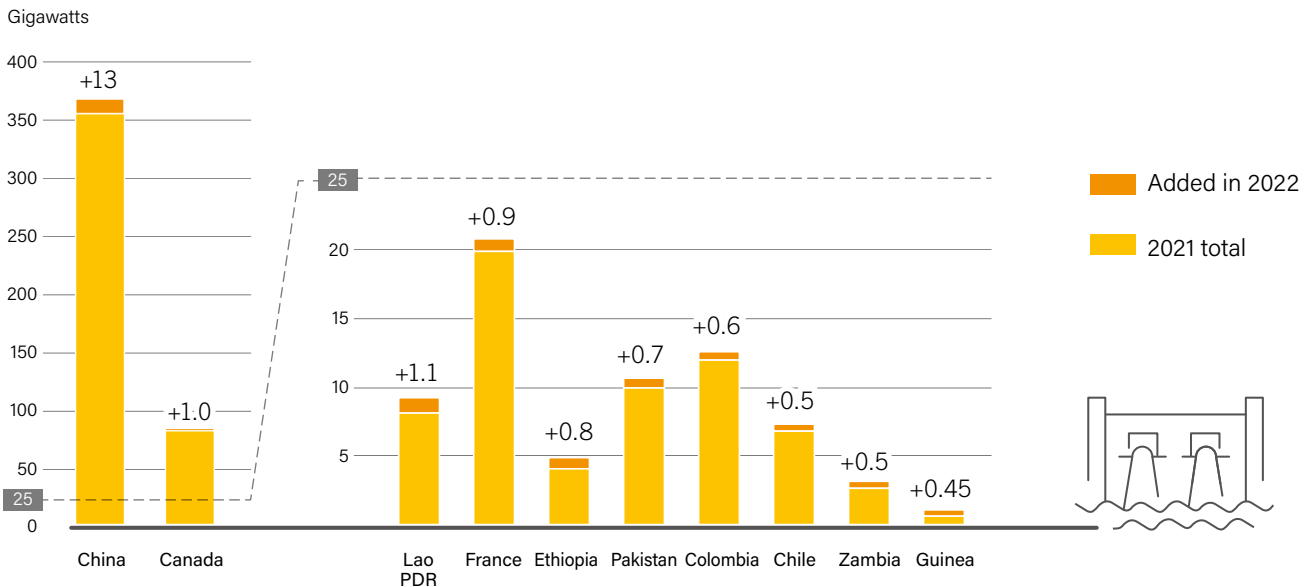


Source: See endnote 9 for this section.

During 2001-2020,  
**China**  
invested a total of  
USD 29.9 billion in  
hydropower projects  
globally.



**FIGURE 23.**  
Hydropower Global Capacity and Additions, Shares of Top 10 Countries, 2022



Source: See endnote 9 for this section.

**China** expanded its hydropower capacity lead, adding 13 GW in 2022 to reach a total installed capacity of 368 GW.<sup>12</sup> The country is home to the world’s largest hydropower facilities and completed several massive projects during the year, including six along the Yangtze River and the last turbines of the 16 GW Baihetan Hydropower Station, the largest since the Three Gorges Dam.<sup>13</sup> Heavy rainfall boosted hydropower generation in South China by 18% in the first five months of 2022, reflecting a recent trend of heightening flood seasons maxing out generation capacities; this helped bring the country’s total annual generation to 1,352 TWh.<sup>14</sup> Conversely, the Yangtze River registered record low water levels, posing a threat to Sichuan Province, which receives 80% of its energy from hydropower.<sup>15</sup>

Through its Belt and Road Initiative, China is the owner or investor in diverse infrastructure projects across Africa, Asia, Latin America, and Oceania, having signed memoranda of understanding with around 150 countries.<sup>16</sup> During 2001-2020, China invested a total of USD 29.9 billion in hydropower projects globally, plus another USD 2.5 billion in related transmission and distribution.<sup>17</sup> Overall, at least 38 GW of Belt and Road Initiative hydropower projects are either in operation or under construction, with another 11 GW planned.<sup>18</sup> While such projects have injected capital outside of China, they reportedly have been prone to construction flaws and operational failures, and some have led to displacement of local communities.<sup>19</sup>

**Brazil** ranked second globally in hydropower installed capacity and generation, although it only added just over 300 MW in 2022.<sup>20</sup> Favourable rain conditions boosted production 17% in the country.<sup>21</sup> In total, Brazil generated 92% of its overall electricity

from renewables during the year, and hydropower contributed 78% of the renewable energy production.<sup>22</sup>

**Canada** remained third in both total hydropower installed capacity as well as hydroelectric generation.<sup>23</sup> The country continues to be a leader in added capacity and brought online 1 GW of projects in 2022, including the 245 MW Romaine 4 hydroelectric plant in Québec.<sup>24</sup> Hydro-Québec, a public utility that oversees 37 GW of hydropower and thermal projects in Canada, signalled that it would halt adding hydropower capacity going forward, citing long project timelines and large upfront capital requirements.<sup>25</sup>

In the **United States**, the world’s fourth largest producer of hydropower, generation increased 4% in 2022 to reach 262 gigawatt-hours (GWh), representing 6.2% of the country’s energy mix.<sup>26</sup> The decades-long megadrought in the US west continued to affect generation in the first half of 2022.<sup>27</sup> The Western Area Power Administration, with around 10 GW of installed hydropower capacity, recorded only 65.7% of average generation during the 2022 fiscal year, attributing the decline to “negligible” snowpack.<sup>28</sup> However, levels rebounded in the second half of 2022 and into 2023 as the Sierra Nevada mountains and the Colorado River Basin experienced heavy snowfall.<sup>29</sup> Overall, generation across California, Oregon and Washington state grew 14.2% in 2022 to 129,918 TWh, representing 49.6% of the US total.<sup>30</sup>

In 2022, 14.2 MW of small hydropower plants came online in the United States, while 8.4 MW were retired.<sup>31</sup> As of the end of 2022, 351 MW of total hydropower was planned or under construction in the country.<sup>32</sup> The US installed hydropower capacity was stagnant for the year, at 80 GW.<sup>33</sup>



i Snowpack refers to the measure of compacted snow from the previous winter. The run-off water from the snowpack feeds into rivers and streams, contributing to higher water levels in spring and summer.



## SIDEBAR 2. Standardising Sustainability in the Hydropower Sector

As the world's oldest renewable energy technology and the largest source of renewable electricity to date, hydropower continues to face challenges related to sustainability – especially large-scale hydropower<sup>i</sup>. Factors contributing to the social and environmental impacts of hydropower include the sourcing of construction materials, disruption of ecosystems from dams and reservoirs, methane production from decomposing organic material in flooded areas, and the displacement of communities, among others.

Hydropower requires far fewer minerals and precious metals than other renewable energy technologies, but it still depends on copper, chromium, zinc and aluminium for plant operations. Because hydroelectric plants serve as both energy production and infrastructure projects, their construction and maintenance rely heavily on cement and steel. Materials contribute just over 30% of the greenhouse gas emissions from hydropower projects, typically releasing around 43 grams per kilowatt-hour (kWh,) but at times reaching 2,200 grams per kWh.

The majority of emissions from hydropower come from sedimentation and the anaerobic decomposition of organic materials in reservoirs, especially in areas with dense vegetation such as the Amazon. Methane emissions from reservoir hydropower projects can reach 88 grams per kWh, or up to 70% of total life-cycle emissions. Overall, global emissions from hydropower totalled 103 million tonnes of CO<sub>2</sub> equivalent in 2022.

In the past, financing for renewable energy projects through green bonds has excluded hydropower because of unclear sustainability criteria. In 2021, however, the Climate Bonds Standard began registering green bonds to finance hydropower projects characterised by low emission intensity and high power density<sup>ii</sup>. To enable access to green bond financing under the Climate Bonds Standard and promote involvement, the Swiss government's Hydropower Sustainability ESG Assessment Fund, open from 2020-2024, is awarding CHF 1 million (USD 1.07 million) to evaluate global hydropower projects' environmental, social and governance performance. As of 2023, at least USD 150 million worth of certified bonds and loans had been issued under the criteria.

However, hydropower projects pose broader sustainability impacts than those covered in these criteria, contributing to biodiversity loss, erosion, and habitat destruction, among other impacts. Life-cycle assessments for projects can range widely because of limited data availability and inconsistent modelling approaches. Moreover, displacement of communities remains a serious concern, as illustrated by recent local opposition to the Janjići plant in Bosnia and Herzegovina and the Bener dam in Indonesia. China's Three Gorges Dam, completed in 2006, resulted in the largest human displacement from a hydropower project, displacing more than 1 million people during the 17-year construction period.



Transmission infrastructure from remote hydropower projects also has affected Indigenous lands, sparking backlash. In the United States, the New England Clean Energy Connect faced fierce opposition as Native American groups claimed that ancestral territories were not properly considered in the development of transmission lines.

Sustainability standards such as the Hydropower Sustainability Assessment Protocol have attempted to standardise assessments and to accredit projects that use good practices to minimise the environmental and social impacts. However, comprehensive assessments are still relatively new to the sector. The 510 MW Teesta V hydropower station in northern India was the first hydropower project globally to base its assessment on criteria related to climate change resilience and the mitigation of carbon emissions. In early 2023, the 11 MW Sebzor hydropower facility in Tajikistan became the first project certified under the Hydropower Sustainability Standard, meeting 12 criteria including preserving biodiversity, maintaining water quality and addressing resettlement of communities.

The International Hydropower Association (IHA) offers training programmes to certify professionals to conduct sustainability assessments and to implement strategies based on the Hydropower Sustainability Standard. Nepal's Hydropower Association recently partnered with the IHA to train 60 professionals to improve hydropower project performance and attract green finance.

- i Large-scale hydropower plants refer to facilities greater than 30 MW. Small and mini hydropower typically imply lower environmental impacts due to small land area use and less disruption to surrounding natural ecosystems.
- ii Projects starting operation after 2020 must meet criteria of either less than 50 grams of CO<sub>2</sub> equivalent per kWh produced or a power density of greater than 10 watts per square metre (W/m<sup>2</sup>); for facilities in operation before 2020, the criteria are less than 100 grams of CO<sub>2</sub> equivalent per kWh or greater than 5 W/m<sup>2</sup>.

Source: See endnote 8 for this section.

In **Europe**, hydropower plants serve as the renewable energy source for baseload electricity, load following and grid support; however, in 2022 the worst drought in 500 years led to a 19% decline in regional output.<sup>34</sup> Severe drought led some hydropower reserves in Italy and Spain to drop by half.<sup>35</sup> To partially fill an energy generation gap of 185 TWh, many countries turned to coal production, which rose 7% in 2022.<sup>36</sup> Hydropower represented 10% (283 TWh) of Europe’s electricity output in 2022, led by Sweden (69 TWh), France (46 TWh), and Austria (36 TWh), which together comprised more than half of the continent’s hydropower generation.<sup>37</sup> In Austria, Croatia, Latvia, and Sweden, hydropower accounted for more than 35% of the total electricity mix in 2022.<sup>38</sup>

Outside of China, **Asia** generated 940 TWh of hydropower in 2022 and added 2.8 GW, for a total installed capacity of 269.6 GW.<sup>39</sup> **Pakistan’s** 720 MW Karot plant, which came online in June, is the first project developed by the China Three Gorges Corporation under the China-Pakistan Economic Corridor, bringing Pakistan’s total hydropower capacity to 10.6 GW.<sup>40</sup> **India’s** 600 MW Kameng plant came online in November 2022 as part of the country’s plan to install 30 GW of hydropower by 2030.<sup>41</sup> In **Nepal**, the energy authority is authorised to export up to 400 MW of hydropower to India’s grid, but it has been unable to meet the maximum power level due to a drop in capacity use from 2,200 to 1,550 MW, related to reduced precipitation and receding glaciers in the Himalaya region.<sup>42</sup>

**Türkiye** added 80 MW in 2022, outpacing additions in 2021 for a total capacity of 32 GW.<sup>43</sup> Over the last two decades, Türkiye has invested heavily in hydropower, adding around 650 systems.<sup>44</sup> The recently completed 588 MW Yusufeli dam, the world’s fifth largest, began filling its reservoir in 2022.<sup>45</sup> The Tigris-Euphrates river system, where increasingly complex water needs involve five countries that share the basin, rebounded after a dry 2021.<sup>46</sup> As result, hydropower plants in Türkiye were able to double their daily generation to more than 110 GWh, helping to minimise power shortages during a 10-day period in January 2022 when natural gas supplies from Iran were disrupted.<sup>47</sup>

In **Africa**, hydropower capacity increased 2.6 GW to reach 37.7 GW in 2022, generating at least 150 TWh.<sup>48</sup> The region is the most untapped globally for hydropower development, with a potential capacity of 474 GW as of 2021, especially in West Africa and parts of Southern and Central Africa.<sup>49</sup> In 2022, drought affected primarily Central and East Africa, and Ethiopia, Kenya and Somalia experienced between 30-60% less rainfall from October to December – the region’s longest and most severe drought on record.<sup>50</sup>

**Kenya’s** Electricity Generating Company reported that hydropower, along with geothermal and wind power, will help meet the country’s growing electricity demand, which exceeded a record 2 GW in 2022.<sup>51</sup> Kenya signed an import deal with **Ethiopia** that will likely include electricity from the Grand Ethiopian Renaissance Dam (5.3 GW), which when completed will be Africa’s largest hydropower project.<sup>52</sup> In August 2022, the dam started producing electricity from the second of 13 turbines of 375 MW each.<sup>53</sup>

Hydropower is set to supply the bulk of energy in **Tanzania**.<sup>54</sup> The reservoir for the 2.1 GW Julius Nyerere Dam started to fill in January 2023 and is expected to produce 5,920 GWh annually.<sup>55</sup> Hydropower already accounts for 31% of Tanzania’s electricity needs, and another 600 MW of small- to medium-sized hydropower plants is in the pipeline.<sup>56</sup> In **Nigeria**, all four 175 MW turbines of the Zungeru Hydropower Station were commissioned in 2022 and began operation.<sup>57</sup> The plant, plus an additional 700 MW of projects in the pipeline, are expected to meet 10% of the country’s energy needs when completed.<sup>58</sup>

Many countries in **Latin America and the Caribbean** were early adopters of hydropower as a primary source of electricity generation. Five countries – Colombia, Costa Rica, Ecuador, Panama and Venezuela – produce more than 70% of their electricity from hydropower.<sup>59</sup> In 2022, the region had a total installed capacity of 20.9 GW and generated 69 TWh.<sup>60</sup>

Hydropower plants have a lifetime of 30 to 80 years, presenting opportunities to improve their efficiency, extend lifespans, and boost capacity and generation through refurbishment and **modernisation**. Based on 2022 estimates, worldwide hydropower modernisation efforts could increase the total installed capacity of existing plants by roughly 9 GW.<sup>61</sup> Around 600 GW of hydropower plants are 30 years or older, and 400 GW are 40 years or older.<sup>62</sup> In Africa, where around 38% of the fleet is in medium to high need of modernisation, it would cost around USD 6.8 billion to bring 0.8 GW of idled hydropower units back online and to upgrade overall regional capacity from 0.7 to 1.6 GW.<sup>63</sup> In Latin America and the Caribbean, an estimated 70 GW of capacity will need short- or medium-term modernisation, at around USD 32 billion.<sup>64</sup>



i This total excludes the Yusufeli project, which was completed in 2022, but was still not in operation as of early 2023.



## KEY FACTS OCEAN POWER

- Europe still leads the race to commercialisation of ocean power, but ambitious support programmes are spurring developments in Canada, China and the United States.
- Five tidal stream devices (2.7 MW) and six wave power devices (165 kW) were deployed in 2022.
- Tidal stream has demonstrated its reliability, with total generation surpassing 80 GWh in 2022.
- The UK government's Contracts for Difference scheme earmarked 41 MW for tidal power in 2022, for the first time ever.
- Developers of ocean power attracted EUR 16 million (USD 17 million) in funding from diverse sources during the year.

Ocean power technologies<sup>i</sup> represent the smallest share of the renewable energy market, although there is a vast global resource.<sup>1</sup> Deployments slowed in 2022, following the large increase in 2021 in the aftermath of the COVID-19 pandemic.<sup>2</sup> A total of 1.9 MW was deployed in 2022, down from 4.6 MW in 2021.<sup>3</sup> The estimated operating installed capacity in 2022 was 514 MW.<sup>4</sup>

Two tidal range systems – the 240 MW La Rance station in France and the 254 MW Sihwa plant in the Republic of Korea – account for the majority of this capacity. Potential locations are limited and large-scale environmental engineering is required; thus, few proposals have been advanced to expand the use of this type of system.

**Tidal stream** devices and wave energy converters are the focus of development efforts. Advancements have been concentrated largely in Europe, although revenue support and ambitious research and development (R&D) programmes in other regions have spurred increased development and deployment, particularly in Canada, the United States and China.<sup>5</sup>

Tidal stream devices are approaching maturity, and pre-commercial projects are under way. Around 41 MW of tidal stream capacity has been deployed since 2010.<sup>6</sup> Most projects targeting industrial-scale production are based on horizontal-axis turbines mounted on the sea floor or on a floating platform.<sup>7</sup> These devices have demonstrated considerable reliability, and total generation surpassed 80 GWh as of the end of 2022.<sup>8</sup>

**Wave power** devices are yet to see the same level of design convergence. Developers are generally aiming to tap into utility-scale electricity markets with devices above 100 kW or to fulfil specialised applications with devices below 50 kW.<sup>9</sup> Around 25 MW of wave power has been deployed since 2010.<sup>10</sup>

### OCEAN POWER INDUSTRY

In 2022, the global ocean power sector continued its journey to commercialisation, with significant new funding announcements and the continuance of successful flagship projects to prove their reliability. Most deployments are pilot projects, with around 60 active teams testing their devices in the open sea.<sup>11</sup> A few developers have advanced beyond small-scale pilots to higher technology readiness levels and a pipeline of commercial-scale deployments.

Five **tidal stream** devices totalling 2.7 MW were successfully deployed in 2022.<sup>12</sup>

In **China**, an additional 1.6 MW turbine was deployed and connected to the grid at LHD's tidal current energy demonstration project at Zhoushan in Zhejiang, bringing the project's total capacity to 3.3 MW.<sup>13</sup> The demonstration project has now been operating continuously for more than five years. At CHN Energy's Jiangxia Tidal Power Station (a 4.1 MW tidal barrage commissioned in 1981), a complementary 100 MW solar PV plant was built at the station's reservoir.<sup>14</sup>

<sup>i</sup> Ocean power technologies harness the energy potential of ocean waves, tides, currents, and temperature and salinity gradients. In this report, ocean power does not include offshore wind, marine biomass, floating solar PV or floating wind.

Minesto deployed a second 100 kW device in the **Faroe Islands**, successfully exporting electricity to the grid.<sup>15</sup> The unique device operates on similar principles to a kite flying in the wind, using the hydrodynamic lift force generated by the underwater current to move a tethered kite that drives a generator. Additional infrastructure has now been installed to connect the two devices and to operate both systems in an array. Minesto devised a comprehensive plan for building out large-scale tidal power arrays in the Faroe Islands, identifying and verifying four additional sites that could meet 40% of the islands' demand.<sup>16</sup>

Kyuden Mirai Energy Ltd. deployed SIMEC Atlantis Energy's 500 kW tidal current generator in Nagasaki Prefecture, **Japan**, as part of a Ministry of the Environment project to promote tidal power.<sup>17</sup>

In the **Republic of Korea**, the 80 kW Uldolmok Tidal Power Pilot Plant was deployed at an open-sea test site.<sup>18</sup> The plant generated close to 9 megawatt-hours (MWh) of electricity during its eight-month test deployment, for which the Korea Energy Agency awarded renewable energy certificates.<sup>19</sup>

In **France**, Sabella redeployed its 1 MW bottom-fixed tidal turbine in the Fromveur passage in Brittany.<sup>20</sup> The deployment is part of the PHARES project, which aims to combine wind, tidal, and solar energy, as well as storage, to provide the off-grid Ushant Island with most of its electricity needs.<sup>21</sup> Sabella also successfully connected a small electrolyser to the turbine for green hydrogen production.

Orbital Marine Power continued testing its O2 turbine at the European Marine Energy Centre (EMEC) in Orkney, Scotland. The company secured 7.2 MW in Contracts for Difference<sup>i</sup> (CfDs) as well as new investment from the Scottish National Investment Bank and individuals via the Abundance Investment platform.<sup>22</sup>

Longstanding leader MeyGen also saw success in the new CfD programme, agreeing to add 28 MW of capacity by 2027.<sup>23</sup> This would effectively make MeyGen the world's first commercial-scale tidal array.

Nova Innovation manufactured and shipped three 100 kW direct-drive turbines: two for deployment in Bluemull Sound, Shetland; and one for deployment at the Nova Tidal Array in Petit Passage, Canada.<sup>24</sup> The company is also on track to deploy a 50 kW demonstrator turbine and has undertaken a feasibility study for a 7 MW tidal array in the Larantuka Strait of Indonesia.<sup>25</sup>

For **wave power**, six additions occurred in 2022, totalling 165 kW in capacity.

In **Israel**, Eco Wave Power was able to deploy the country's first grid-connected wave power project, an attenuator device with a capacity of 100 kW, thanks to a combination of public and private support, including feed-in tariffs.<sup>26</sup>

In **China**, Hann Ocean deployed its 15 kW wave rotor device at Shengsi island.<sup>27</sup> The Wanshan 1 MW Wave Energy Demonstration Project successfully tested two 500 kW devices in open-sea trials in Guangdong Province, where the units withstood several typhoons.<sup>28</sup> The project is scheduled for demonstration operation in 2023.

In **France**, a quarter-scale prototype of a wave energy converter specifically designed to be integrated into dyke infrastructure, was successfully installed at the port of Sainte Anne du Portzic.<sup>29</sup> The prototype was undergoing testing, which was expected to conclude by March 2023, with the eventual device targeting a capacity of 800 kW.<sup>30</sup>

At the EMEC in **Scotland**, AWS Ocean Energy reported positive results from a test deployment of its Waveswing device.<sup>31</sup> The converter achieved average power of more than 10 kW and peak power of 80 kW under moderate wave conditions.<sup>32</sup> In **Belgium**, EXOWAVE completed the demonstration of its 3.5 kW wave-to-water plant at the Blue Accelerator test site in Oostende.<sup>33</sup>

In the **Republic of Korea**, a demonstration wave energy converter was constructed and underwent performance evaluations as part of a government-funded R&D project to develop a 30 kW wave energy converter suitable for breakwaters in remote islands.<sup>34</sup>



i The UK's Contracts for Difference (CfD) scheme aims to support low-carbon electricity generation by protecting project developers from volatile wholesale prices.

The 296 kW Mutriku Wave Power Plant in Basque Country, **Spain** is approaching a milestone of 3 GWh of production since being connected to the grid in July 2011.<sup>35</sup> The facility, built into a breakwater, has now been integrated into the testing infrastructure of the Biscay Marine Energy Platform (BiMEP) and will be available for trialling new designs of key components, such as air turbines, electrical generators and control systems.<sup>36</sup>

Development of other ocean power technologies, such as **ocean thermal energy conversion** (OTEC), remains slow, and only a handful of pilot projects have been launched.<sup>37</sup>

Saga University in **Malaysia** and other research institutions are conducting ongoing research on a hybrid system of OTEC and desalination.<sup>38</sup> The research includes the development of a 3 kW hybrid OTEC experimental system that will be installed in Malaysia in 2023 to initiate further research.<sup>39</sup>

Ocean power is not yet competitive in utility markets due to the need for significant cost reductions and further technological advancements, particularly for wave power. The sector remains highly dependent on public funding to leverage private investment and is yet to receive clear market signals to encourage the final steps towards commercialisation.<sup>40</sup> Dedicated revenue support is essential to achieve predictable returns and to attract private investors until the industry reaches a higher level of maturity.<sup>41</sup>

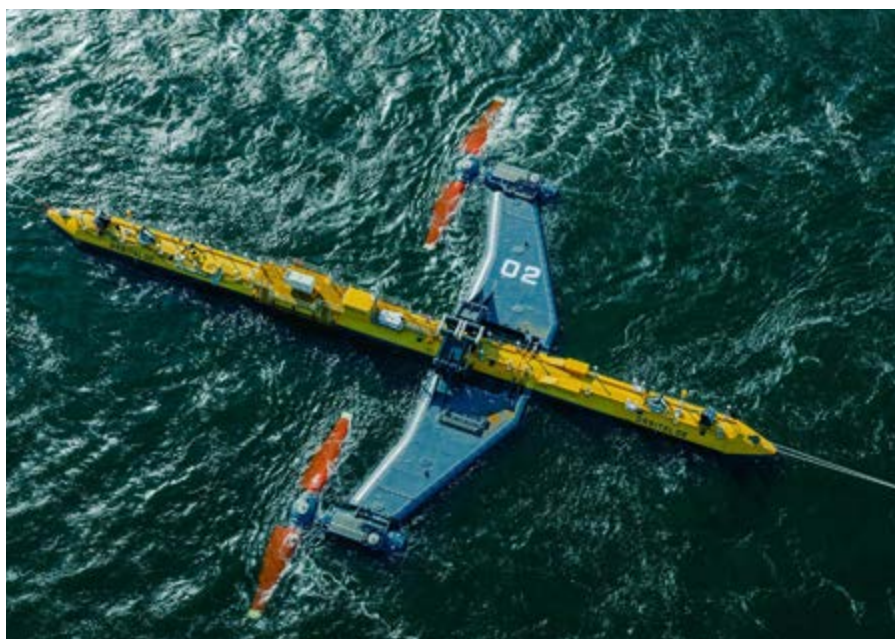
A 2018 European Commission implementation plan estimated that EUR 1.2 billion (USD 1.5 billion) in funding was needed by 2030 to commercialise ocean power technologies in Europe, requiring equal input from private sources, national and regional programmes, and EU funds.<sup>42</sup> In total, an estimated EUR 6 billion (USD 7.4 billion) has been invested in ocean power projects worldwide, of which 75% was private finance.<sup>43</sup> In 2022, the EU announced a funding budget of EUR 40 million (USD 42.7 million) for demonstration of tidal arrays under the Horizon Europe framework, with a similar call for wave power in 2023.<sup>44</sup>

The UK government's CfD scheme allocated 41 MW to tidal stream technologies for the first time in 2021, which will provide GBP 10 million (USD 12.1 million).<sup>45</sup> Tidal power projects from Orbital Marine Power, Simec Atlantis Energy and Magallanes Renovables were awarded contracts.<sup>46</sup> In Canada, the government announced a refundable 30% investment tax credit that will cover tidal, wave and river current technology.

In 2022, EUR 16 million (USD 17.1 million) was provided through a range of private investment pathways.<sup>47</sup> SeaQurrent received EUR 4.8 million (USD 5.1 million) from both existing and new shareholders; Orbital Marine Power secured EUR 4.5 million (USD 4.8 million) through the Abundance Investment platform; Sabella raised EUR 2.5 million (USD 2.6 million) through bond issues; QED Naval received EUR 1.7 million (USD 1.8 million) for the construction of a demonstrator platform; Mocean Energy secured EUR 873,000 (USD 932,000) in equity funding from existing funders to advance the design of the next generation of its wave power device; and Wavepiston raised EUR 600,000 (USD 640,000) from existing shareholders to finalise the installation of its full-scale system in 2023.<sup>48</sup>

Deploying ocean power at scale also will require streamlined consenting processes.<sup>49</sup> Uncertainty regarding environmental interactions has often led regulators to require significant data collection and strict environmental impact assessments, which can be costly and threaten the financial viability of projects and developers.<sup>50</sup> Current scientific knowledge suggests that the deployment of a single device poses little risk to the marine environment, although the impacts of multi-device arrays are not well understood. This calls for an "adaptive management" approach that responds to new information over time, supported by more long-term data and greater knowledge sharing across projects.<sup>51</sup>

The EU committed  
**USD  
 42.7 million**  
 for demonstrating tidal  
 arrays.





## KEY FACTS SOLAR PHOTOVOLTAICS (PV)

- Solar PV maintained its record-breaking streak, with new capacity increasing 37% in 2022, while global solar production reached an average of 6.2%, up from 5% in 2021.
- For the tenth consecutive year, Asia dominated regionally in new solar PV installations, contributing 64% of the global added capacity in 2022.
- The leading countries for cumulative installed solar PV capacity remained China, the United States, India, Brazil, and Spain, while the leading markets for per capita capacity remained Australia, the Netherlands and Germany.
- Poland was a new entrant to the top 10 solar PV installers (eighth globally and third in Europe), adding 4.9 GW of capacity, nearly 50% more than its capacity added in 2021.
- Centralised utility-scale solar PV reached a total of 124.8 GW of new installations, driven by tenders and the attractiveness of power purchase agreements. Distributed PV added 115.2 GW and was driven by falling module costs, which made installations more attractive and accessible.
- Although solar PV panel production remains concentrated in China, more countries have strengthened import barriers and incentives for local manufacturing, pioneered by the United States and India.

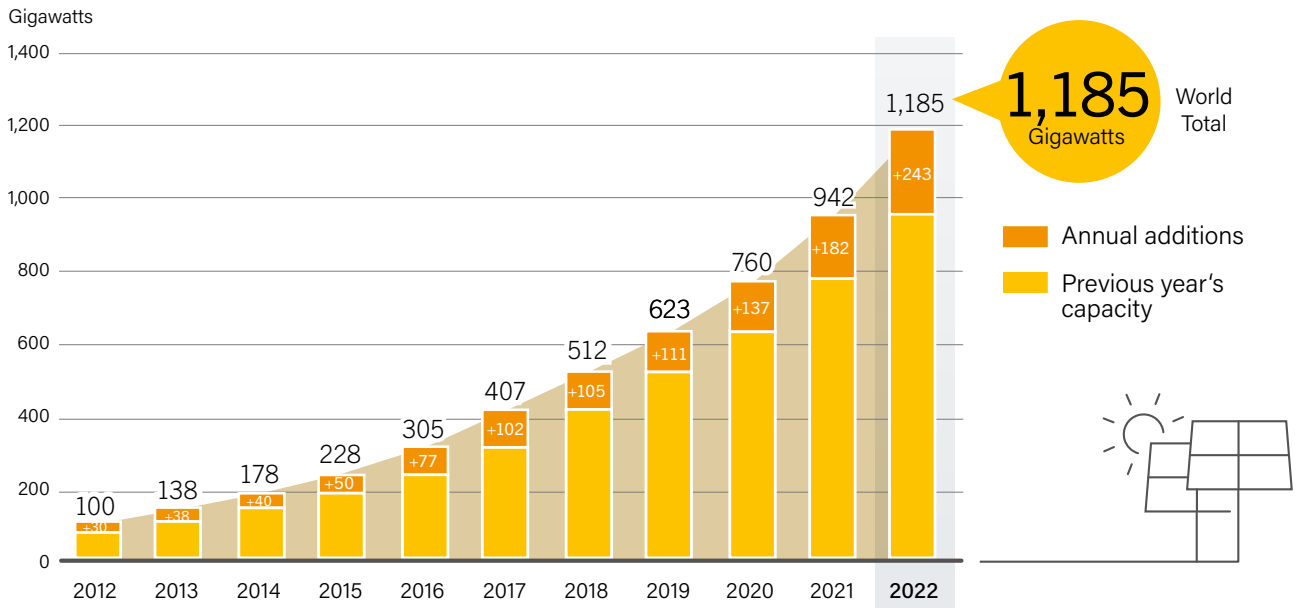
The solar PV market continued its steady growth in 2022, with 243 GW of new installations added, 61 GW more than in 2021.<sup>1</sup> (→ See Figure 24.) This was the largest increase in annual capacity ever recorded and brought the cumulative global solar PV capacity to 1,185 GW, passing the 1-terawatt milestone.<sup>2</sup> This record-breaking increase was possible despite ongoing disruption across the solar supply chain due to both shortages and rising costs of raw materials.<sup>3</sup>

Solar PV contributed an estimated 6.2% of global electricity generation in 2022, up from 5% in 2021.<sup>4</sup> With the expansion of capacity, several countries relied on solar PV generation to meet a large share of their electricity demand. By the end of 2022, at least nine countries had sufficient installed solar PV capacity to meet at least 10% of their electricity demand, up from seven countries in 2021.<sup>5</sup> Around 22 countries had enough installed solar PV capacity to meet 5% of their electricity demand, up from 18 countries in 2020.<sup>6</sup> Spain had the highest share of solar PV in annual generation, at 19.1%, followed by Greece (17.5%), Chile (17%), the Netherlands (15.9%) and Germany (15.7%).<sup>7</sup>

For the tenth consecutive year, Asia dominated regionally in new solar PV installations, followed by the Americas, which again surpassed Europe.<sup>8</sup> The top five countries<sup>1</sup> by capacity added (in descending order) were China, the United States, India, Brazil, and Spain, together comprising around 66% of newly installed capacity (up from 61% in 2021).<sup>9</sup> (→ See Figure 25.)

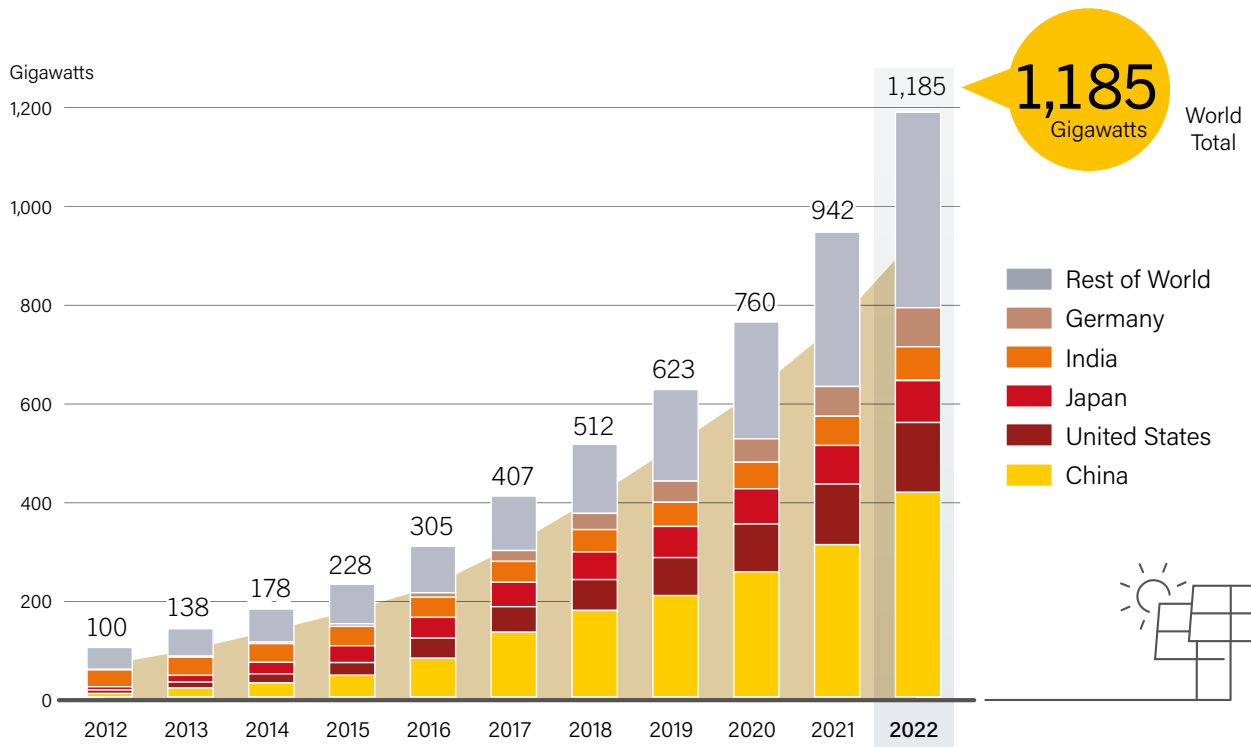


**FIGURE 24.**  
Solar PV Global Capacity and Annual Additions, 2012-2022



Source: See endnote 1 for this section.

**FIGURE 25.**  
Solar PV Global Capacity, by Country and Region, 2012-2022



Source: See endnote 9 for this section.

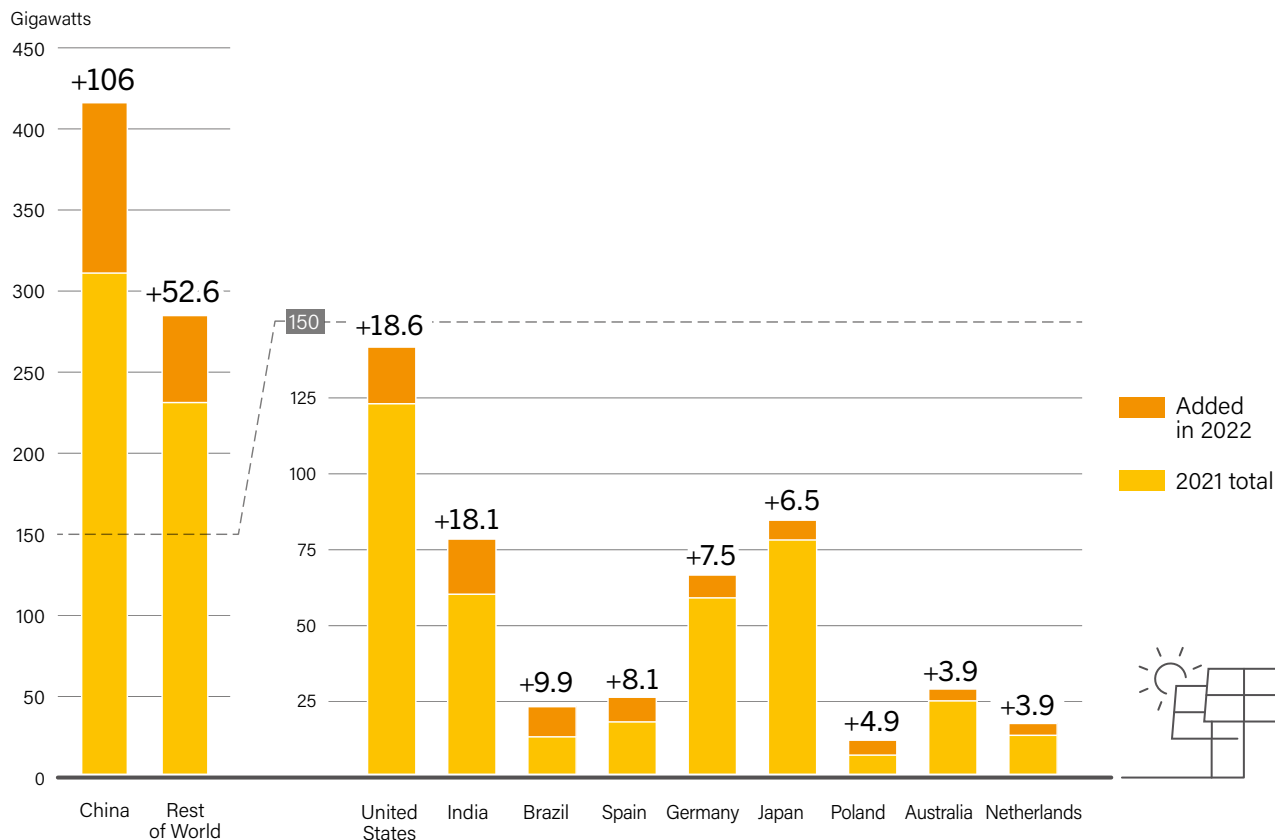
The next five markets in 2022 were Germany, Japan, Poland, Australia and the Netherlands. The annual market size required to rank among the top 10 countries in 2022 was 3.9 GW, up from 3.4 GW in 2021.<sup>10</sup> (→ See Figure 26.) The leading countries for cumulative solar PV capacity remained China, the United States, Japan, India, and Germany, while the leading markets for per capita capacity continued to be Australia, the Netherlands and Germany.<sup>11</sup> (→ See Figure 27)

Global capacity additions of utility-scale solar PV – large-scale, centralised systems connected to the grid – increased around 25%, to reach a total of 124.8 GW, while **rooftop solar PV** rose around 54% to reach 115.2 GW.<sup>12</sup> Similar to 2021, installations of rooftop PV in 2022 occurred mainly in China, the United States, Spain, Australia and Germany.<sup>13</sup>

Global rooftop solar PV additions rose around **54%** in 2022 to reach 115.2 GW.



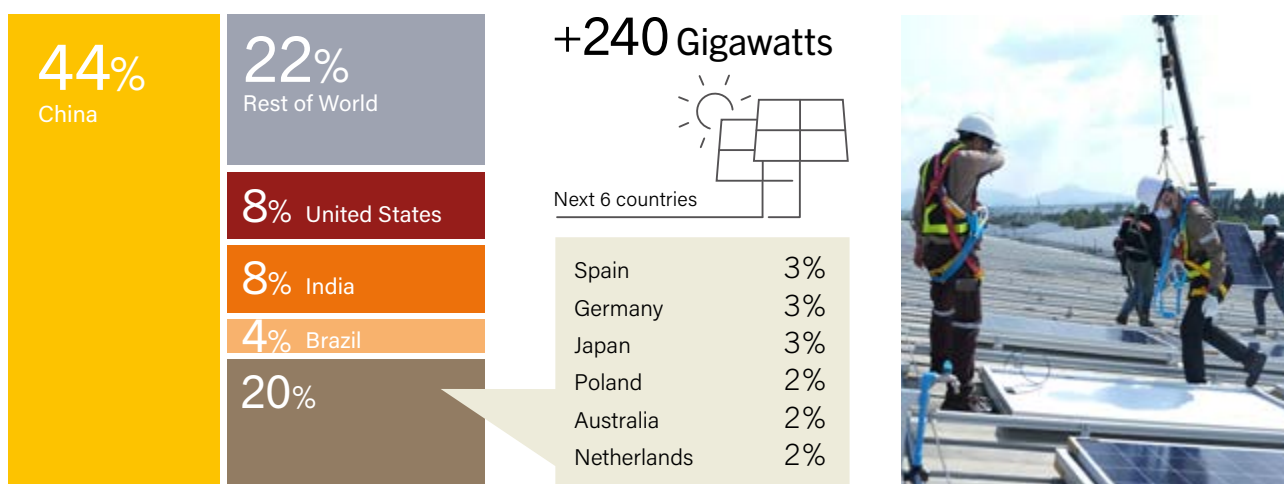
**FIGURE 26.** Solar PV Capacity and Additions, Top 10 Countries for Capacity Added, 2022



Source: See endnote 10 for this section.



**FIGURE 27.**  
Solar PV Global Capacity Additions, Shares of Top 10 Countries and Rest of World, 2022



Source: See endnote 10 for this section.

Several countries announced measures in 2022 to expand the share of rooftop PV systems in the energy market. To incentivise residential systems, Norway increased the maximum subsidy per kW installed as well as the maximum system size eligible for rebates, from 15 kW to 20 kW.<sup>14</sup> Germany reduced the value-added tax (VAT) to 0% for residential PV systems up to 30 kW in size and provided tax exemptions to operators of small PV systems.<sup>15</sup> Belgium lowered the VAT for PV installations and heat pumps deployed on buildings constructed in the last ten years.<sup>16</sup> Italy loosened permits for utility-scale PV and simplified the permitting process for commercial rooftop systems up to 200 kW.<sup>17</sup> Portugal and Spain both streamlined permits to promote self-consumption, and for 2022 the Austrian government more than quadrupled the budget of its rooftop solar rebate programme.<sup>18</sup>

**China's** solar PV market experienced unprecedented growth in 2022, adding an estimated 106 GW, or around 93% more than in 2021.<sup>19</sup> Around 58% of the new capacity was distributed solar PV (61.4 GW), while 44.6 GW was centralised solar PV.<sup>20</sup> In total, China's market grew 35.5% in 2022 to reach a cumulative capacity of 414.5 GW, with 165.8 GW (40%) from distributed generation<sup>i</sup> and 248.7 GW (60%) from centralised plants.<sup>21</sup> China's market for centralised solar PV plants grew around 18%, while distributed solar PV grew 47%.<sup>22</sup> The country's rooftop market was driven largely by the three-year whole-county rooftop solar scheme, which launched in early 2021 and registered double the number of installations in 2022 compared to 2021.<sup>23</sup>

Total electricity production (from all sources) increased 3.6% in China, whereas electricity from solar PV surged 27.8%, to 418 TWh.<sup>24</sup> The country's total electricity demand in 2022 reached 8,840 TWh, with solar PV representing 4.7% of the total.<sup>25</sup>

**India** was again the second largest market in Asia for new solar PV capacity, and third globally. The country added around 18.1 GW in 2022, more than the previous year, representing around 80% of the country's total added power capacity (from all sources).<sup>26</sup> The solar PV additions included around 15.7 GW of utility-scale solar (87%) and 2.4 GW of rooftop PV installations.<sup>27</sup> This brought India's cumulative installed solar PV capacity to around 79 GW.<sup>28</sup>

However, this was still well below India's target of 100 GW of solar by 2022.<sup>29</sup> Utility-scale solar fell short by around 2 GW and rooftop PV by a staggering 25 GW. The shortfall can be traced to multiple factors including net metering limits, customs duties that came into effect in April 2022, unsigned renewable power supply agreements that have been tendered but not signed by distribution companies, and banking restrictions (with higher banking charges and the banking period for renewable power changed from annually to monthly).<sup>30</sup>

In **Japan**, the annual growth in solar PV installations stagnated in 2022, with the country again adding around 6.5 GW, to bring the total installed capacity to an estimated 84.5 GW.<sup>31</sup> A new mandate for solar PV announced in Tokyo requires all new homes and buildings to install rooftop PV starting in 2025.<sup>32</sup> Japan also hosts the largest number of agriculture-based solar PV plants globally, as dual-use systems such as agrivoltaics and floating solar PV

i Distributed generation refers to systems that provide power to grid-connected consumers, or directly to the grid, but on distribution networks rather than on bulk transmission or off-grid systems. In this section, distributed generation refers to rooftop and ground-mounted PV for residential, commercial and industrial applications.

ii The rooftop space should be more than 20 square metres for homes and less than 2,000 square metres for buildings.



have major potential in the country considering the limited land availability.<sup>33</sup> (→ See *Niche Solar PV Markets sub-section*.) In 2022, around 100 MW of agricultural PV capacity was added in Japan, for a cumulative total of around 300 MW.<sup>34</sup>

The solar PV market in the **United States** contracted in 2022. The country added 18.6 GW during the year, down 16% from 2021 levels, to reach a cumulative capacity of 141.6 GW.<sup>35</sup> For the fourth consecutive year, solar PV was the leading source of US added power generation capacity, accounting for a record half of the total capacity brought online in 2022.<sup>36</sup> The top state for new solar PV additions was California (4.7 GW), followed by Texas (3.3 GW) and Florida (1.7 GW).<sup>37</sup> US solar PV generation totalled 201 TWh, with the bulk of it utility-scale (143 TWh) and the rest grid-connected, distributed rooftop systems (58 TWh); altogether, solar PV contributed 4.7% of US electricity generation in 2022.<sup>38</sup>

In March 2022, the US government carried out an investigation after a solar module manufacturer claimed that Chinese companies based in Southeast Asia were exporting panels to the United States while avoiding US anti-dumping and countervailing tariffs in place since 2012.<sup>39</sup> The investigation led to a temporary halt in shipments from module manufacturers, leading to a module shortage in the country and contributing to slower-than-usual annual growth, mainly in the utility-scale market.<sup>40</sup> In another setback for the US solar market, customs officials detained an estimated 10 GW of solar panels from China in 2022 under enforcement of the Uyghur Forced Labor Prevention Act.<sup>41</sup>

The US Inflation Reduction Act, signed in August 2022, is expected to have a positive long-term impact on the solar PV market.<sup>42</sup> Two of the main incentives for solar PV are an increase in the Investment Tax Credit from 26% to 30% for residential and commercial projects, and the approval of large-scale arrays to qualify for Production Tax Credits of up to 2.5 cents per kWh.<sup>43</sup>

**Brazil** continued to lead in solar PV capacity in Latin America, adding nearly 10 GW, a new record and roughly double the amount added in 2021.<sup>44</sup> This included a record 7.6 GW of new distributed capacity and 2.5 GW of centralised PV systems.<sup>45</sup> Market growth in Brazil

was driven mainly by high electricity bills and by new regulations for distributed generation.<sup>46</sup> In early 2022, the government made PV systems of up to 5 MW in size eligible for net metering until 2045, and established a grid fee starting in 2023.<sup>47</sup> Other notable capacity additions in Latin America were in Chile (1.8 GW) and Mexico (680 MW), while Panama's largest solar PV plant (120 MW) began operation, with potential annual generation of around 240 GWh.<sup>48</sup>

**Europe** added 40.5 GW of solar PV in 2022 to reach 206 GW of installed capacity, marking another year of outstanding growth.<sup>49</sup> New installations in the EU-27 reached 38.9 GW, 63% more than the 25.9 GW added in 2021.<sup>50</sup> In early 2022, as part of a plan to reduce its reliance on Russian natural gas and to accelerate the deployment of renewables, the EU announced that it would expedite by more than 20% the target of 420 GW of solar PV by 2030.<sup>51</sup> The top EU additions were in Spain (8.1 GW), Germany (7.5 GW), Poland (4.9 GW), the Netherlands (3.9 GW) and France (2.9 GW), while the leaders for total capacity were Germany, Spain, Italy, France and the Netherlands.<sup>52</sup> Portugal added a notable 2.5 GW in 2022, reflecting 250% year-on-year growth, and Italy added 2.6 GW, with 174% growth.<sup>53</sup>

China's added solar PV capacity was around

**93%**

more than in 2021.

**Germany's** solar PV capacity additions were up almost 50% in 2022, well above the 8% growth rate recorded in 2021, and total installations reached 67 GW.<sup>54</sup> The German market was driven mainly by government auctions and more than 3 GW of tenders.<sup>55</sup> Power purchase agreements (PPAs) also played a role, with unsubsidised installations accounting for around 872 MW of capacity added.<sup>56</sup> In 2022, solar PV contributed a record 11.8% of Germany's electricity production, up from 9.8% in 2021.<sup>57</sup>

The Russian Federation's invasion of Ukraine stirred up Germany's energy market, pushing the government to release amendments in 2022 supporting renewables in the coming years. To improve energy security and advance climate neutrality, Germany adopted an acceleration scheme (the Easter Package) that revised energy laws and proposed new measures, including higher feed-in tariff (FIT) rates, removal of the FIT surcharge for self-consumed systems of 10-30 kW, and an increase in the auction threshold to 1 MW (previously 300 kW for rooftop and 750 kW for ground-mounted systems).<sup>58</sup>

**Spain** added around 8.1 GW of solar PV in 2022, 65% more than in 2021 (4.9 GW), bringing the country's total capacity to 26.6 GW.<sup>59</sup> Installations included 4.3 GW of utility-scale and 2.7 GW of self-consumption distributed PV systems.<sup>60</sup> Around 47% of the new installations under self-consumption were installed in the industrial sector, 32% in the residential sector and 20% in the commercial sector.<sup>61</sup> Spain's utility-scale PV market continued to be driven by unsubsidised PPAs, while the rooftop PV market, which grew at a steady rate of around 102% in 2022, was driven by high electricity prices.<sup>62</sup> Spain now faces a potential overcapacity challenge, necessitating investments in grid expansion and energy storage.<sup>63</sup>

**Poland** was a new entrant to the list of top 10 solar PV installers in 2022, adding 4.9 GW or nearly 50% more than in 2021 (3.3 GW).<sup>64</sup> Residential prosumers<sup>i</sup> represented around 80% of the new capacity, motivated by an attractive net metering scheme and

by rising electricity prices.<sup>65</sup> However, the spike in household installations posed challenges for the distribution network, and in April 2022 Poland replaced the net metering scheme with net billing, a slightly less attractive option for households.<sup>66</sup>

**The Netherlands**, the other new entrant to the top 10 installers, added 4 GW of solar PV in 2022.<sup>67</sup> Nearly half of the new installations (1.8 GW) were rooftop PV, up 38% in 2022 and driven largely by the country's net metering scheme.<sup>68</sup> In 2022, the Netherlands boasted Europe's highest share of solar PV in the energy generation mix, at 14% (up from 11.8% in 2021).<sup>69</sup>

**Australia** remained the largest solar PV market in Oceania adding around 3.9 GW in 2022 for a total capacity of nearly 30 GW.<sup>70</sup> Solar PV generation rose around 20% to 34.3 TWh, contributing 14.7% of Australia's total electricity generation; rooftop PV alone accounted for 25.8% of renewable generation and for 9.3% of all generation.<sup>71</sup>

Australia's solar rooftop segment added an estimated 2.8 GW, driven by a 15-20% increase in electricity bills nationwide, although this was less than the 3.3 GW added 2021, due mainly to supply chain disruptions.<sup>72</sup> By year's end, an estimated 3.4 million homes across the country had rooftop solar systems installed.<sup>73</sup> Household battery additions also grew significantly (44%) in 2022, with an estimated 50,000 battery systems added.<sup>74</sup> To facilitate wider uptake of rooftop PV without compromising grid stability, the state of Western Australia has followed the steps of Southern Australia to implement remote disconnection of new and upgraded solar and battery installations.<sup>75</sup>

The **Middle East and Africa** added around 7.2 GW of solar PV in 2022.<sup>76</sup> Africa installed around 950 MW – up 14% from the 833 MW installed in 2021 – bringing the total capacity to at least 10 GW.<sup>77</sup> The region's top installer was Angola, adding around 284 MW, followed by South Africa (111.8 MW), Egypt (80 MW), Ghana (71.3 MW) and Mozambique (41.9 MW).<sup>78</sup>



By the end of 2022,  
an estimated

**3.4 million**

homes across Australia  
has rooftop solar  
systems installed.

i Prosumers are those who consume electrical energy as well as produce and export excess electricity to the grid.

## NICHE SOLAR PV MARKETS

In addition to conventional PV installations, **floating solar PV** and **agricultural PV** gained greater recognition in 2022, with multiple countries defining supportive measures for these installations. Although the total installed capacity of floating PV plants is difficult to track, with limited documentation of recent additions, the capacity was well over 3 GW by the end of 2022.<sup>79</sup> The top five countries with the highest estimated floating PV potential are the United States, China, Brazil, India and Canada.<sup>80</sup> India's largest project (around 100 MW) was commissioned in 2022, and the Czech Republic also finished building its first floating PV plant in early 2022.<sup>81</sup>

Germany's new Easter Package supported the development of agricultural PV, including it as part of the large-scale tender scheme instead of the innovation tender.<sup>82</sup> France, which considers agricultural PV critical in efforts to achieve the country's target of 100 GW of solar by 2050, compiled a new set of standards defining and characterising this approach.<sup>83</sup> Similarly, Italy compiled a detailed list of standards for agricultural PV projects, facilitating the expansion of this market in the country.<sup>84</sup>

**Building-integrated PV (BIPV) systems** and **vehicle-integrated PV**<sup>i</sup> are niche methods of installation that involve the integration of solar PV within the surface of buildings (façades and rooftops) as well as vehicles. In 2022, China released a plan aimed at deploying 50 GW of rooftop and BIPV by the end of 2025.<sup>85</sup> In the Republic of Korea, the Seoul metropolitan government announced a rebate scheme that covers up to 80% of the costs of purchasing and constructing BIPV systems.<sup>86</sup>



## SOLAR PV INDUSTRY

In 2022, China continued to dominate the global manufacturing of solar panels, with more than an 80% stake across all production stages.<sup>87</sup> A leading barrier to the wider geographical spread of PV manufacturing is the gap in costs between China and other countries that seek to increase domestic production. Compared to China, costs are higher 10% in India, 20% higher in the United States and 35% higher in Europe.<sup>88</sup>

The cost of **polysilicon**<sup>iii</sup>, which represents around 35% of the total cost of a PV module, continued to increase in 2022.<sup>89</sup> By mid-year, the average cost of polysilicon was USD 45.4 per kilogram, its highest recorded cost in more than a decade, which prompted China's national energy agency and state regulator to ask regional authorities to step in to stop the rampant cost increase.<sup>90</sup> The rise in price is attributed to increased demand, macroeconomic fluctuations and supply chain issues.<sup>91</sup> Although global shipping costs across all industries decreased slightly in 2022, they remained substantially higher than in 2019, before the COVID-19 pandemic, with large impacts on solar PV markets.<sup>92</sup>

India continued to support **domestic production** of solar modules in 2022, both by increasing financial incentives and broadening tax exemptions, and by imposing a high customs duty (40%) on developers to discourage the use of imported solar modules.<sup>93</sup> In Europe, the European Commission is preparing a new legal instrument to ban the sale of goods made with forced labour, including solar panels made in Xinjiang, China, where abuses have reportedly occurred.<sup>94</sup> Germany, in particular, is strategising to restore the country's fully fledged solar PV manufacturing supply chain.<sup>95</sup>

In the United States, the government's 2021 ban on imports of materials manufactured in Xinjiang came into effect in June 2022.<sup>96</sup> However, the US solar manufacturing market remains relatively unprepared to meet the rising demand for modules, as the operational cost of US module factories is much higher than in Asia, due mostly to higher labour and electricity costs.<sup>97</sup> In July 2022, the US government announced a USD 56 million investment to expedite domestic solar manufacturing.<sup>98</sup>

**Cell technologies** in 2022 followed somewhat similar trends as previous years. Passivated emitter cell (PERC)<sup>iv</sup> solar panels continued to dominate over n-type cells, such as tunnel-oxide passivated contact (TOPCon<sup>v</sup>) and heterojunction technology (HJT).<sup>99</sup> However, with PERC cells approaching their theoretical efficiency limit, emerging manufacturers outside of China are pursuing HJT over PERC.<sup>100</sup> Major cell manufacturers in China also have ramped up manufacturing capacity of TOPCon modules.<sup>101</sup>

i Agricultural PV uses the same site for both energy and crop production.

ii Not to be confused with building and applied PV (BAPV and VAPV), which consist of fitting PV modules onto a surface.

iii Polysilicon is the raw material for crystalline silicon which is used to manufacture PV wafers.

iv PERC is a technique that reflects solar rays 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.

v TOPCon cells adapt a sophisticated passivation scheme to advance cell architectures for higher efficiencies.



## KEY FACTS CONCENTRATING SOLAR THERMAL POWER

- Following the first-ever year of contraction in global CSP capacity, 200 MW was added in the United Arab Emirates in 2022 to reach a total of 6.3 GW worldwide.
- For nearly one decade, no new CSP capacity has been added in historical leaders of Spain and the United States. China is poised to become a global leader in installed CSP capacity, with at least 30 projects under various stages of construction and commissioning as of the end of 2022. Several African countries also were developing CSP projects.
- Hybrid projects, where CSP is co-located with solar PV and wind power, are increasingly common and have been responsible for driving down costs. Nearly all new CSP plants contain some form of thermal energy storage.
- The cost of electricity generated by CSP plants fell 68% between 2010 and 2021.

## CSP MARKETS

The global installed capacity of concentrating solar thermal power (CSP) increased by 200 MW in 2022 to reach a total of 6.3 GW.<sup>1</sup> (→ See Figure 28.) This growth followed the first year ever of contraction of global CSP capacity in 2021.<sup>2</sup> Overall, the global CSP market has slowed following an initial surge of development in Spain and the United States in the early 2010s.<sup>3</sup> Neither of these historically leading markets has added capacity in nearly a decade. However, new projects have come online and are under construction in emerging markets, including Chile, China, Israel, Morocco, South Africa and the United Arab Emirates.<sup>4</sup>

In 2022, the first portion (200 MW) of a 600 MW parabolic trough facility came online at a large-scale hybrid CSP power plant in the **United Arab Emirates**.<sup>5</sup> Once completed, the plant will be the world's largest CSP facility at 700 MW (including the 100 MW central tower).<sup>6</sup> It is spread over 77 square kilometres and combines solar PV and CSP; the 266 metre solar tower, the world's largest, entered commercial operations in early 2023.<sup>7</sup>

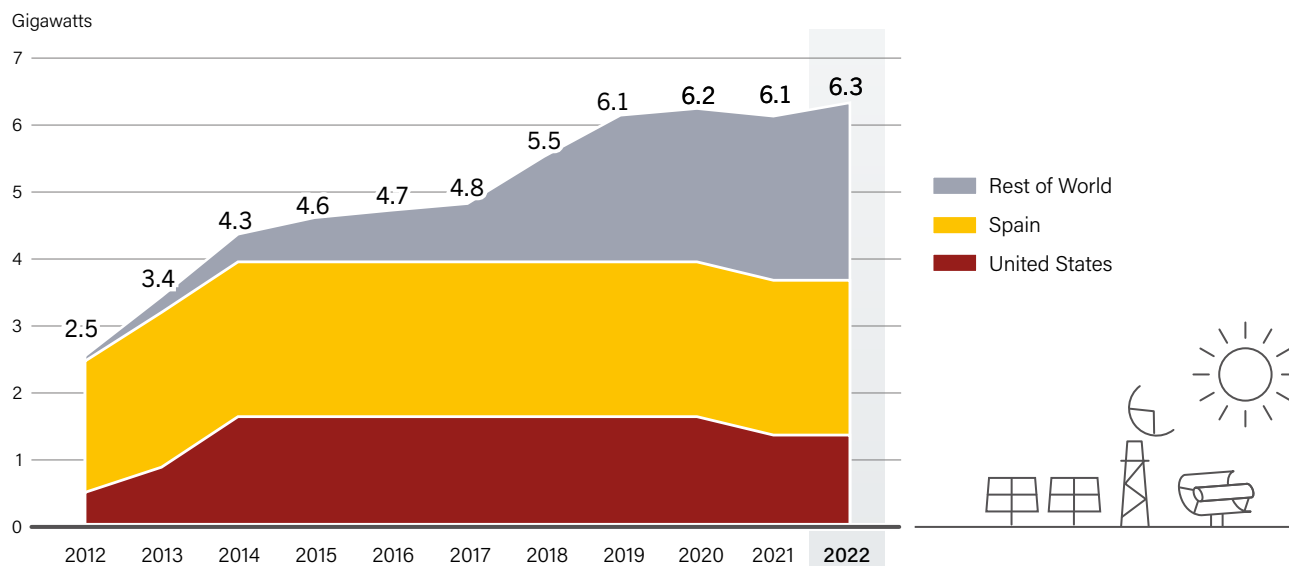
Most of the world's CSP capacity under construction is in **China**. As of the end of 2022, at least 30 CSP projects were in various stages of construction and commissioning in the country, with 14 projects (totalling 1.4 GW of capacity) scheduled to come online during 2023.<sup>8</sup> If these projects are completed as scheduled (which is highly uncertain), it would raise the global cumulative CSP capacity by roughly 23%, equivalent to the total operational capacity in the United States as of 2022.<sup>9</sup> In early 2023, the first of these Chinese projects started commercial operations, a 50 MW tower CSP facility.<sup>10</sup>

The main drivers for CSP in China are the "dual carbon" plan, which aims to give flexibility to the grid; policy support to drive cost reductions; R&D at 11 major universities; and a local CSP supply chain comprising more than 500 Chinese firms.<sup>11</sup> A state council action plan also proposes developing CSP, promoting its co-location with wind power and solar PV.<sup>12</sup> In addition, the 14th Five-Year Plan for a Modern Energy System (2021-2025) promotes the active development of CSP as well as the coordinated deployment and joint operation of CSP, wind and PV power generation facilities in regions such as Gansu, Inner Mongolia, Qinghai and Xinjiang.<sup>13</sup> Western regions in China with a high level of solar irradiation are encouraged to use CSP as a power source for peak shaving.<sup>14</sup>

China is notable for its focus on solar tower systems. Whereas most of the world's historic CSP capacity (more than three-quarters) is parabolic trough (and only 20% tower), in China more than 63% of projects are solar tower, while only a quarter are parabolic trough.<sup>15</sup>

As of end-2022, around 1.3 GW of CSP capacity was still in operation in the **United States**, with no projects under planning or construction.<sup>16</sup> The country has not added new CSP capacity since 2015.<sup>17</sup> However, the Inflation Reduction Act of 2022 was expected to give CSP a boost, earmarking USD 24 million to fund CSP technologies for electricity generation as well as for industrial process heat.<sup>18</sup>

**FIGURE 28.**  
**Concentrating Solar Thermal Power Global Capacity, by Country and Region, 2012-2022**



Source: See endnote 1 for this section.

**Spain** has added no new CSP capacity since 2013 and faced further setbacks during 2022. Although the country had aimed to award 220 MW of new CSP capacity at a renewable energy auction in October, no capacity was awarded.<sup>19</sup> This was due mainly to industry requesting a higher price than the government was willing to offer, and to industry uncertainty about the possibilities to access the electricity grid.<sup>20</sup> Spain aims to double its CSP capacity from 2.3 GW to 4.8 GW by 2025 and 7.3 GW by 2030, yet the country had no capacity under construction in 2022.<sup>21</sup>

**Italy** had 8 MW of CSP capacity under construction in 2022 and aims to add 880 MW by 2030.<sup>22</sup> In **South Africa**, the Redstone CSP plant began construction and is expected to be completed in 2023, with 100 MW capacity and 12 hours of storage.<sup>23</sup> In Africa, **Botswana** moved forward in a tendering process for a 200 MW CSP plant, and a feasibility study was conducted for a CSP facility in **Namibia**.<sup>24</sup> An **Australian** company received AUD 65 million (USD 44 million) to construct a novel plant design consisting of several small towers, as opposed to the single large tower that is typical of solar tower plants.<sup>25</sup>

**CSP INDUSTRY**

The main companies active in the CSP industry in 2022 were based in China, Spain and the United Arab Emirates.<sup>26</sup> They included project developers Shanghai Electric, Abengoa, Acciona Energia, and ACWA Power, as well as several smaller firms.

The **cost<sup>i</sup> of electricity generated by CSP** plants fell 68% between 2010 and 2021.<sup>27</sup> This decline was driven largely by decreases in total installed costs and by improved capacity factors.<sup>28</sup> The growing addition of thermal energy storage also has grown plant capacity factors, improving plant dispatchability

while decreasing levelised electricity costs.<sup>29</sup> In addition, hybridisation with solar PV has been responsible for driving down CSP costs, especially in China.<sup>30</sup>

Upfront costs rebounded in 2021, although the increase should be considered with caution, as only one project was brought online.<sup>31</sup> (Cost data for 2022 were not available at the time of publication.) Technology could play a growing role in driving down costs, as cleaning of heliostats (a major component in tower CSP plants) and cloud cover prediction have the highest potential for increasing the value of CSP plants.<sup>32</sup> Hybrid projects could drive costs down further. A 2021 study found that Chilean hybrid solar PV-CSP plants could reach lower levelised electricity costs than gas-fired power plants, while providing the same flexibility benefits to the system.<sup>33</sup>

Research and development of CSP systems continued in 2022. The United States and China lead the world in patent applications for the technology, each accounting for around 20% of all applications.<sup>34</sup> In early 2023, construction began on the final stage of a USD 100 million CSP demonstration project in the United States.<sup>35</sup> The US Department of Energy has a goal to reduce the cost of heliostats one-third by 2030 from its 2021 level.<sup>36</sup> In 2022, China provided total funding of RMB 8.06 million (USD 1.2 million) for a total of 21 CSP research projects (12 youth projects, 8 general programmes, and 1 regional and international cooperation and exchange project).<sup>37</sup>

For nearly one decade, all CSP capacity has been added in emerging markets.

i Refers to the global weighted levelised cost of electricity (LCOE).



## KEY FACTS SOLAR THERMAL HEATING

- The global solar thermal market contracted 9.3% in 2022, due largely to a drop in China.
- Sales grew at double-digit rates in several large markets including Italy (up 43%), France (29%), Greece (almost 17%), Germany and Poland (both 11%).
- Although small-scale systems for water and space heating continued to lose market share in many countries, demand for large-scale projects increased.
- Solar thermal continued to face fierce competition from solar PV as well as heat pumps and biomass boilers.
- By the end of 2022, millions of residential, commercial and industrial clients in some 150 countries were benefiting from solar thermal heating systems.
- The leading markets for solar thermal technology in district heating were China, which commissioned an estimated 25 systems, and Germany, which had a record year with 8 new plants.
- More solar industrial heat plants (SHIP) began operation in 2022 than in any other year since surveys began in 2017, with at least 114 projects coming online. The Netherlands led with 38 systems, followed by China (17) and France (14).

The global solar heat market contracted 9.3% in 2022 to an estimated 22.8 GW<sub>th</sub><sup>i</sup>, after an increase in 2021 that followed seven years of decline.<sup>1</sup> Sales grew at double-digit rates in several large solar thermal markets, including Italy (43%), France (29%), Greece (almost 17%), and Germany and Poland (both 11%); in addition, South Africa, the strongest market in Sub-Saharan Africa, reported an increase (9%) over 2021.<sup>2</sup> However, sales declined in other large markets including India (-21%), China (-12.3%), Spain (-12%) and Portugal (-11%), following strong growth in 2021.<sup>3</sup>

The solar thermal industry was challenged by supply chain issues, logistics disruptions and inflation, which pushed up costs. In some countries, manufacturers struggled to procure raw materials for the production of collectors and storage tanks, leading to longer delivery times and rising prices.<sup>4</sup> Despite higher fossil fuel prices, on the demand side a lack of awareness of solar thermal options and an imbalance in policies and utility incentives in many countries meant that solar thermal continued to face fierce market competition – from solar PV in particular, but also from heat pumps and biomass boilers, both of which offer stand-alone solutions for hot water and/or space heating.<sup>5</sup>

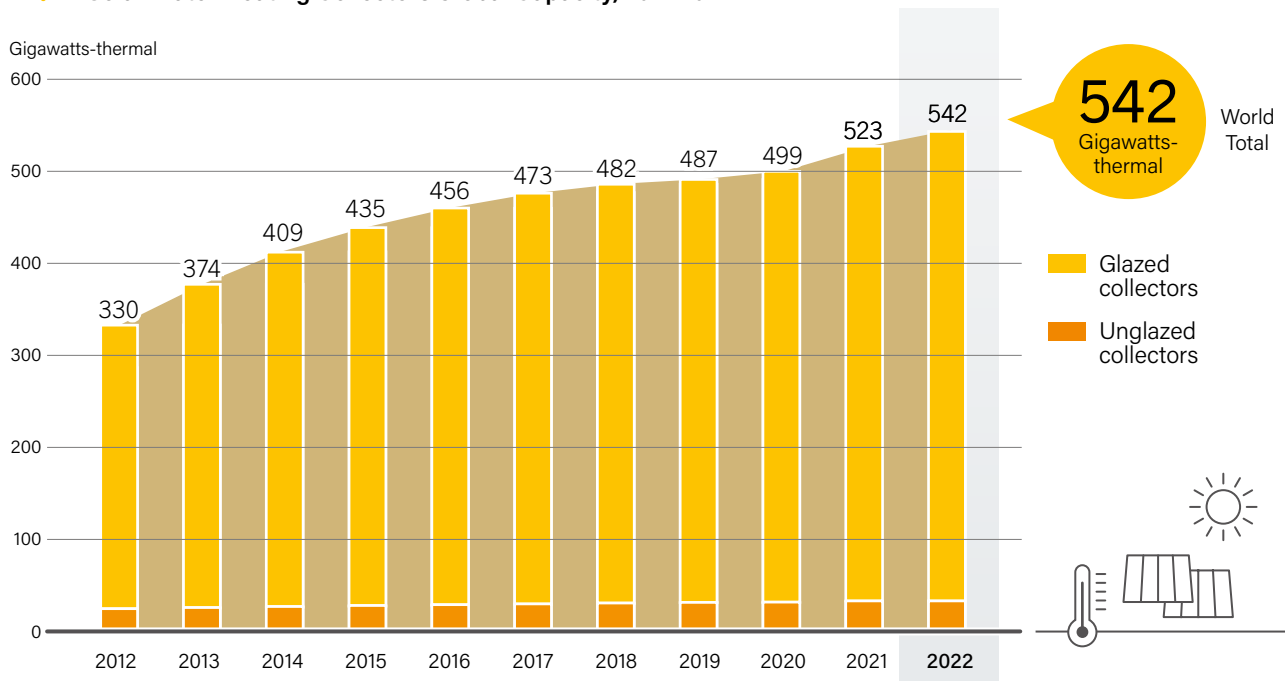
Small-scale solar thermal systems and combi-systems (for water and space heating) continued to account for around 60% of annual installations, but in recent years they have lost market share across much of Europe and China.<sup>6</sup> Demand for large-scale projects, in contrast, is increasing, with several multi-megawatt plants under construction in 2022 for commercial and industrial clients, signalling a new era for big solar in those regions.<sup>7</sup> In some countries, interest also is rising in hybrid systems, particularly combined solar thermal and heat pump systems in district heating networks.<sup>8</sup>

By year's end, millions of residential, commercial and industrial clients in around 150 countries were benefiting from solar thermal heating systems.<sup>9</sup> Cumulative global capacity in operation reached an estimated 542 GW<sub>th</sub> in 2022, up 3.3% from 523 GW<sub>th</sub> in 2021.<sup>10</sup> (→ See Figure 29.) Total global capacity of solar water collectors in operation at the end of 2022 was enough to provide around 442 TWh of heat annually, equivalent to the energy content of 260 million barrels of oil.<sup>11</sup>

**China** remained the largest market for solar thermal systems of all types, accounting for around 73% of the cumulative world capacity, followed distantly by Türkiye, the United States, Germany and Brazil.<sup>12</sup> The top 20 countries for new additions remained largely the same as in 2021, led by China, Türkiye, Brazil, India and the United States.<sup>13</sup> (→ See Figure 30.) A significant addition was Lebanon, where installations rose more than four-fold in 2022 as the removal of subsidies drove up prices for fuel and electricity.<sup>14</sup>

<sup>i</sup> Global data are for solar thermal water collectors (glazed and unglazed) only.

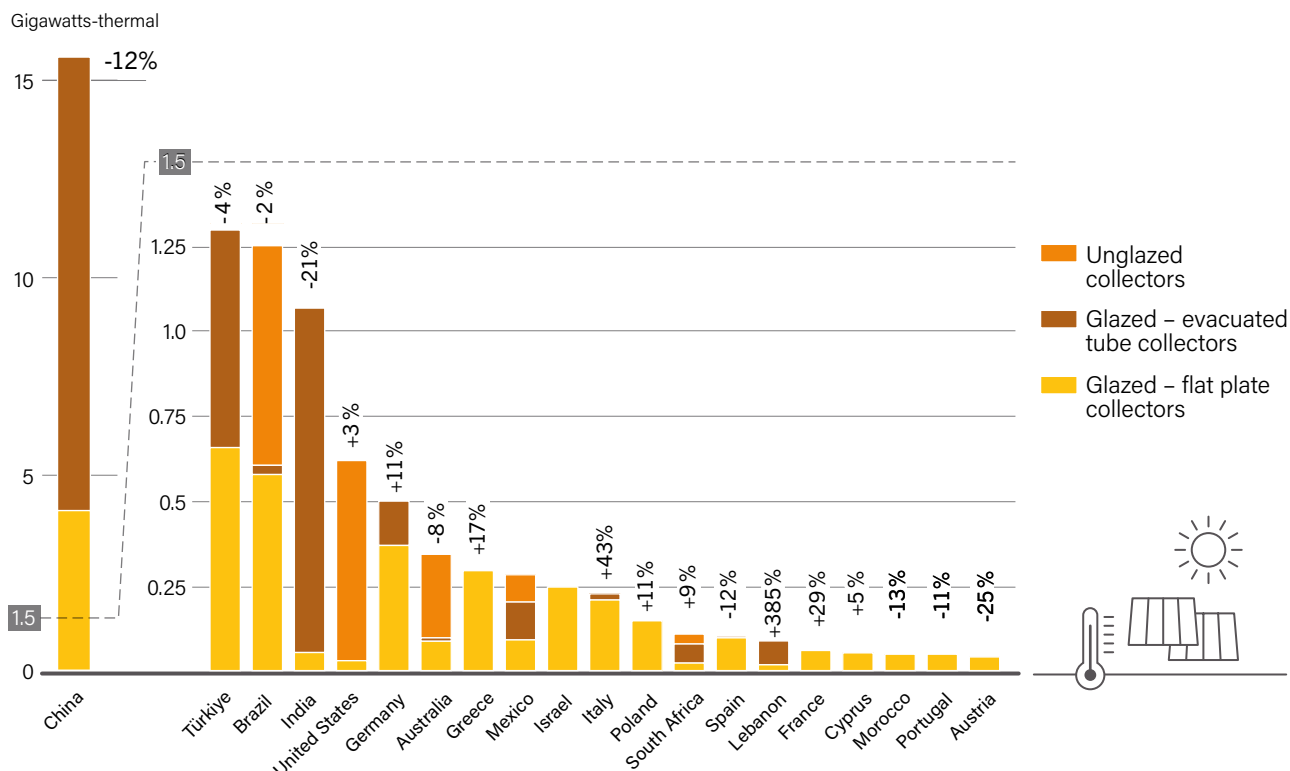
**FIGURE 29.**  
Solar Water Heating Collectors Global Capacity, 2012-2022



Source: IEA SHC. See endnote 10 for this section.

Note: Data are for glazed and unglazed solar water collectors and do not include concentrating, air or hybrid collectors.

**FIGURE 30.**  
Solar Water Heating Collector Additions, Top 20 Countries for Capacity Added, 2022



Source: See endnote 13 for this section.

Note: Additions represent gross capacity added and are rounded to nearest whole number. The additions for Mexico and Israel refer to 2021 (latest data available). For Morocco, the share of collector types was not available.



TOP COUNTRY MARKETS

After stabilising in 2021, **China's** solar thermal sales continued the downward slide that began in 2014, as the market was affected by pandemic-related restrictions and a resulting slowdown in new construction.<sup>15</sup> Even so, the country continued to account for the largest share of global annual sales, at nearly 69%.<sup>16</sup> China added an estimated 15.2 GW<sub>th</sub> (21.7 million square metres, m<sup>2</sup>) in 2022, down 12.3% from 2021, for a total of 396.2 GW<sub>th</sub> (566 million m<sup>2</sup>).<sup>17</sup> By 2022, China's energy savings from the use of solar thermal technologies exceeded an estimated 1 billion tonnes of standard coal.<sup>18</sup>

Sales of vacuum tube collectors in China fell 11%, to 11.2 GW<sub>th</sub>, accounting for nearly three-fourths of total sales, while flat plate sales declined 19%, to 4 GW<sub>th</sub>.<sup>19</sup> Most new installations were in the engineering market<sup>i</sup> (83%), with the rest in the retail market.<sup>20</sup> Water heating remained the primary use for China's solar thermal systems, but the market for space heating continued to expand, up 9.5% in 2022.<sup>21</sup> China's industry moved further towards modularisation and increased intelligence of systems, while price competition became increasingly fierce.<sup>22</sup>

Despite industry expectations of double-digit growth, **Brazil's** market contracted 2.1% relative to 2021, when sales grew 28% to a record high.<sup>23</sup> The decline was due to economic challenges, concern about investment security in advance of state and federal elections, and expected government support policies for solar thermal that did not materialise in 2022.<sup>24</sup> Brazil added a total of 1.26 GW<sub>th</sub> (nearly 1.8 million m<sup>2</sup>), with systems for swimming pools (unglazed collectors) accounting for nearly 52% of the newly installed collector area, or 0.6 GW<sub>th</sub> (920,463 m<sup>2</sup>).<sup>25</sup> Although the residential sector (73%) remained the largest market, solar heating in hotels has increased rapidly, with investments generally paying off in 2-4 years.<sup>26</sup> Brazil's total operating capacity grew 8.5% in 2022, to 9.1 GW<sub>th</sub>.<sup>27</sup>

Following strong growth in 2021, **India's** market declined 21% in 2022.<sup>28</sup> The country added an estimated 1.06 GW<sub>th</sub> (1.52 million m<sup>2</sup>) for a total of 13.9 GW<sub>th</sub> (19.8 million m<sup>2</sup>), close to meeting the Solar

Mission target for 2022.<sup>29</sup> Sales of vacuum tube collectors dropped 19%, while flat plate collector sales fell 50%, to their lowest share (5%) in eight years.<sup>30</sup> The decline was due largely to falling solar PV prices plus a net metering scheme and a newly enacted (2021) federal subsidy for solar PV, which encouraged customers to install solar PV over solar thermal.<sup>31</sup> The state of Karnataka continued to lead with a market share above 75%, due to rising electric rates and a solar building obligation in place since 2007.<sup>32</sup>

As in India, most solar thermal systems in **Türkiye** are residential water heaters; however, systems also have been installed in hotels, hospitals and other facilities, placing the country second after China for the number of large systems in operation.<sup>33</sup> The payback periods for solar thermal along the Mediterranean coast are relatively short due to high irradiation and a good match between hot water demand and the high solar-yield season.<sup>34</sup> Türkiye also is home to the world's largest solar thermal cooling system, inaugurated in 2022.<sup>35</sup> In total, Türkiye added an estimated 1.3 GW<sub>th</sub> in 2022, down more than 4% from 2020, for a cumulative operating capacity of 19.1 GW<sub>th</sub>.<sup>36</sup> The market decline was due to a mix of high inflation, uncertainty about upcoming elections, and competition from natural gas, which is distributed to an increasing number of rural areas.<sup>37</sup>

The **United States** ranked fifth for sales in 2022, adding 617 megawatts-thermal (MW<sub>th</sub>), bringing its total solar thermal capacity to 18.2 GW<sub>th</sub>.<sup>38</sup> As in Brazil and Australia, new pool heating systems drove the US market.<sup>39</sup> The United States remained the second largest market for unglazed collectors (587 MW<sub>th</sub>) after Brazil, followed by Australia (245 MW<sub>th</sub>), where unglazed collectors represented over 71% of 2022 additions.<sup>40</sup>

Unlike in Türkiye, Brazil, and India, where solar water heaters are cost-effective compared to electricity-driven solutions, in the United States and most European countries financial incentives are still needed to reduce upfront investment costs, due to higher equipment and labour costs and in some cases lower solar resources.<sup>41</sup>

Several multi-megawatt plants were under construction in 2022 for commercial and industrial clients, signalling a new era for **big solar thermal** in much of Europe and China.



<sup>i</sup> Chinese statistics characterise systems as either standardised small residential solar water heaters or "engineered" systems, which include larger systems used in, for example, industry, agriculture, public institutions and residential housing projects.

Market strength varied across Europe, with continued expansion in several countries (including Italy, France, Greece and Poland) and surprising growth in Germany, but declines elsewhere (including in Austria and Switzerland).<sup>42</sup> Most solar thermal systems in Europe are on rooftops and are used for residential water heating.<sup>43</sup> The top five European countries for new additions in 2022 were Germany, Greece, Italy, Poland and Spain.<sup>44</sup>

In **Germany**, the world's sixth largest solar thermal market, annual sales were up 11%, with an estimated 91,000 solar thermal systems added, totalling 496 MW<sub>th</sub> (709,000 m<sup>2</sup>).<sup>45</sup> This was Germany's third year of market stability or growth following several years of contraction.<sup>46</sup> The increase came despite supply bottlenecks and weakened demand in construction and renovation caused by economic uncertainty, and was due to rising fuel prices and continued national funding for residential installations.<sup>47</sup> By the end of 2022, Germany reached an estimated 15.5 GW<sub>th</sub> (22.1 million m<sup>2</sup>) of capacity in operation.<sup>48</sup>

The second largest European market, **Greece**, added a record 293 MW<sub>th</sub> (419,000 m<sup>2</sup>), up 17% over 2021, for a total of 3.8 GW<sub>th</sub> (5.4 million m<sup>2</sup>) in operation.<sup>49</sup> The Greek market was driven mainly by high electricity prices and a desire to shift away from fossil fuels.<sup>50</sup> Greece's solar thermal industry is growing rapidly, with annual production of collector area rising from 540,000 m<sup>2</sup> in 2014 to 1.2 million m<sup>2</sup> in 2021.<sup>51</sup> Domestic sales were up 33% over this period while exports tripled, accounting for 70% of 2021 production.<sup>52</sup> Production increased a further 19.4% in 2022, and exports rose 21%.<sup>53</sup>

**Italy's** market expanded 43% in 2022, to an estimated 225 MW<sub>th</sub>.<sup>54</sup> This followed a record 83% increase in 2021, the first positive year after more than a decade of contraction.<sup>55</sup> The increases were driven mainly by the Superbonus<sup>i</sup>, a 110% tax reduction for energy efficiency measures that include replacing fossil boilers with renewable heating systems.<sup>56</sup>

In **Poland**, additions increased 11% over 2021, to 147 MW<sub>th</sub> (210,000 m<sup>2</sup>), with flat plate collectors accounting for more than 99%<sup>ii</sup> of the market.<sup>57</sup> Increased public investment combined with rising fossil fuel prices and the threat of fuel supply disruption drove the market.<sup>58</sup> At year's end, Poland had an estimated 2.4 GW<sub>th</sub> (3.4 million m<sup>2</sup>) in operation.<sup>59</sup>

As in 2021, **Spain** was the only top-five European market where additions fell during the year.<sup>60</sup> The 12% decline in 2022 followed a 24% decline over the period 2017-2021, with an estimated 102 MW<sub>th</sub> (145,500 m<sup>2</sup>) added in 2022.<sup>61</sup> Solar thermal has struggled to compete with solar PV, which is widely publicised and is the focus of most solar installers, making it difficult to find installers for solar thermal systems.<sup>62</sup> This is despite significant government incentives, such as grants for industry and for up to 60% of some residential installations.<sup>63</sup>

## DISTRICT HEATING

Although most solar thermal capacity installed globally continued to be for water heating in individual buildings, the use of solar thermal technology in district heating continued to expand in 2022. The leading market was China, followed by Germany.<sup>64</sup> Additional plants, or extensions of existing ones, were commissioned in Austria, Denmark and Italy (where two new plants came online).<sup>65</sup> By year's end, 325 large-scale<sup>iii</sup> solar thermal district heating systems with a total capacity of nearly 1.8 GW<sub>th</sub> (2.56 million m<sup>2</sup>) were documented as operating around the world, many of them with seasonal storage capacity.<sup>66</sup>

**China** reported<sup>iv</sup> commissioning a total of 119.7 MW<sub>th</sub> (171,068 m<sup>2</sup>) in an estimated 25 solar district heating systems.<sup>67</sup> By the end of 2022, the country had around 67 solar district heating systems totalling 400 MW<sub>th</sub>.<sup>68</sup> Work continued on the 79.8 MW<sub>th</sub> (114,000 m<sup>2</sup>) plant for a tourism resort in Handan Bay; the facility, due to open in 2023, will use parabolic trough collectors to supply water and space heating for the hotel and an indoor pool, as well as ice and snow for an indoor ski slope.<sup>69</sup>

**Germany** had a record year, with eight plants (totalling 30.8 MW<sub>th</sub> or 44,000 m<sup>2</sup>) starting operations in 2022, compared with nine plants (33 MW<sub>th</sub>) in all of Europe during 2021.<sup>70</sup> Large systems for district heating remain a small segment (6%) of the German market but saw the strongest growth in 2022, driven by solar thermal's potential to achieve climate protection goals while making energy supply less susceptible to crises and stabilising district heating prices.<sup>71</sup>



i The Superbonus entered into force in 2021, and in 2022 it was extended through 2025 (with rates decreasing over time).

ii This represents a marked shift away from vacuum tube systems in Poland, where vacuum tube collectors account for 15% of total operating capacity. See endnote 59 for this section.

iii Solar district heating systems are considered to be large-scale if they are more than 350 kilowatts-thermal (500 m<sup>2</sup>).

iv China's national statistics do not distinguish between collector fields heating individual buildings and those heating multiple buildings via district networks.

Germany's largest new plants were a 13.1 MW<sub>th</sub> (18,732 m<sup>2</sup>) system in Greifswald, on the Baltic Sea, and a 5.2 MW<sub>th</sub> (9,118 m<sup>2</sup>) system in the town of Lemgo, which is combined with natural gas-driven combined heat and power plants and a heat pump.<sup>72</sup> By the end of 2022, 48 solar district heating plants totalling 99.8 MW<sub>th</sub> (142,500 m<sup>2</sup>) were operating in Germany, with a further 9 plants (21.8 MW<sub>th</sub>) under construction or in advanced planning, and around 50 plants (200 MW<sub>th</sub>) in preparation.<sup>73</sup> A growing number of projects have been initiated by local energy co-operatives.<sup>74</sup>

Only one solar district heating system began operating in **Denmark** during 2022, a 1.9 MW<sub>th</sub> (2,664 m<sup>2</sup>) project in the city of Hørsholm, following one new plant in 2021.<sup>75</sup> Despite limited additions in 2021 and 2022, Denmark remained the world leader in solar district heating, with 123 systems totalling more than 1.1 GW<sub>th</sub> (1.6 million m<sup>2</sup>) operating at the end of 2022.<sup>76</sup> Despite the spike in electricity prices, which helped highlight solar thermal's potential to provide low-cost heat, there were no signs that Denmark's solar thermal market would return to its previous scale under existing policies.<sup>77</sup> The country has prioritised renewable electricity (particularly wind energy), with policy support driving a huge shift from solar thermal to heat pumps in district heating starting in 2020.<sup>78</sup> However, public funding expanded in 2022 to include solar thermal.<sup>79</sup>

Total solar collector sales in **Austria** fell 15% in 2022, despite a significant extension to a large system for district heating in Graz.<sup>80</sup> However, high energy prices and a government campaign to renovate buildings and move away from oil and natural gas sparked new interest in solar thermal for district heating.<sup>81</sup> In early 2023, 27 feasibility studies were under way for nearly 1 million m<sup>2</sup> of solar collector area.<sup>82</sup>

Elsewhere in Europe, rising concerns about energy security, heightened by the Russian Federation's war on Ukraine, overtook climate change and air quality concerns as the primary motivator for new systems in the Western Balkan countries.<sup>83</sup> The European Bank for Reconstruction and Development (EBRD) extended its solar district heating support to additional cities in Albania, Bosnia and Herzegovina, Kosovo and Serbia in 2022.<sup>84</sup> The European Commission, Germany's KfW bank and the EBRD, together with a local contribution, will fund a 40.6 MW<sub>th</sub> collector field with absorption heat pumps and a 408,000 m<sup>3</sup> seasonal storage facility in Kosovo's capital, Pristina.<sup>85</sup>

According to one estimate, solar thermal provides 3 times the energy yield per area of solar PV and up to 43 times that of biomass or ethanol for heat.<sup>86</sup> Despite rising concerns about heat costs and energy security in many countries, obstacles remain, including a lack of awareness about the benefits of solar thermal in district heating, competition with heat pumps, challenges finding suitable sites for large installations close to urban areas with heat networks, and lengthy permitting processes, which are causing bottlenecks across Europe.<sup>87</sup>

Lack of awareness about the benefits of solar thermal systems and competition with solar PV and heat pumps are slowing their adoption.



i In September, Germany introduced a federal subsidy for efficient heating networks that includes large-scale solar thermal projects and is available to municipalities, energy suppliers and energy communities. See endnote 74 for this section.

## INDUSTRIAL HEAT

Solar thermal technologies provide emission-free heat for numerous industrial processes<sup>i</sup> requiring low (below 150°C) or medium (150-400°C) temperature heat.<sup>88</sup> Industrial companies around the world are turning to renewable heat solutions, including solar heat technologies, to meet social and environmental goals and to achieve energy price stability<sup>ii</sup>.<sup>89</sup>

More **solar industrial heat plants** (SHIPs) began operation in 2022 than in any other year since surveys began in 2017.<sup>90</sup> At least 114 SHIP projects with a total capacity of 30 MW<sub>th</sub> came online during the year, up from 78 completed projects in 2021, although the total capacity installed was lower (down from 36 MW<sub>th</sub>).<sup>91</sup> By the end of 2022, at least 1,089 SHIP installations, totalling more than 856 MW<sub>th</sub>, were supplying process heat to factories worldwide.<sup>92</sup> Food and beverage industries had the largest number of systems, and the mining sector had the largest share (59%) of total operating capacity.<sup>93</sup>

Nine different technology types<sup>iii</sup> for SHIP were installed in 2022.<sup>94</sup> Most systems in operation use flat plate collectors, followed by parabolic trough collectors and vacuum tubes.<sup>95</sup> At least in Europe, the market is expanding for parabolic trough, linear Fresnel and concentrating dish collectors, which can provide temperatures above 100°C.<sup>96</sup> As in other sectors, there is a growing interest in combining solar thermal technologies with heat pumps.<sup>97</sup>

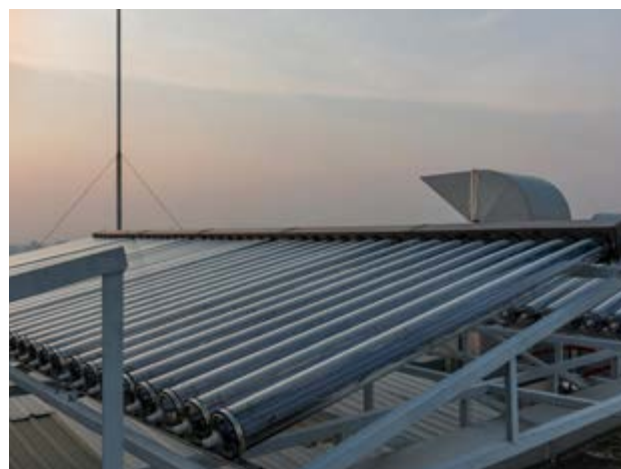
The list of countries with the highest numbers of newly commissioned SHIP projects<sup>iv</sup> changed again in 2022, with the Netherlands taking the lead over China and Mexico with 38 systems, followed by China (17), France (14), Mexico (13) and Germany (9).<sup>98</sup> The leading markets for new capacity installed<sup>v</sup> were the Netherlands (7.3 MW<sub>th</sub>), China (7.2 MW<sub>th</sub>), the United States (5.4 MW<sub>th</sub>) and Spain (2.8 MW<sub>th</sub>).<sup>99</sup>

In China, completed projects used a variety of technologies for applications in dairies, textiles, vehicle manufacturing, petroleum refining, and other industries, with the largest facility having 3,570 m<sup>2</sup> of gross collector area.<sup>100</sup> Outside of China, the number of annual installations nearly doubled from 55 systems in 2020 (totalling 22 MW<sub>th</sub>) to 97 in 2022 (23 MW<sub>th</sub>).<sup>101</sup> The Netherlands and France (1.8 MW<sub>th</sub>) led in Europe due to a large number of subsidised agricultural systems.<sup>102</sup> After several years with little activity, the United States brought online four new systems, including its first solar steam boiler.<sup>103</sup>

In most major markets, demand for SHIP systems is driven by policy incentives.<sup>104</sup> Despite high fossil fuel prices in 2022, SHIP project developers faced significant obstacles to concluding contracts.<sup>105</sup> Even where SHIP is cost-competitive without public support, the lack of awareness about the benefits of solar heat has led to limited progress.<sup>106</sup> Of the 114 systems completed in 2022, only 20 did not receive government funding.<sup>107</sup> However, in Mexico rising fossil fuel costs and interest in reducing carbon emissions have boosted interest in SHIP projects without government subsidies.<sup>108</sup> Latin America's first purchase agreement<sup>vi</sup> for solar-generated steam was signed in Mexico in 2022.<sup>109</sup>

Such **heat purchase agreements** are increasingly common and are moving SHIP into new markets.<sup>110</sup> Projects under development in France (dairy), Spain (brewery) and Belgium (chemical producer) all were realised under heat purchase agreements, which minimise the market risk for investors<sup>vii</sup>.<sup>111</sup>

In recent years, several suppliers have left the SHIP sector while new ones have entered, with the share of those offering concentrating solar thermal solutions increasing from 31% in 2017 to 41% in 2022.<sup>112</sup> SHIP remains a challenging sector because awareness of the options remains low, clients typically want short payback periods, and projects require significant lead time<sup>viii</sup>.<sup>113</sup> GlassPoint (United States), which built the world's largest SHIP plant in Oman (33 MW<sub>th</sub>) in 2019, was liquidated in 2020 but restarted operations in 2022, committing to develop a 1.5 GW<sub>th</sub> solar steam plant<sup>ix</sup> for a mining company in Saudi Arabia.<sup>114</sup>



- i Industries include chemical (boiling, distilling), food and beverage (drying, boiling, pasteurising, sterilising), machinery (cleaning, drying), mining (copper electrolytic refining, mineral drying, nitrate melting), textile (washing, bleaching, dyeing) and wood (e.g., steaming, compressing, drying).
- ii Significant energy price volatility has increased interest in solar thermal solutions; however, those same price fluctuations have slowed decision processes as industrial companies are uncertain about at what level it is most attractive to lock in a price. See endnote 89 for this section.
- iii These included flat plate (39%), vacuum tube (24%), parabolic trough (12%), air collectors (11%), high-temperature flat plate (6%), linear Fresnel (4%), PVT (3%), unglazed polymer (1%) and concentrating dish (0.4%). Concentrating collectors were mostly parabolic trough, but included three new linear Fresnel systems in Spain and some concentrating dish capacity (making up 0.4% of total SHIP installations). See endnote 94 for this section.
- iv In 2021, the rankings for number of systems installed were China first, followed by Mexico, the Netherlands and Austria. Note that China's numbers are likely higher than reported and vary from year to year due to fluctuations in reporting. See endnote 98 for this section.
- v In 2021, the top countries for capacity installed were France, China and Türkiye. See endnote 99 for this section.
- vi Under the agreement, the client is charged per tonne of steam monthly, saving money compared to the previous fossil-based system.
- vii However, even in countries where SHIP systems are competitive with fossil fuels, government incentives remain critical for increasing awareness and encouraging clients to sign heat purchase contracts. See endnote 111 for this section.
- viii In addition to project contracting, planning and construction, industry decisions have been slowed by as much as 6-12 months because many potential consumers want to apply for government subsidies, even when solar thermal systems are offered at a competitive price. See endnote 113 for this section.
- ix The plant will replace natural gas in the refining of bauxite into alumina, and is expected to reduce the company's carbon footprint by an estimated 50%. See endnote 114 for this section.



## KEY FACTS WIND POWER

- An estimated 89 GW of wind power capacity was mechanically installed in 2022, of which more than 77 GW was added to the world's grids, bringing the total grid-connected capacity to an estimated 906 GW.
- Global grid-connected additions fell more than 17% due mainly to slowdowns in China and the United States; Europe was the only region where installations rose.
- Countries around the world increased their wind power targets, driven by climate change, energy security, and economic growth goals, as well as the cost-competitiveness of wind energy.
- While offshore installations declined relative to 2021, due mainly to a temporary slowdown in China, the global pipeline nearly doubled in 2022 to nearly 1.2 terawatts across 38 countries.
- The industry continued to innovate to change the cost base of projects; to address challenges associated with scaling up production, transport and other logistical issues; and to enhance the value of wind energy while further improving its environmental and social sustainability.

More than 77 GW<sup>i</sup> of wind power capacity – including 68.4 GW onshore and nearly 8.8 GW offshore – was added to the world's grids in 2022, increasing the total operating capacity 9% to an estimated 906 GW.<sup>1</sup> (→ See Figure 37.) In total, an estimated 89 GW<sup>ii</sup> was mechanically installed around the world during 2022.<sup>2</sup>

The year 2022 was the third largest ever for new installations.<sup>3</sup> However, relative to 2021, global grid-connected additions fell more than 17% (5% onshore and 58% offshore) due mainly to slowdowns in China and the United States; Europe was the only region where installations rose in 2022.<sup>4</sup> Investment in future projects also dropped in all regions except Asia-Pacific, even as many countries increased their ambitions for wind power and as fossil fuel prices surged, making renewables more competitive.<sup>5</sup>

The top policy mechanisms supporting wind power installations in 2022 were China's "grid parity" scheme, auctions in multiple countries, and the US Production Tax Credit.<sup>6</sup> Countries around the world increased wind power targets, driven by climate change, energy security and economic growth goals, as well as the cost-competitiveness of wind energy.<sup>7</sup> Private sector power purchase agreements (PPAs) also played a key role in driving demand for new capacity, with an estimated 10.9 GW of contracts signed in 2022.<sup>8</sup>

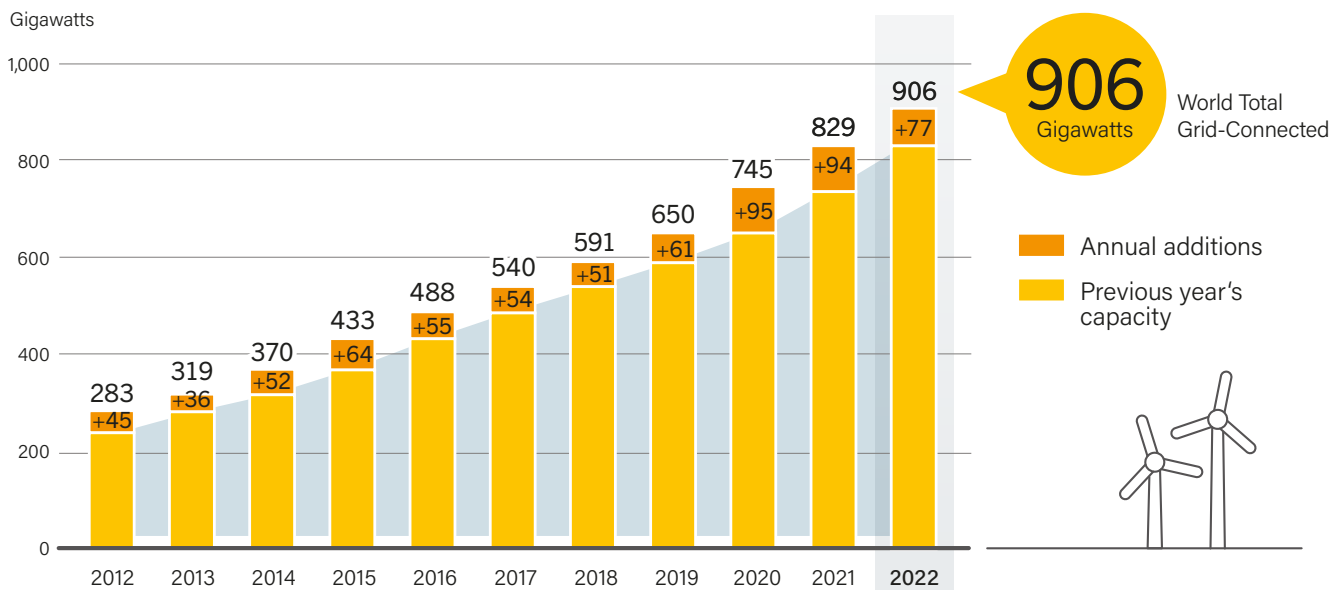
Despite the competitiveness of wind energy and ambitious national targets, new obstacles in 2022 compounded existing challenges, affecting installations and investments, the health of the wind industry and its ability to scale production to meet future demand.<sup>9</sup> Pressured by policies that for years focused almost exclusively on achieving the lowest possible price of wind energy, manufacturers have raced to build ever-larger turbines – at great expense – to compete on price.<sup>10</sup> Delayed permitting for new projects has constrained deployment across much of the world, as have protracted, complex and expensive grid planning and long grid connection queues.<sup>11</sup> The COVID-19 pandemic disrupted supply chains, created logistics challenges, pushed up costs for shipping and materials, and delayed projects<sup>iii</sup> – challenges that continued into 2022.<sup>12</sup>

i Additions are gross (although only a few countries decommissioned significant amounts of capacity in 2022). See endnote 1 for this section.

ii Global additions in 2022 were an estimated 89 GW, for a year-end total of at least 934 GW mechanically installed, including capacity added in China and Vietnam but not officially grid-connected at the end of 2022. Starting with this edition of the GSR, only grid-connected additions are included in text and figure data, unless otherwise noted. "Mechanically installed" refers to capacity that is installed in place and ready to produce electricity but not necessarily officially connected to the grid. See endnote 2 for this section.

iii Project delays created additional challenges as many manufacturers were bound by pre-existing contracts, resulting in sales at significant loss.

**FIGURE 31.**  
**Wind Power Global Capacity and Annual Additions, 2012-2022**



Source: See endnote 1 for this section.  
Note: Totals may not add up due to rounding. Additions in 2022 are gross.

Throughout the year, shortages of skilled labour and inflation – exacerbated by the Russian Federation's war on Ukraine – pushed energy and materials costs higher, further impacting the profitability of both onshore and offshore<sup>i</sup> wind energy.<sup>13</sup> Unfavourable policies and shifting regulatory landscapes in

In 2022, the top western wind turbine manufacturers all saw heavy financial losses.

many countries increased market uncertainty, while developers delayed projects due to rising costs and interest rates, thereby reducing new turbine orders.<sup>14</sup> Western manufacturers also faced increased competition from Chinese turbine makers, which have pro-actively pursued sales overseas.<sup>15</sup>

For the top European and US manufacturers, these trends resulted in job cuts, shuttered facilities and underinvestment in new manufacturing capacity, at a time when expansion of production is needed to meet ambitious government targets.<sup>16</sup> The top western wind turbine manufacturers all saw heavy financial losses in 2022, despite rising fossil fuel prices and turmoil in natural gas markets, and even as fossil fuel companies saw record profits.<sup>17</sup>



<sup>i</sup> Offshore wind power was long shielded from the challenges facing onshore wind power because of the long time frame from planning to completion. See endnote 13 for this section.

Large manufacturers in China have fared better in recent years thanks to predictable policies and a large domestic steel industry, but also have witnessed eroding profits.<sup>18</sup> Following on western manufacturers, which began raising turbine prices in 2021, China's Goldwind noted in early 2022 that, after years of dramatic price reductions, there was no more room for prices to fall.<sup>19</sup>

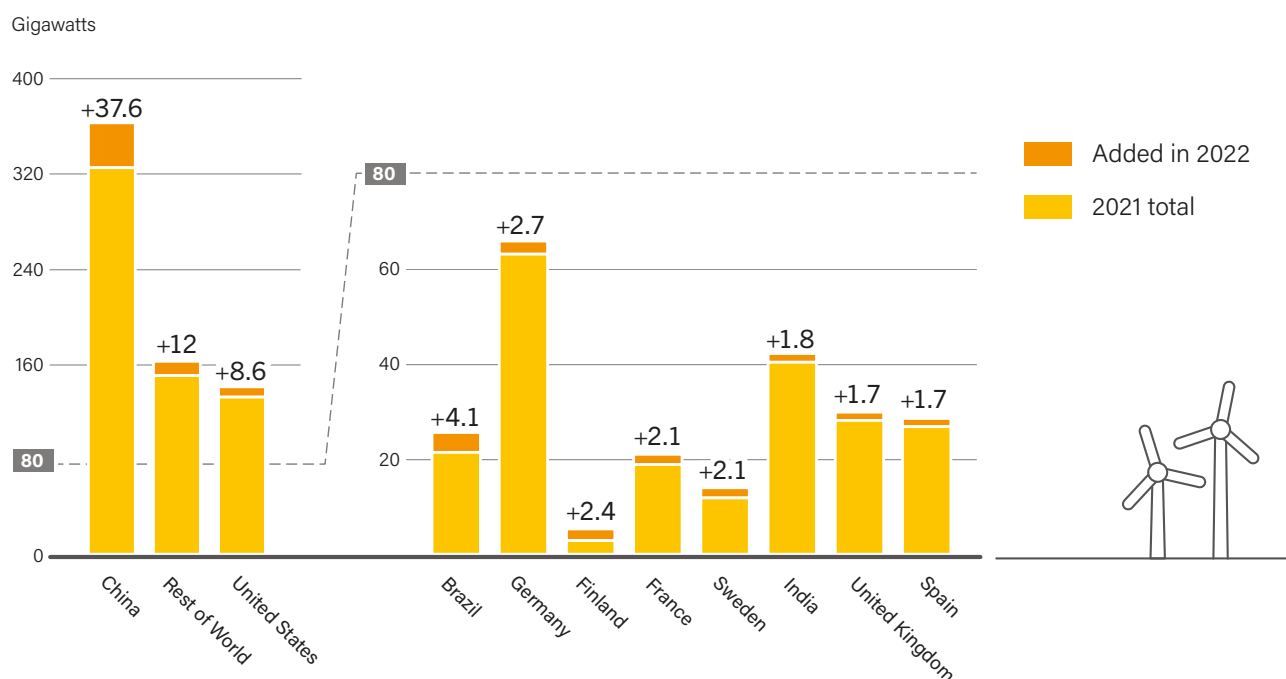
Against such challenges, the industry (at least outside of China) has expressed the need for policy makers to address barriers related to permitting and grid access and to take a more holistic approach, prioritising the economic and societal benefits of wind power rather than focusing solely on minimising price.<sup>20</sup> On a positive note, non-price criteria are increasingly being included in policy design, at least for offshore wind auctions in Europe.<sup>21</sup> In addition, strong community engagement and local investment have helped reduce local resistance to projects and speed the permitting process in many countries.<sup>22</sup>

### TOP MARKETS

New wind farms reached full commercial operation in at least 45 countries in 2022, down from 52 countries in 2021.<sup>23</sup> For the 15th consecutive year, Asia (mostly China) was the largest regional market, representing 55% of new grid-connected capacity (down from 58% in 2021).<sup>24</sup> Most of the remaining installations were in Europe (23%), home to 6 of the top 10 countries worldwide; North America (12%); and Latin America and the Caribbean (6.8%).<sup>25</sup> By country, China was followed distantly by the United States, which was well ahead of Brazil, Germany and Finland; these five countries together accounted for almost 72% of annual installations.<sup>26</sup> Other countries in the top 10<sup>i</sup> for total capacity additions were France, Sweden, India, the United Kingdom and Spain.<sup>27</sup> (→ See Figure 32.) The list of the 10<sup>ii</sup> leading countries for cumulative capacity remained the same as in 2021.<sup>28</sup>

- i The top 10 markets in 2021 were China, the United States, Brazil, Vietnam, the United Kingdom, Sweden, Germany, Australia, India and Türkiye. To rank among the top 10 in 2022, annual installations of more than 1.6 GW were required, up from 1.4 GW in 2021 and 1.1 GW in 2020. See endnote 27 for this section.
- ii The top 10 countries for cumulative capacity at the end of 2021 and 2022 were China, the United States, Germany, India, Spain, the United Kingdom, Brazil, France, Canada and Sweden.

**FIGURE 32.**  
Wind Power Capacity and Additions, Top 10 Countries, 2022



Source: See endnote 27 for this section.

Note: Numbers above bars are gross additions, but bar heights reflect year-end totals. Net additions were lower for China (36.5 GW), the United States (8.3 GW) and Germany (2.5 GW) due to decommissioning. Totals may not add up due to rounding.

**China** completed its shift to “grid parity” at the start of 2022 with the expiration of the national feed-in tariff (FIT) for offshore projects, meaning that all new wind projects receive the regulated price for coal-fired generation in each province.<sup>29</sup> Installers connected 37.6 GW<sup>i</sup> of wind capacity to the national grid (32.6 GW onshore and more than 5 GW offshore), accounting for more than half of global additions in 2022.<sup>30</sup> Although land-based grid-tied additions rose 6.2%, to 32.6 GW (net of 31.5 GW after decommissioning), total grid-connected installations declined nearly 21% as new offshore capacity fell more than 70% following the policy-driven boom in 2021.<sup>31</sup> Project commissioning late in the year also was slowed significantly by pandemic-related restrictions.<sup>32</sup>

At the end of 2022, China’s total grid-connected wind power capacity was 365.4 GW, including 334 GW onshore and 31.4 GW offshore.<sup>33</sup> Wind generation rose 16.3% in 2022 and accounted for 8.8% of Chinese electricity production, up from 7.8% in 2021 and 6.1% in 2020.<sup>34</sup> In late December, the government announced a target to reach 430 GW of wind power capacity by the end of 2023.<sup>35</sup>

China continued to dominate wind turbine manufacturing as well as the global supply chain for critical components (with a market share of more than 70%) and raw materials.<sup>36</sup> The country accounts for some 60% of global turbine and component manufacturing capacity.<sup>37</sup> Although most Chinese-made turbines continue to be installed domestically, declining demand and fierce competition at home has triggered price wars and pushed manufacturers to turn elsewhere, and the competitive pricing and technological improvements of Chinese turbines have attracted greater international interest.<sup>38</sup> Six of the world’s top 10 turbine producers in 2022 were based in China; the remaining four were Vestas (Denmark), which by some accounts was edged out for first place by China’s Goldwind, followed by Siemens Gamesa (Spain), GE (US) and Nordex Group (Germany).<sup>39</sup>

The **United States** continued to rank second for capacity additions and year-end total. However, US installations in 2022 were down 37% relative to 2021, totalling 8.6 GW<sup>iii</sup> (gross additions, all onshore), the country’s lowest annual additions since 2018.<sup>40</sup> Both the nascent offshore sector and more than 10 GW of onshore capacity were delayed due to supply chain constraints, grid interconnection issues and policy uncertainty.<sup>iv,41</sup> By year’s end, the United States had 144.2 GW (including 42 MW offshore) of wind power capacity in operation.<sup>42</sup> Wind energy accounted for 10.2% of US utility-scale electricity generation in 2022, up from 9.2% in 2021.<sup>43</sup>

The US pipeline of projects also declined (down 13%) in 2022; at year’s end, capacity in advanced development exceeded 26.7 GW, of which 16.7 GW was offshore.<sup>44</sup> Announcements for wind PPAs rose 15% relative to 2021, although they were below those for the period 2018-2020.<sup>45</sup> PPA prices also increased, by 27% year-on-year, but fell late in 2022 for the first time since 2020 as the US Inflation Reduction Act began to have some effect.<sup>46</sup>

The third ranking country for newly installed capacity was **Brazil**, for the third year running. Wind represented almost half of the country’s new power capacity, with record additions of nearly 4.1 GW.<sup>47</sup> Brazil accounted for almost 80% of installations in Latin America and the Caribbean during 2022.<sup>48</sup> The country’s strong growth was driven by public auctions and particularly by private PPAs, with the shift towards corporate PPAs continuing.<sup>49</sup> Wind energy has achieved the country’s lowest free market price for electricity.<sup>50</sup> At the end of 2022, Brazil had more than 25.6 GW of operating wind power capacity.<sup>51</sup> Wind energy was the country’s second largest source of electricity after hydropower, accounting for 13.6% of the mix in 2022.<sup>52</sup>

Europe was the only region where installations were up in 2022, with record additions of **17.9%**.



i The Chinese Wind Energy Association reported that 44.7 GW was mechanically installed onshore, but more than 12 GW of this capacity was not grid-connected by year’s end. See endnote 30 for this section.

ii As of the end of 2022, more than 4,000 Chinese turbines had been exported, representing a cumulative capacity of around 12 GW, or less than 3% of non-Chinese capacity. See endnote 38 for this section.

iii In addition, 11 projects were partially repowered (1.8 GW) during the year and 6 completed full repowering (0.5 GW). See endnote 40 for this section.

iv The Production Tax Credit expired at the end of 2021 but was increased and extended in August 2022 with passage of the Inflation Reduction Act (IRA). The IRA’s impact on the wind industry was muted during 2022 by lack of guidance about how to access credits. See endnote 41 for this section.





**Europe** placed second after Asia for regional share of new global installations and accounted for all of the remaining top 10 countries, with the exception of India. It was the only region where installations increased in 2022, up nearly 12%.<sup>53</sup> All of Europe added a record 17.9 GW (net 17.4 GW<sup>i</sup>) of capacity in 2022, most of which was installed onshore (86.2%), for a year-end total of 242.4 GW (212.1 GW onshore and 30.3 GW offshore).<sup>54</sup> The EU accounted for most of the installations, adding nearly 15.8 GW (14.5 GW onshore, more than 1.2 GW offshore) to total 204.1 GW (187.8 GW onshore and nearly 16.3 GW offshore).<sup>55</sup>

Despite the region's record installations in 2022, an estimated 80 GW of capacity was stuck in permitting procedures across the EU and Norway at year's end.<sup>56</sup> Individual countries worked to simplify planning procedures during the year, and in December the EU formally agreed on emergency measures to address permitting challenges.<sup>57</sup>

Across the EU Member States, targets for wind power capacity total around 423 GW by 2030.<sup>58</sup> In 2022, however, Europe's turbine orders fell 36% (to 10.7 GW), following a smaller decline in 2021.<sup>59</sup> Investment in new projects reached the lowest level since 2009, due to high inflation and government market interventions that undermined investor confidence.<sup>60</sup>

The region's top installers were Germany, Finland, France, Sweden, the United Kingdom (which lost the regional lead after regaining it in 2021) and Spain.<sup>61</sup> These six countries accounted for nearly 60% of Europe's annual wind power installations and were all among the global top 10.<sup>62</sup> Except for Sweden and the

United Kingdom, annual additions increased significantly in all of these countries in 2022.<sup>63</sup>

**Germany** claimed Europe's top spot for new capacity in 2022 and ranked fourth globally. The country added more than 2.7 GW (2.4 GW onshore, 0.3 GW offshore) and decommissioned nearly 0.3 GW, for a year-end total of more than 66.3 GW (almost 58.3 GW onshore, 8.1 GW offshore).<sup>64</sup> Net installations were up sharply (46.5%) over 2021 but still well below the peak of 6.1 GW in 2017, the last year in which new capacity qualified under Germany's FIT system.<sup>65</sup> Wind energy generation increased 9%<sup>ii</sup> in 2022, to 125.3 TWh.<sup>66</sup>

To accelerate deployment, Germany committed to installing 10 GW of onshore wind power annually starting in 2025 and set new targets for offshore capacity.<sup>67</sup> During 2022, however, all wind-specific auctions in Germany were undersubscribed, and at year's end investor confidence was down due to an impending levy<sup>iii</sup> on profits from generation.<sup>68</sup> Such measures, intended to help consumers deal with the energy crisis sparked by the Russian Federation's war on Ukraine, have reportedly stifled development in other European countries as well.<sup>69</sup>

Following Germany for new wind power capacity was **Finland**, which had a record year with 2.4 GW added (all onshore), to rank second in Europe and fifth worldwide.<sup>70</sup> Finland's total operating wind power capacity rose more than 74%, to 5.7 GW, as the country worked to achieve net zero emissions by 2035 and speed its transition from imported fuels.<sup>71</sup> Finland met around 14% of its electricity demand with wind energy in 2022.<sup>72</sup>

i The difference is due to decommissioning. See endnote 54 for this section.

ii However, it was down relative to 2019 and 2020, due to low wind speeds for much of 2022. See endnote 66 for this section.

iii The levy would take 90% of wind (and solar) energy profits above EUR 130 (USD 138.8) per MWh, or above a benchmark based on the feed-in tariff assigned to a specific project. Other EU Member States also began imposing limits on electricity prices, including at levels below those agreed by the EU in September 2022. See endnote 68 for this section.

**France** also set a new record for annual installations, ranking third in Europe and sixth worldwide.<sup>73</sup> The country added nearly 2.1 GW in 2022, including the first commercial-scale wind project off French shores, for a year-end total approaching 21.1 GW (almost 20.7 GW onshore and nearly 0.5 GW offshore).<sup>74</sup> Wind energy met an estimated 8% of France’s electricity demand during the year.<sup>75</sup>

Annual installations in **Sweden** fell slightly, but 2022 was still the country’s second strongest year ever, with nearly 2.1 GW added (all onshore) for a total of 14.2 GW (including 0.2 GW offshore).<sup>76</sup> The country ranked fourth in Europe and seventh globally for new capacity.<sup>77</sup> Sweden does not use auctions to support deployment of wind power capacity, but the domestic industry is supported by a strong PPA market.<sup>78</sup> Wind energy generation made up for a 6% drop in hydropower output during 2022 and, in the first two months of 2023, it accounted for 27% of Sweden’s total generation.<sup>79</sup>

Despite a 36% decline in additions relative to 2021, the **United Kingdom** continued to rank among the top countries in Europe (fifth) and the world (ninth).<sup>80</sup> Onshore additions rose slightly (0.5 GW), while offshore installations fell nearly 50% (below 1.2 GW), following a record year in 2021.<sup>81</sup> After several years of low onshore installation rates, the UK government signalled plans to relax restrictions on land-based construction set in 2015.<sup>82</sup> At year’s end, total capacity approached 28.5 GW (14.6 GW onshore, 13.9 GW offshore).<sup>83</sup> Thanks to increased capacity and good winds, UK wind farms generated a record 74 TWh in 2022, enough to power more than 19 million British homes and helping to reduce reliance on natural gas.<sup>84</sup>

**Spain** added nearly 1.7 GW (all onshore), more than twice the additions of 2021, bringing total capacity to 29.8 GW.<sup>85</sup> The country ranked sixth in Europe and tenth globally for new installations. Spain’s only onshore wind power auction in 2022 saw poor results due to a very low secret-bidding price cap; on the positive side, the country launched a scheme to support the repowering of old turbines.<sup>86</sup> Wind energy generation increased slightly over 2021 to an estimated 61 TWh.<sup>87</sup>

As of 2022, global off-shore wind targets aim to install **380 GW** by 2030.

Over the past two decades, the EU has seen a consistent increase<sup>i</sup> in wind energy’s output and share of total electricity demand.<sup>88</sup> In 2022, wind generation in the EU and United Kingdom combined was up more than 9%, due to new installations and strong winds in many countries, and met around 17.3% of electricity demand (14.1% onshore, 3.2% offshore).<sup>89</sup> Denmark (55%) and Ireland (34%) had the highest wind energy shares in their electricity mix, and shares exceeded 20% in the United Kingdom (28%), Germany (26%), Portugal (26%), Spain and Sweden (both 25%).<sup>90</sup> At year’s end, Germany continued to lead in Europe for total wind power capacity, with 66.3 GW, followed by Spain (29.8 GW), the United Kingdom (28.5 GW), France (21.1 GW) and Sweden (14.2 GW).<sup>91</sup> These five countries together accounted for nearly 66% of the regional total.<sup>92</sup>

**India** also ranked among the world’s top 10 countries for wind power additions in 2022, rising one spot to rank eighth.<sup>93</sup> Although installations remained below the peak in 2017, when India shifted from FITs to tendering via “reverse auctions”<sup>ii</sup>, annual installations were up 26.6% over 2021, to 1.8 GW, for a year-end total exceeding 41.9 GW (all onshore).<sup>94</sup> Despite this market growth, India did not meet its national target of 60 GW by 2022.<sup>95</sup>

**OFFSHORE WIND**

In the offshore wind power segment, six countries in Europe and three in Asia added nearly 8.8 GW of capacity in 2022, for a global total of 64.3 GW.<sup>96</sup> Wind turbines operating offshore accounted for 11.4% of new grid-connected wind power capacity in 2022 and represented more than 7% of total capacity operating at year’s end.<sup>97</sup> Installations were down 59% from the record high in 2021, due almost entirely to a decline in China, but 2022 was still the second highest year for additions.<sup>98</sup> China continued to lead the sector for the fifth consecutive year, with nearly 58% of new capacity, and Europe and Chinese Taipei installed nearly all the rest.<sup>99</sup>

China added 5.1 GW of offshore wind power capacity in 2022, followed in Asia by Chinese Taipei (1.2 GW), where the country’s first offshore project began commercial operation, and Japan (84 MW).<sup>100</sup> (→ See *Snapshot: Japan*) China’s dramatic decline in added capacity (down from 16.9 GW in 2021) was due mostly to a slowdown after the rush to commission projects before the national FIT expired at the end of 2021, as well as to pandemic-related restrictions.<sup>101</sup> In late 2022, China’s largest unsubsidised offshore wind power project (0.9 GW) entered full operations off the coast of Guangdong Province.<sup>102</sup> In total, the country had 31.4 GW operating at year’s end, widening its lead over the former front runner (until 2021), the United Kingdom.<sup>103</sup>

i The year 2021 was an exception, with output down relative to 2020 due to poor wind conditions.  
 ii An auction in which suppliers that meet certain minimum criteria can submit non-negotiable price bids, and the buyer selects winners based on lowest-priced bids first. The reverse auctions / bidding policy was halted in 2022. See endnote 94 for this section.

## SNAPSHOT



## JAPAN



### Japan's First Large-Scale Offshore Wind Farm in Operation

In December 2022, Japan's first large-scale offshore wind farm began operation in Akita prefecture in the Tohoku region. This marks a turning point for the country, which has been seen as lagging in the energy transition. Japan aims to achieve carbon neutrality by 2050, and offshore wind power is expected to play a key role in this effort, taking advantage of the country's long coastline and strong wind resource. In 2020, Japan set ambitious targets for 10 GW of offshore wind capacity by 2030 and 30 – 45 GW by 2040.

The new offshore farm is expected to be able to power the equivalent of 150,000 households for 20 years. The electricity is sold to Tohoku Electric Power Network Co., Inc. under a power purchase agreement. Realisation of the plant was made possible through stakeholder cooperation. Public universities in Akita and the operating counties agreed on a scheme whereby students can learn the basics of offshore wind energy. The regional government provided funding for local companies to participate in operations and maintenance. Following an auction held in 2021, more Japanese offshore wind projects are scheduled for the coming years. The government also held a public auction for offshore wind in December 2022 under revised rules. Akita prefecture, one of the country's most promising target areas, anticipates creating 40,000 jobs through the projects.

Source: See endnote 100 for this section.



Europe connected 2.5 GW of new offshore capacity to the grid, the region’s lowest additions since 2016.<sup>104</sup> Nearly half of this new capacity was operating in UK waters (1.2 GW), where the world’s largest offshore project, the Hornsea Two (totalling 1.4 GW), was fully commissioned.<sup>105</sup> In mid-2022, the United Kingdom held the world’s first commercial leasing round to support large-scale floating wind power<sup>i</sup>, and soon thereafter the government approved a further 8 GW of offshore wind power deployment to help achieve commitments for net zero emissions and energy security.<sup>106</sup>

Elsewhere in Europe, several firsts occurred: France brought online its first commercial-scale offshore wind farm, adding nearly 0.5 GW; the Netherlands (0.4 GW) generated electricity from its first “subsidy-free” wind farm, the 1.5 GW Hollandse Kust Zuid project; Norway commissioned 60 MW of the Hywind Tampen floating project (95 MW total), due for completion in 2023; and Italy brought online its first offshore project (30 MW) and the first in the Mediterranean Sea.<sup>107</sup> Germany also added capacity (0.3 GW) during 2022.<sup>108</sup>

At year’s end, Europe’s total offshore capacity reached 30.3 GW across 13 countries.<sup>109</sup> Several European countries accelerated their offshore targets: by the close of 2022, EU Member States were committed to a combined 111 GW by 2030, and the United Kingdom alone aimed for 50 GW (including 10 GW of floating wind) by 2030.<sup>110</sup> However, offshore wind investments in Europe during 2022 were the lowest since 2007, with final investment decisions delayed for several projects due to inflation as well as price and market uncertainty.<sup>111</sup>

As new investment in offshore wind power and related infrastructure declined in Europe, it nearly tripled in the United States, to USD 9.8 billion.<sup>112</sup> More than 13 GW was awarded through state and federal lease sales, including the first offshore wind lease sale<sup>ii</sup> in the Pacific Ocean (California).<sup>113</sup> Although no additional capacity came online during 2022, the United States had nearly 16.7 GW of capacity in advanced development by year’s end.<sup>114</sup> In all, 10 US states had combined procurement targets of more than 74 GW.<sup>115</sup>

At least 16 national and sub-national governments set new or increased targets for offshore wind capacity in 2022 – including Nova Scotia (Canada), Victoria State (Australia) and the Philippines – with targets for offshore wind power by 2030 approaching 380 GW globally.<sup>116</sup> Australia declared the first offshore wind energy zones, India issued a draft plan for the country’s first offshore wind tenders, and in Brazil proposals for more than 170 GW of projects had been submitted for approval by year’s end.<sup>117</sup> Between early 2022 and early 2023, the global offshore wind power pipeline increased by 508 GW, to 1,174 GW across 38 countries, with the global pipeline for floating wind power already exceeding 120 GW by mid-2022.<sup>118</sup>

By the end of 2022, 19 countries (13 in Europe, 5 in Asia and 1 in North America) had at least some offshore wind capacity in operation, up from 18 countries in 2021.<sup>119</sup> China led in total capacity (31.4 GW), followed distantly by the United Kingdom (13.9 GW), Germany (8.1 GW), the Netherlands (2.8 GW), Denmark and Belgium (both around 2.3 GW).<sup>120</sup> Asia (mostly China) was home to nearly 53% of global offshore capacity, taking over the lead long held by Europe.<sup>121</sup>



i Floating wind power uses floating platforms that are anchored to the seabed with mooring chains, rather than fixed structures that lock turbines to the sea floor. It enables the use of the best offshore locations for capturing energy from the wind. By one estimate, the use of floating turbines can triple the size of the potential market. See endnote 106 for this section.

ii It was also the first lease sale in the United States to support commercial-scale floating wind power.

## TECHNOLOGY AND INNOVATION

The wind power industry has responded to the transition to auctions as well as to rising material costs and other pressures through consolidation among manufacturers and innovation.<sup>122</sup> In 2022, the industry continued to innovate to change the cost base of projects; to address challenges associated with scaling up production, transport and other logistical issues; and to enhance the value of wind energy while further improving its environmental and social sustainability.<sup>123</sup> Chinese firms led in the volume of new wind-related patent applications.<sup>124</sup>

Turbine size continued to increase in order to optimise cost and performance.<sup>125</sup> In 2022, the average size of turbines delivered to market passed 4 MW, 15% larger than in 2021.<sup>126</sup> The average turbine size installed onshore was 3.9 MW, and the average installed offshore exceeded 7.6 MW.<sup>127</sup>

Western turbine manufacturers continued to invest in new models even though they were not making enough profit to cover the costs.<sup>128</sup> For example, Vestas launched the world's tallest tower for onshore turbines (199 metres) in 2022, and GE confirmed in early 2023 that it was developing a 17-18 MW version of its Haliade-X offshore turbine.<sup>129</sup> Chinese firms also have been driven by price pressures to innovate and are competing to outsize one another in turbines.<sup>130</sup> MingYang, for example, launched the world's largest onshore turbine (8.5 MW) in 2022, only to be surpassed by Envision Energy (near 10 MW) and then SANY (11 MW); meanwhile, several Chinese manufacturers began marketing offshore turbines in the 16-18 MW range during the year.<sup>131</sup>

The rapid push to develop more powerful machines has strained manufacturing, making it harder to reach the supply chain efficiencies needed to achieve economies of scale; it also has provided little opportunity to learn from installed turbines before moving to the next size up; and, in some cases, has increased permitting challenges.<sup>132</sup> Some western manufacturers have begun shifting their focus from upscaling turbines to standardising product lines in order to reduce production costs and to manufacture turbines more quickly and efficiently.<sup>133</sup>

Innovation in the industry continued to focus on making wind energy fully sustainable in a way that is cost-effective in order to remain competitive.<sup>134</sup> Initiatives to reduce emissions associated with turbine production and installation have included redesigning the logistics network and shifting to cleaner sources of energy for production.<sup>135</sup> Substantial efforts also continued to focus on reducing the life-cycle impacts of turbine blades, which typically are made from fibreglass and carbon fibre and end up in landfill sites when they are discarded.<sup>136</sup> In 2022, companies were working on a variety of technologies to recycle blades made from traditional materials or to develop new more-sustainable blade materials.<sup>137</sup>

In 2022, companies were working a variety of on technologies to **recycle blades** and to develop new more-sustainable blade materials.



i Larger, higher-efficiency turbines mean that fewer turbines, foundations, converters and cables, and less labour and other resources, are required for the same output, translating into faster project development, reduced risk, lower costs of grid connection and of operation and maintenance, and overall greater yield, all important for the offshore sector in particular. See endnote 125 for this section.



## CHALLENGES AND OPPORTUNITIES

for the Uptake of Renewables in Energy Supply



### CHALLENGES

→ In the short term, **inflation and disrupted supply chains** have slowed the deployment of most renewables and pushed up costs.



→ Countries have struggled to adjust to price fluctuations in materials and energy, resulting in **undersubscribed auctions and tenders** due to their conditions not matching the market reality.

→ Delayed permitting and unfavourable and/or **inconsistent policies** have led to uncertainty, stalling wind power deployment and slowing investment in new manufacturing capability.

→ The global markets for CSP and ocean power have slowed, as the historical **market leaders have added little new capacity** in recent years.

→ The biggest challenges for renewable heat and fuel markets are the **low (sometimes subsidised) prices of fossil fuels** and the difficulties in accessing affordable finance.

→ **Extreme drought** has hampered hydropower production across parts of Africa, Asia, Europe and North America.





## OPPORTUNITIES

- Renewables offer the potential **to mitigate climate change, improve energy security, create jobs and boost local economies.**
- Even accounting for rising costs, wind and solar power continue to be **cost-competitive** with fossil fuels and are cheaper than coal-fired generation in most countries.



- The rooftop solar PV market has increased steadily since 2018 and **experienced record growth in 2022** as the market became more attractive for both residential and commercial customers.



- **The momentum around hydrogen is building**, but policies need to prioritise the use of renewable energy to avoid simple displacement of emissions and to harness hydrogen's huge potential to decarbonise heavy industry, maritime transport and aviation.
- **Heat pumps** can provide a valuable source of energy system flexibility, enabling greater integration of variable renewable sources and lower energy bills for consumers.
- **Bioenergy provides solutions for heating and fuels** in heavy industry and transport, such as pharmaceuticals, cement, steel, food and beverages, aviation and maritime shipping.



## PHOTO CREDITS

- page 8: © crystal51; shutterstock  
 page 11: © Benoît Deschasaux; unsplash  
 page 12: © Etienne Girardet; unsplash  
 page 13: © Bohbeh; shutterstock  
 page 14: © Shaiith; shutterstock  
 page 14: © Casey Horner; unsplash  
 page 15: © Markus Spiske; unsplash  
 page 17: © Diyana Dimitrova; shutterstock  
 page 18: © Sharomka; shutterstock  
 page 18: Cousine Island, Seychelles; © Martin Harvey; shutterstock  
 page 20: © IM Imagery; shutterstock  
 page 20: Production of gearboxes for wind turbines; © industryviews; shutterstock  
 page 20: © Markus Spiske; unsplash  
 page 23: © anatoliy\_gleb; shutterstock  
 page 24: © fokke baarssen; shutterstock  
 page 25: Almere city, the Netherlands; © Pavlo Glazkov; shutterstock  
 page 27: © TimSiegert-batcam; shutterstock  
 page 30: New Delhi, India; © PradeepGaur; shutterstock  
 page 30: Sugar cane harvesting in Queensland, Australia; © Francesca Pianzola; shutterstock  
 page 31: © Animaflora PicsStock; shutterstock  
 page 32: Algae production; Wageningen, Netherlands; © INTREEGUE Photography; shutterstock  
 page 32: Hydrogen fuel cell bus; Tokyo, Japan; © Ned Snowman; shutterstock  
 page 33: © Roman Zaiets; shutterstock  
 page 34: © Snapshot freddy; shutterstock  
 page 35: Biogas plant; Czech Republic; © Kletr; shutterstock  
 page 36: Sugarcane field; Santa Clara, Cuba; © possohh; shutterstock  
 page 38: Kunduvillage, Senegal, Africa; © Agarianna76; shutterstock  
 page 39: Adkins Energy ethanol plant; Lena, Illinois, US; © dvande; shutterstock  
 page 41: © francesco de marco; shutterstock  
 page 42: Geothermal power station pipeline; © N.Minton; shutterstock  
 page 44: Hebei, China; © James Jiao; shutterstock  
 page 45: Geothermal Power Plant; Sumatera, Indonesia; © Harinnita Detta; shutterstock  
 page 46: Heat Pump Maintenance; © Virrage Images; shutterstock  
 page 48: Heat pump; Warsaw, Poland; © Grand Warszawski; shutterstock  
 page 49: © guteksk7; shutterstock  
 page 50: © FOTOGRIN; shutterstock  
 page 52: © Audio und werbung; shutterstock  
 page 53: © Free Wind 2014; shutterstock  
 page 53: © Scharfsinn; shutterstock  
 page 54: © Jose Luis Stephens; shutterstock  
 page 54: Hydroelectric powerplant; © Andrey Shchekalev; shutterstock  
 page 55: Englebright Dam; Yuba River, California, US; © Gary Saxe; shutterstock  
 page 55: © Dejan Dosenovic; shutterstock  
 page 56: Baihetan Dam Construction; Yangtze River, China; © burakyalcin; shutterstock  
 page 56: © Pierre Jean Durieu; shutterstock  
 page 57: © Cosmin Sava; shutterstock  
 page 58: Kiew Lom Dam, Lampang, Thailand; © Aedka Studio; shutterstock





page 59: © SIMEC Atlantis Energy  
page 60: © Minesto  
page 60: Sihwa Lake Tidal Power Plant; Ansan-si, Gyeonggi-do, South Korea; © Stock for you; shutterstock  
page 61: © O2; Orbital Marie Power's O2 turbine  
page 62: © Tukio; shutterstock  
page 62: © BiniClick; shutterstock  
page 64: © anatoliy\_gleb; shutterstock  
page 65: © kik muthita; shutterstock  
page 66: Miagao, Iloilo, Philippines; © MDV Edwards; shutterstock  
page 67: © salajeon; shutterstock  
page 68: © Tsetso Photo; shutterstock  
page 69: © Sopotnicki; shutterstock  
page 71: © RussieseO; shutterstock  
page 73: © John\_T; shutterstock  
page 74: Underground district heating pipes; © Zigmunds Dizgalvis; shutterstock  
page 75: © Kenneth Bagge Jorgensen; shutterstock  
page 76: © FMonkey Photo; shutterstock

page 77: © LIUSHENGFILM; shutterstock  
page 78: © sdf\_qwe; shutterstock  
page 80: Tramandaí, Rio Grande do Sul, Brazil; © Viagens e Caminhos; shutterstock  
page 81: © Vladimka production; shutterstock  
page 83: © MUNGKHOOD STUDIO; shutterstock  
page 83: © Lance Bellers; shutterstock  
page 84: © Michael Brian Shannon; shutterstock  
page 85: Saint Nazaire, France; © MC MEDIASTUDIO; shutterstock  
page 85: © Henrik A. Jonsson; shutterstock  
page 86: © Jirapong Manustrom; shutterstock  
page 86: Colorado river upstream of the Hoover Dam; US; © Milan Rademakers; shutterstock  
page 86: © Mabeline72; shutterstock  
page 87: © Industrial Donut Picks; shutterstock  
page 87: © Bohbeh; shutterstock  
page 87: © NavinTar; shutterstock  
page 88: © fokke baarsen; shutterstock

## COPYRIGHT & IMPRINT

**Renewable Energy Policy Network  
for the 21st Century**

REN21 Secretariat  
c/o UN Environment Programme  
1 rue Miollis, Building VII  
75015 Paris  
France



## ENDNOTES – MODULE OVERVIEW

- 1 International Energy Agency (IEA), "Global Energy Crisis", <https://www.iea.org/topics/global-energy-crisis>, accessed March 8, 2023.
- 2 Ibid.
- 3 V. Romei and A. Smith, "Global Inflation Tracker: See How Your Country Compares on Rising Prices", Financial Times, March 6, 2022, <https://www.ft.com/content/088d3368-bb8b-4ff3-9df7-a7680d4d81b2>.
- 4 IEA, "Renewable Power's Growth Is Being Turbocharged as Countries Seek to Strengthen Energy Security", December 6, 2022, <https://www.iea.org/news/renewable-power-s-growth-is-being-turbocharged-as-countries-seek-to-strengthen-energy-security>.
- 5 McKinsey, "The Inflation Reduction Act: Here's What's in It", October 24, 2022, <https://www.mckinsey.com/industries/public-and-social-sector/our-insights/the-inflation-reduction-act-heres-whats-in-it>; European Commission, "REPowerEU: Affordable, Secure and Sustainable Energy for Europe", [https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/repowerEU-affordable-secure-and-sustainable-energy-europe\\_en](https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/repowerEU-affordable-secure-and-sustainable-energy-europe_en), accessed March 1, 2023.
- 6 International Energy Agency (IEA), "World Energy Balances 2020: Extended Energy Balances", <https://www.iea.org/data-and-statistics/data-product/world-energy-balances>; 2022. **Figure 1** from IEA, op. cit. note 6.
- 7 Ibid.
- 8 Ibid. **Figure 2** from Ember, "Global Electricity Review 2023", April 12, 2023, <https://ember-climate.org/insights/research/global-electricity-review-2023/>.
- 9 **Figure 3** from IEA, op. cit. note 6.
- 10 Ibid.
- 11 Ibid.
- 12 Ibid.
- 13 P. Day, "Hydrogen as a backup for renewables remains a distant proposition", Reuters, February 1, 2023, <https://www.reuters.com/business/energy/hydrogen-backup-renewables-remains-distant-proposition-2023-02-01>; IEA, "Global Hydrogen Review 2022", 2022, <https://www.iea.org/reports/global-hydrogen-review-2022>.
- 14 REN21 Policy Database. See GSR 2023 Data Pack, available at [www.ren21.net/gsr2023-data-pack/supply](http://www.ren21.net/gsr2023-data-pack/supply).
- 15 BloombergNEF, "Energy Transition Investment Trends: Executive Summary", 2023, <https://about.bnef.com/energy-transition-investment>.
- 16 Ibid.
- 17 Ibid.
- 18 IEA, "World Energy Balances 2021", <https://www.iea.org/data-and-statistics/data-product/world-energy-balances>.
- 19 Global market based on data from W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2022, Detailed Market Figures 2021, 2023 Edition", International Energy Agency (IEA) Solar Heating and Cooling Programme (SHC), 2023, pp. 6, 58, 60, <https://www.iea-shc.org/solar-heat-worldwide>, and from M. Spörk-Dür, AEE – Institute for Sustainable Technologies (AEE INTEC), personal communication with REN21, May 2023 and IEA, op. cit. note 1.
- 20 Ibid.
- 21 Calculation based on Lund and Toth, 2023. Growth of 14.2 TWh in 2022 based on differentiated five-year compound annual growth rate across nine end-use categories from 2014 through 2019 (total output having grown from 265,790 TJ in 2014 to 420,906 TJ in 2019); power capacity data from sources in the Geothermal power and heat section; capacity data for other countries from International Renewable Energy Agency (IRENA), "Renewable Capacity Statistics 2023", March 2023, <https://www.irena.org/Publications/2023/Mar/Renewable-capacity-statistics-2023>; estimated electricity generation in 2022 based on International Energy Agency (IEA), "Renewables 2022 Data Explorer", December 6, 2022, <https://www.iea.org/data-and-statistics/data-tools/renewables-data-explorer>.
- 22 IEA, "World Energy Balances 2021: Extended Energy Balances", op. cit. note 1.
- 23 Ibid.
- 24 Ibid.
- 25 Government of Australia, Department of Climate Change, Energy, the Environment and Water, "State of Hydrogen 2022", 2022, <https://www.dccceew.gov.au/energy/publications/state-of-hydrogen-2022>.
- 26 Ember, op. cit. note 8.
- 27 **Figure 4** from Ibid.
- 28 Ibid.
- 29 Ibid.
- 30 Ibid.
- 31 Ibid.
- 32 Ibid.
- 33 Ibid.
- 34 Ibid.
- 35 Ibid.
- 36 Ibid.
- 37 Ibid.
- 38 Ibid.
- 39 Ibid.
- 40 Ibid.
- 41 Ibid.
- 42 Ibid.
- 43 Ibid.
- 44 Ibid.
- 45 Ibid.
- 46 **Figure 5** from International Hydropower Association, personal communication with REN21, May 11 2023 ; IEA Photovoltaic Power Systems Programme, "Snapshot 2023"; <https://iea-pvps.org/snapshot-reports/snapshot-2023/>; Global Wind Energy Council, "Global Wind Report 2023", 2023, <https://gwec.net/globalwindreport2023/>; International Renewable Energy Agency, "2023 Renewable Capacity Statistics", 2023, [https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Jul/IRENA\\_Renewable\\_energy\\_statistics\\_2022.pdf?rev=8e3c22a36f964fa2ad8a50e0b4437870](https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Jul/IRENA_Renewable_energy_statistics_2022.pdf?rev=8e3c22a36f964fa2ad8a50e0b4437870) (Other Renewable Power: Bioenergy, Geothermal, Concentrated Solar Power, Marine).
- 47 **Figure 6** from IEA, "Net Zero by 2050", 2021, [https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroBy2050-ARoadmapfortheGlobalEnergySector\\_CORR.pdf](https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroBy2050-ARoadmapfortheGlobalEnergySector_CORR.pdf)
- 48 Ibid.
- 49 Ibid.
- 50 IEA, "The State of Clean Technology Manufacturing", May 2023, <https://www.iea.org/reports/the-state-of-clean-technology-manufacturing>.
- 51 Ibid.
- 52 IEA, op. cit. note 47.
- 53 IEA, op. cit. note 50.
- 54 Ibid.
- 55 Ibid.
- 56 Ibid.
- 57 IEA, "Special Report on Solar PV Global Supply Chains", July 2022, <https://www.iea.org/reports/solar-pv-global-supply-chains>.
- 58 South China Morning Post, "Chinese Wind Turbine Makers Eye Asia, Europe for Growth as Climate Change, Energy Security Take Centrestage", August 29, 2022, <https://www.scmp.com/business/china-business/article/3190585/chinese-wind-turbine-makers-eye-asia-europe-growth-climate>.
- 59 IEA, op. cit. note 51.
- 60 Ibid.
- 61 Ibid.

## ENDNOTES – POLICY

- 1 International Energy Agency (IEA), "Global Energy Crisis – Topics", <https://www.iea.org/topics/global-energy-crisis>, accessed April 13, 2023.
- 2 IEA, "World Energy Outlook 2022 Shows the Global Energy Crisis Can Be a Historic Turning Point Towards a Cleaner and More Secure Future", October 27, 2022, <https://www.iea.org/news/world-energy-outlook-2022-shows-the-global-energy-crisis-can-be-a-historic-turning-point-towards-a-cleaner-and-more-secure-future>.
- 3 Ibid.
- 4 IEA, "Global Government Spending on Clean Energy Transitions Rises to USD 1.2 Trillion Since the Start of the Pandemic, Spurred by Energy Security Concerns", December 9, 2022, <https://www.iea.org/news/global-government-spending-on-clean-energy-transitions-rises-to-usd-1-2-trillion-since-the-start-of-the-pandemic-spurred-by-energy-security-concerns>.
- 5 REN21 Policy Database. See GSR 2023 Data Pack, available at [www.ren21.net/gsr2023-data-pack/supply](http://www.ren21.net/gsr2023-data-pack/supply).
- 6 Ibid.
- 7 Ibid.
- 8 **Figure 7** from Ibid.
- 9 Ibid.
- 10 Ibid.
- 11 Ibid.
- 12 Ibid.
- 13 Ibid.
- 14 **Figure 8** from *ibid.*
- 15 Ibid.
- 16 Ibid.
- 17 Ibid.
- 18 M. Madden, "FTC Announces New Rates for Power Sold to National Grid", *Barbados Today*, January 10, 2023, <https://barbadostoday.bb/2023/01/10/ftc-announces-new-rates-for-power-sold-to-national-grid>.
- 19 M. Willuhn, "Germany Raises Feed-in Tariffs for Solar up to 750 KW", *pv magazine*, July 7, 2022, <https://www.pv-magazine.com/2022/07/07/germany-raises-feed-in-tariffs-for-solar-up-to-750-kw>.
- 20 DLA Piper, "Africa Energy Futures Mauritius", 2022, <https://www.dlapiper.com/en/insights/publications/2022/11/africa-energy-futures/africa-energy-futures-mauritius>.
- 21 E. Bellini, "South Africa to Introduce Feed-in Tariffs for Rooftop PV", *pv magazine*, July 26, 2022, <https://www.pv-magazine.com/2022/07/26/south-africa-to-introduce-feed-in-tariffs-for-rooftop-pv>.
- 22 B. Santos, "Thailand Introduces FIT Scheme for Solar, Storage", *pv magazine*, October 31, 2022, <https://www.pv-magazine.com/2022/10/31/thailand-introduces-fit-scheme-for-solar-storage>; Enerdata, "Japan Sets Feed-in Tariff Levels for Renewable Projects in 2022-2023", February 25, 2022, <https://www.enerdata.net/publications/daily-energy-news/japan-sets-feed-tariff-levels-renewable-projects-2022-2023.html>.
- 23 REN21 Policy Database, *op. cit.* note 5.
- 24 E. Bellini, "Dutch Parliament Approves Proposal to Phase Out Net Metering", *pv magazine*, February 9, 2023, <https://www.pv-magazine.com/2023/02/09/dutch-parliament-approves-proposal-to-phase-out-net-metering>.
- 25 Ibid.
- 26 I. Tsagas, "Cyprus Expands Funding for Solar Net Metering", *pv magazine*, August 26, 2022, <https://www.pv-magazine.com/2022/08/26/cyprus-expands-funding-for-solar-net-metering>.
- 27 B. Santos, "Finland to Extend Net Metering to All PV Systems in 2023", *pv magazine*, October 26, 2022, <https://www.pv-magazine.com/2022/10/26/finland-to-extend-net-metering-to-all-pv-systems-in-2023>.
- 28 F. Salah, "Ahead of COP27 – Egypt Relaxes the Restrictions on Net Metering and Self Consumption Solar Plants", *Riad-Riad.com*, March 9, 2022, <https://riad-riad.com/ahead-of-cop27-egypt-relaxes-the-restrictions-on-net-metering-and-self-consumption-solar-plants>.
- 29 S. Sundar, "Ghana Aims to Become a Regional Manufacturing Hub for Solar Value Chains", *Zawya*, November 29, 2022, <https://www.zawya.com/en/projects/industry/ghana-aims-to-become-a-regional-manufacturing-hub-for-solar-value-chains-cfpvtl2q>; E. Bellini, "Philippines Increases Net-Metering Size Limit for Renewables to 1 MW", *pv magazine Australia*, November 30, 2022, <https://www.pv-magazine-australia.com/2022/11/30/philippines-increases-net-metering-size-limit-for-renewables-to-1-mw>.
- 30 E. Bellini, "Dutch Parliament Approves Proposal to Phase Out Net Metering", *pv magazine*, February 9, 2023, <https://www.pv-magazine.com/2023/02/09/dutch-parliament-approves-proposal-to-phase-out-net-metering>.
- 31 M.R. Lown, "Poland's Transition from Net Metering to Net Billing", *pv magazine*, July 13, 2022, <https://www.pv-magazine.com/2022/07/13/polands-transition-from-net-metering-to-net-billing>.
- 32 R. Kennedy, "Community Solar Up, Net Metering Down in US This Year", *pv magazine*, February 1, 2023, <https://www.pv-magazine.com/2023/02/01/community-solar-up-net-metering-down-in-us-this-year>.
- 33 S. Wasson, "NEM 3.0: Why April 2023 Will Change the Solar Game in CA", *Today's Homeowner*, January 17, 2023, <https://todayshomeowner.com/solar/guides/nem-3-0-why-april-2023-will-change-the-solar-game-in-ca>.
- 34 IEA, "Renewable Electricity – Renewables 2022 – Analysis", 2022, <https://www.iea.org/reports/renewables-2022/renewable-electricity>.
- 35 U. Gupta, "Renewable Energy Auctions Not in Tandem with Government Targets", *pv magazine India*, February 21, 2023, <https://www.pv-magazine-india.com/2023/02/21/renewable-energy-auctions-not-in-tandem-with-government-targets>; C. Akkaravoranun et al., "Thailand: The Wait Is Over! New Round of Renewable Energy Auctions Have Officially Been Launched – Bidding Ends in November 2022", *Global Compliance News*, November 9, 2022, [https://www.globalcompliancenes.com/2022/11/09/https-insightplus-bakermckenzie-com-bm-energy-mining-infrastructure\\_1-here\\_11022022](https://www.globalcompliancenes.com/2022/11/09/https-insightplus-bakermckenzie-com-bm-energy-mining-infrastructure_1-here_11022022).
- 36 Enerdata, "The Philippines Will Auction 11.6 GW of Renewable Capacity in June 2023", March 22, 2023, <https://www.enerdata.net/publications/daily-energy-news/philippines-will-auction-116-gw-renewable-capacity-june-2023.html>.
- 37 Willuhn, *op. cit.* note 19; I. Tsagas, "Greece's Renewables Tender Awards 372 MW of PV at Average of €47.98/MWh", *pv magazine*, September 13, 2022, <https://www.pv-magazine.com/2022/09/13/greeces-renewables-tender-awards-372-mw-of-pv-at-average-of-e47-98-mwh>; W. Norman, "Poland Awards 486MW of Solar PV in Latest Renewables Auction", *PV Tech*, December 21, 2022, <https://www.pv-tech.org/poland-awards-486mw-of-solar-pv-in-latest-renewables-auction>.
- 38 E. Bellini, "South Africa's Sixth Renewables Auction Concludes with Lowest Bid of \$0.02689/KWh", *pv magazine*, December 12, 2022, <https://www.pv-magazine.com/2022/12/12/south-africas-sixth-renewables-auction-concludes-with-lowest-bid-of-0-02689-kwh>.
- 39 J. Touriño Jacobo, "New South Wales Launches Renewables Auction, Targets 12GW of Deployment by 2030", *PV Tech*, October 4, 2022, <https://www.pv-tech.org/new-south-wales-launches-renewables-auction-targets-12gw-of-deployment-by-2030>.
- 40 WindEurope, "Increasing Cost Pressures and Design Flaws Undermine Spanish Auction", November 25, 2022, <https://windeurope.org/newsroom/press-releases/increasing-cost-pressures-and-design-flaws-undermine-spanish-auction>; reNEWS, "France Secures 339MW in Undersubscribed Solar Auction", August 9, 2022, <https://renews.biz/79717/france-secures-339mw-in-undersubscribed-solar-auction>; B. Radowitz, "Few Bidders in German Clean Energy Tender as Macroeconomics Hit Wind and Solar Build-Out", *Recharge News*, December 20, 2022, <https://www.rechargenews.com/energy-transition/few-bidders-in-german-clean-energy-tender-as-macroeconomics-hit-wind-and-solar-build-out/2-1-1377668>.
- 41 WindEurope, "Messy Permitting Leads to yet Another Undersubscribed Wind Auction in Italy", February 1, 2022, <https://windeurope.org/newsroom/press-releases/messy-permitting-leads-to-yet-another-undersubscribed-wind-auction-in-italy>.
- 42 B. Radowitz, "Better Starting Position' – German Regulator Raises Price Cap for Wind and Solar Tenders", *Recharge News*, December 29, 2022, <https://www.rechargenews.com/energy-transition/better-starting-position-german-regulator-raises-price-cap-for-wind-and-solar-tenders/2-1-1381200>.
- 43 S.A. Qadir et al., "Incentives and Strategies for Financing the Renewable Energy Transition: A Review", *Energy Report*, Vol. 7 (November 2021), pp. 3590-3606, <https://doi.org/10.1016/j.egy.2021.06.041>.
- 44 REN21 Policy Database, *op. cit.* note 5.
- 45 M. Barbanell, "A Brief Summary of the Climate and Energy Provisions of the Inflation Reduction Act of 2022", *World Resources Institute*, October 28, 2022, <https://www.wri.org/update/brief-summary-climate-and-energy-provisions-inflation-reduction-act-2022>.
- 46 Ibid.

- 47 J. Espinoza et al., "EU Plans to Relax Curbs on Tax Credits in Response to 'Toxic' US Subsidies", *Financial Times*, January 30, 2023, <https://www.ft.com/content/53eb769b-6ce1-4f50-9703-f2463c465001>.
- 48 J.L., "Canadian Gov't Sets out \$83B for Clean Investment Tax Credits", *Carbon Credits*, March 29, 2023, <https://carboncredits.com/canadian-govt-sets-out-83b-for-clean-investment-tax-credits>.
- 49 Zawya, "Renewable Energy, Solar Tax Incentive Introduced for Businesses, Individuals", February 23, 2023, <https://www.zawya.com/en/economy/africa/renewable-energy-solar-tax-incentive-introduced-for-businesses-individuals-egjqo046>; K. Whyte Subban Virusha, "South Africa: ESG Windfall with the Expanded Renewable Energy Tax Incentive", *Global Compliance News*, March 15, 2023, [https://www.globalcompliancencws.com/2023/03/15/https-insightplus-bakermckenzie-com-bm-tax-south-africa-two-birds-with-one-sunbeam-esg-windfall-with-the-expanded-renewable-energy-tax-incentive\\_02282023](https://www.globalcompliancencws.com/2023/03/15/https-insightplus-bakermckenzie-com-bm-tax-south-africa-two-birds-with-one-sunbeam-esg-windfall-with-the-expanded-renewable-energy-tax-incentive_02282023).
- 50 I. Todorović, "Bulgaria Prepares EUR 102 Million in Grants for Green Energy in Tourism Sector", *Balkan Green Energy News*, October 18, 2022, <https://balkangreenenergynews.com/bulgaria-prepares-eur-102-million-in-grants-for-green-energy-in-tourism-sector>.
- 51 C. Munda, "Mini-Grids Get Tax Cut to Take on Kenya Power", *Business Daily*, January 3, 2022, <https://www.businessdailyafrica.com/bd/economy/mini-grids-get-tax-cut-take-on-kenya-power-3671380>.
- 52 H. Alcoseba Fernandez, "Philippines Raises Minimum Renewable Energy Capacity to 2.5% in Power Mix", *Eco-Business*, October 3, 2022, <https://www.eco-business.com/news/philippines-raises-minimum-renewable-energy-capacity-to-25-in-power-mix>.
- 53 US Energy Information Administration (EIA), "Renewable Energy Explained – Portfolio Standards", <https://www.eia.gov/energyexplained/renewable-sources/portfolio-standards.php>, accessed May 8, 2023.
- 54 Food & Water Watch, "MD Legislators Announce Bill to Clean Up Renewable Portfolio Standard", January 31, 2023, <https://www.foodandwaterwatch.org/2023/01/31/md-legislators-announce-bill-to-clean-up-renewable-portfolio-standard>.
- 55 B. Santos, "EU Wants Rooftop PV Mandate for Public, Commercial Buildings by 2027, Residential by 2029", *pv magazine*, May 18, 2022, <https://www.pv-magazine.com/2022/05/18/eu-wants-rooftop-pv-mandate-for-public-commercial-buildings-by-2025-residential-by-2029>.
- 56 REN21 Policy Database, op. cit. note 5.
- 57 S. Rai-Roche, "EU Solar Plan Sets 2030 Target at 740GWdc as Rooftop PV Mandates, Permitting Plans Are Unveiled", *PV Tech*, May 18, 2022, <https://www.pv-tech.org/eu-solar-plan-sets-2030-target-at-600gw-as-rooftop-pv-mandates-permitting-plans-are-unveiled>; Santos, op. cit. note 55.
- 58 Public Senat, "L'obligation de pose de panneaux photovoltaïques sur les grands parkings extérieurs adoptée au Sénat", November 4, 2022, <https://www.publicsenat.fr/article/parlementaire/l-obligation-de-pose-de-panneaux-photovoltaïques-sur-les-grands-parkings>.
- 59 SolarPower Europe, "Solar Mandates in Europe", [https://api.solarpowereurope.org/uploads/SPE\\_Note\\_Solar\\_Mandates\\_in\\_Europe\\_4103dcc90d.pdf](https://api.solarpowereurope.org/uploads/SPE_Note_Solar_Mandates_in_Europe_4103dcc90d.pdf), accessed May 15, 2023.
- 60 Ibid.
- 61 Yale Environment 360, "Tokyo to Mandate Rooftop Solar Panels on New Homes", <https://e360.yale.edu/digest/tokyo-rooftop-solar>; H. Takahashi, "Kawasaki to Become 2nd City in Japan to Require Solar Panels on New Buildings", *The Mainichi*, February 10, 2023, <https://mainichi.jp/english/articles/20230209/p2a/00m/0sc/004000c>.
- 62 Kennedy, op. cit. note 32.
- 63 Ibid.
- 64 R. Kennedy, "US Targets 5 Million Community Solar Households by 2025", *pv magazine*, March 3, 2022, <https://www.pv-magazine.com/2022/03/03/us-targets-5-million-community-solar-households-by-2025>.
- 65 Australian Government, Department of Climate Change, Energy, the Environment and Water, "Powering Australia", <https://www.energy.gov.au/government-priorities/australias-energy-strategies-and-frameworks/powering-australia>, accessed May 8, 2023.
- 66 S. Jacobsen, "Four Countries Pledge Tenfold Rise in EU Offshore Wind Power Capacity", *Reuters*, May 18, 2022, <https://www.reuters.com/business/energy/four-eu-countries-increase-offshore-wind-power-capacity-tenfold-2022-05-17>.
- 67 reNEWS, "EU Approves German Offshore Wind Policy Changes", December 22, 2022, <https://renews.biz/82706/eu-approves-german-offshore-wind-policy-changes>.
- 68 NOPSEMA, "Offshore Electricity Infrastructure Regulations Now Available", November 2, 2022, <https://www.nopsema.gov.au/blogs/offshore-electricity-infrastructure-regulations-now-available>.
- 69 H. Dung, "New Power Development Plan Needs Quality More than Speed: PM", *The Investor*, February 4, 2023, <https://theinvestor.vn/new-power-development-plan-needs-quality-more-than-speed-pm-d3579.html>.
- 70 G. Rajgor, "Leaders Pledge Support to Deliver Meshed Offshore Grids for Europe", *Windpower Monthly*, May 4, 2023, <https://www.windpowermonthly.com/article/1821712>.
- 71 Euractiv, "Polish Parliament Votes 700 Metre Rule for Wind Turbines", March 10, 2023, <https://www.euractiv.com/section/energy-environment/news/polish-parliament-votes-700-metre-rule-for-wind-turbines>.
- 72 P. Tisheva, "Ireland Presents Policy for Second Phase of Offshore Wind", *Renewables Now*, March 10, 2023, <https://renewablesnow.com/news/ireland-presents-policy-for-second-phase-of-offshore-wind-817069>.
- 73 REN21 Policy Database, op. cit. note 5.
- 74 Ibid.
- 75 Government of the Netherlands, "Joint statement of Chile and The Netherlands on collaboration in the field of green hydrogen import and export", July 1, 2021, <https://www.government.nl/documents/diplomatic-statements/2021/07/01/joint-statement-of-chile-and-the-netherlands-on-collaboration-in-the-field-of-green-hydrogen-import-and-export>.
- 76 IEA, "Hydrogen – Analysis", 2022, <https://www.iea.org/reports/hydrogen>.
- 77 Green Hydrogen Organisation, "Argentina", <https://gh2.org/countries/Argentina>, accessed April 7, 2023.
- 78 FuelCellsWorks, "South Africa Launches Hydrogen Society Roadmap", February 21, 2022, <https://fuelcellworks.com/news/south-africa-launches-hydrogen-society-roadmap>.
- 79 A. Gupta, "Austria Targets 4 TWh Green Hydrogen Production Annually Under Hydrogen Strategy by 2030", *EQ Mag Pro*, June 7, 2022, <https://www.eqmagpro.com/austria-targets-4-twh-green-hydrogen-production-annually-under-hydrogen-strategy-by-2030-eq-mag-pro>.
- 80 Ministerio de Industria, Energía y Minería, "Hidrógeno Verde", <https://www.gub.uy/ministerio-industria-energia-mineria/hidrogenoverde>, accessed May 8, 2023.
- 81 C. Clifford, "The Clean Hydrogen Energy Economy Was a Dream. The Climate Bill Could Make It a Reality This Decade", *CNBC*, September 8, 2022, <https://www.cnbc.com/2022/09/08/clean-hydrogen-industry-got-huge-boost-from-inflation-reduction-act.html>.
- 82 Climate Champions, "Africa Green Hydrogen Alliance", <https://climatechampions.unfccc.int/africa-green-hydrogen-alliance>, accessed April 7, 2023.
- 83 European Heat Pump Association, "Shaping Europe's Energy Landscape: A Deep Dive into 'Fit for 55' and Renewable Heating and Cooling", May 19, 2023 [https://www.ehpa.org/2023/05/19/ehpa\\_news/shaping-europes-energy-landscape-a-deep-dive-into-fit-for-55-and-renewable-heating](https://www.ehpa.org/2023/05/19/ehpa_news/shaping-europes-energy-landscape-a-deep-dive-into-fit-for-55-and-renewable-heating).
- 84 Ibid.
- 85 European Commission, "The Green Deal Industrial Plan: Putting Europe's Net-zero Industry in the Lead", February 1, 2023, [https://ec.europa.eu/commission/presscorner/detail/en/ip\\_23\\_510](https://ec.europa.eu/commission/presscorner/detail/en/ip_23_510).
- 86 Ibid.
- 87 European Commission, "Strategic Energy Technology Plan", [https://energy.ec.europa.eu/topics/research-and-technology/strategic-energy-technology-plan\\_env](https://energy.ec.europa.eu/topics/research-and-technology/strategic-energy-technology-plan_env), accessed May 2023.
- 88 IEA, "District Heating – Analysis", 2022, <https://www.iea.org/reports/district-heating>.
- 89 B. Epp, "Fund of EUR 3 Billion for Decarbonising German District Heating", *Solar Thermal World*, April 6, 2023, <https://solarthermalworld.org/news/fund-of-eur-3-billion-for-decarbonising-german-district-heating>.
- 90 C. Cariaga, "Danish Parliament Adopts New Rules to Support Geothermal", *Think GeoEnergy*, March 2, 2023, <https://www.thinkgeoenergy.com/danish-parliament-adopts-new-rules-to-support-geothermal>.
- 91 IEA, "Net Zero Strategy – Heat and Buildings – Policies", October 27, 2021, <https://www.iea.org/policies/14334-net-zero-strategy-heat-and-buildings>.
- 92 IEA, "The Future of Heat Pumps – Analysis", 2022, <https://www.iea.org/reports/the-future-of-heat-pumps>.
- 93 REN21 Policy Database, op. cit. note 5.

- 94 European Heat Pump Association, "REPowerEU: Heat Pump Strategy Required to Help Sector Deliver", June 12, 2022, [https://www.ehpa.org/2022/06/12/ehpa\\_news/repowereu-heat-pump-strategy-required-to-help-sector-deliver](https://www.ehpa.org/2022/06/12/ehpa_news/repowereu-heat-pump-strategy-required-to-help-sector-deliver).
- 95 N.J. Kurmayer, "Brussels Prepares 'Strategy' to Boost Deployment of Heat Pumps", Euractiv, March 10, 2023, <https://www.euractiv.com/section/energy-environment/news/brussels-prepares-strategy-to-boost-deployment-of-heat-pumps>.
- 96 Connexion France, "Recap: 12 Changes in France – Eye Tests, Covid Rules, Heat Pumps, Fuel", February 23, 2023, <https://www.connexionfrance.com/article/French-news/Recap-12-changes-in-France-eye-tests-Covid-rules-heat-pumps-fuel>.
- 97 M. Willuhn, "Germany's New Rebate Program for Residential Heat Pumps Has Come Into Effect", pv magazine, January 5, 2023, <https://www.pv-magazine.com/2023/01/05/germany-launches-rebate-program-for-residential-heat-pumps>.
- 98 R. Desmornes, "The Inflation Reduction Act 'Pumps Up' Heat Pumps", Hvac, November 4, 2022, <https://live-hvac-ci.pantheonsite.io/resources/inflation-reduction-act-heat-pump-rebates>.
- 99 Ministry of Housing and Urban-Rural Development of China, "Notice of the Ministry of Housing and Urban-Rural Development on Printing and Distributing the '14th Five-Year Plan' Building Energy Conservation and Green Building Development Plan", March 1, 2022, [http://www.gov.cn/zhengce/zhengceku/2022-03/12/content\\_5678698.htm](http://www.gov.cn/zhengce/zhengceku/2022-03/12/content_5678698.htm) (using Google Translate).
- 100 Natural Resources Canada, "Making Home Heating More Affordable for Canadians While Fighting Climate Change", November 21, 2022, <https://www.canada.ca/en/natural-resources-canada/news/2022/11/making-home-heating-more-affordable-for-canadians-while-fighting-climate-change.html>; EnergyTech, "New York Investing \$70M for 30,000 Heat Pumps for Electrifying Public Housing", August 4, 2022, <https://www.energytech.com/energy-efficiency/article/21248084/new-york-investing-70m-for-30000-heat-pumps-for-electrifying-public-housing>.
- 101 IEA, op. cit. note 92, p. 23.

## ENDNOTES – INVESTMENT AND FINANCE

- 1 BloombergNEF, "Energy Transition Investment Trends 2023", 2023, <https://about.bnef.com/energy-transition-investment>.
- 2 Ibid.
- 3 Ibid.
- 4 International Renewable Energy Agency (IRENA) and Climate Policy Initiative (CPI), "Global Landscape of Renewable Energy Finance 2023", 2023, [https://mc-cd8320d4-36a1-40ac-83cc-3389-cdn-endpoint.azureedge.net/-/media/Files/IRENA/Agency/Publication/2023/Feb/IRENA\\_CPI\\_Global\\_RE\\_finance\\_2023.pdf](https://mc-cd8320d4-36a1-40ac-83cc-3389-cdn-endpoint.azureedge.net/-/media/Files/IRENA/Agency/Publication/2023/Feb/IRENA_CPI_Global_RE_finance_2023.pdf).
- 5 International Energy Agency (IEA), "Russia's War on Ukraine – Topics", <https://www.iea.org/topics/russias-war-on-ukraine>, accessed March 29, 2023.
- 6 Ibid.
- 7 N. Bullard, "Clean Energy Sets \$1.1 Trillion Record That's Bound to Be Broken", Bloomberg, January 26, 2023, <https://www.bloomberg.com/news/articles/2023-01-26/clean-energy-fossil-fuel-investment-tied-for-first-time-in-2022>.
- 8 Ibid.
- 9 IRENA and CPI, op. cit. note 4.
- 10 Ibid.
- 11 **Figure 9** from BloombergNEF, op. cit. note 1.
- 12 Ibid.
- 13 Ibid.; IEA, "Renewable Power Is Set to Break Another Global Record in 2022 Despite Headwinds from Higher Costs and Supply Chain Bottlenecks", May 11, 2022, <https://www.iea.org/news/renewable-power-is-set-to-break-another-global-record-in-2022-despite-headwinds-from-higher-costs-and-supply-chain-bottlenecks>; WindEurope, "Wind Energy in Europe 2022 Statistics and the Outlook for 2023-2027", February 2023, <https://windeurope.org/intelligence-platform/product/wind-energy-in-europe-2022-statistics-and-the-outlook-for-2023-2027/#downloads>.
- 14 A. Joshi, "Investments in Renewables Reach New High in 2022 But Need Massive Increase", Mercom India, March 16, 2023, <https://mercomindia.com/investments-renewables-2022-need-increase>.
- 15 IRENA and CPI, op. cit. note 4.
- 16 Joshi, op. cit. note 14; IRENA and CPI, op. cit. note 4.
- 17 IRENA and CPI, op. cit. note 4.
- 18 BloombergNEF, op. cit. note 1.
- 19 Ibid.
- 20 Ibid.
- 21 Ibid.
- 22 Ibid.
- 23 Ibid.
- 24 Ibid.
- 25 A. Izadi-Najafabadi, BloombergNEF, personal communication with REN21, April 10, 2023.
- 26 Ibid..
- 27 Ibid.
- 28 BloombergNEF, op. cit. note 1.
- 29 WindEurope, "Investments in Wind Energy Are Down – Europe Must Get Market Design and Green Industrial Policy Right", January 31, 2023, <https://windeurope.org/newsroom/press-releases/investments-in-wind-energy-are-down-europe-must-get-market-design-and-green-industrial-policy-right>.
- 30 BloombergNEF, op. cit. note 1.
- 31 Ibid.
- 32 Ibid.
- 33 F. Harvey, "UK Investment in Clean Energy Transition Falls 10%, Bucking Global Trend", *The Guardian*, April 27, 2023, <https://www.theguardian.com/environment/2023/apr/27/uk-investment-in-clean-energy-transition-falls-10-bucking-global-trend>; H. Horton, "De Facto Ban on Solar Farms in England to Continue, Coffey Signals", *The Guardian*, November 17, 2022, <https://www.theguardian.com/environment/2022/nov/17/de-facto-ban-on-solar-farms-in-england-to-continue-therese-coffey-signals>.
- 34 BloombergNEF, op. cit. note 1.
- 35 Ibid.
- 36 Ibid.
- 37 Ibid.
- 38 Izadi-Najafabadi, op. cit. note 25.
- 39 Ibid.
- 40 BloombergNEF, op. cit. note 1.
- 41 Izadi-Najafabadi, op. cit. note 25.
- 42 BloombergNEF, op. cit. note 1.
- 43 Ibid.
- 44 R. Wiser, Lawrence Berkeley National Laboratory, personal communication with REN21, February 23, 2023.
- 45 BloombergNEF, op. cit. note 1.
- 46 Ibid.
- 47 Ibid.
- 48 Izadi-Najafabadi, op. cit. note 25.
- 49 Ibid.
- 50 BloombergNEF, op. cit. note 1.
- 51 Ibid.
- 52 J. Ellis, BloombergNEF, personal communication with REN21, March 29, 2023.
- 53 Ibid.
- 54 Ibid.
- 55 Ibid.
- 56 BloombergNEF, op. cit. note 1.
- 57 Ibid.
- 58 Ibid.
- 59 Ellis, op. cit. note 52.
- 60 Ibid.
- 61 Ibid.
- 62 Ibid.
- 63 BloombergNEF, op. cit. note 1.
- 64 Ibid.
- 65 European Commission, "South Africa Just Energy Transition Investment Plan", November 7, 2022, [https://ec.europa.eu/commission/presscorner/detail/en/statement\\_22\\_6664](https://ec.europa.eu/commission/presscorner/detail/en/statement_22_6664).
- 66 Ibid.
- 67 B. Ireri and R. Shirley, "Powering Growth", IMF, *Finance & Development*, Vol. 58, No. 3 (September 2021), <https://www.imf.org/en/Publications/fandd/issues/2021/09/fighting-climate-change-in-Africa-ireri>; IEA, "Financing Clean Energy Transitions in Emerging and Developing Economies", 2021, [https://iea.blob.core.windows.net/assets/6756ccd2-0772-4ffd-85e4-b73428ff9c72/FinancingCleanEnergyTransitionsinEMDEs\\_WorldEnergyInvestment2021SpecialReport.pdf](https://iea.blob.core.windows.net/assets/6756ccd2-0772-4ffd-85e4-b73428ff9c72/FinancingCleanEnergyTransitionsinEMDEs_WorldEnergyInvestment2021SpecialReport.pdf).
- 68 IEA, "The Cost of Capital in Clean Energy Transitions – Analysis", December 17, 2021, <https://www.iea.org/articles/the-cost-of-capital-in-clean-energy-transitions>.
- 69 Ibid.
- 70 **Figure 11** from IEA. World Energy Investment 2022, <https://iea.blob.core.windows.net/assets/b0beda65-8a1d-46ae-87a2-f95947ec2714/WorldEnergyInvestment2022.pdf>.
- 71 IRENA and CPI, op. cit. note 4.
- 72 P.R. Shukla et al., "Summary for Policymakers. Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change", 2022, [https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC\\_AR6\\_WGIII\\_SPM.pdf](https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_SPM.pdf).
- 73 Ibid.
- 74 IRENA and CPI, op. cit. note 4; BloombergNEF, "Wind and Solar Propel Net-Zero Power Supply Investment", January 19, 2023, <https://about.bnef.com/blog/wind-and-solar-propel-net-zero-power-supply-investment>. **Figure 12** from BloombergNEF, "Energy Transition Investment Trends 2023", 2023, <https://assets.bbhub.io/professional/sites/24/energy-transition-investment-trends-2023.pdf>; IRENA, "Global Landscape of Renewable Energy Finance 2023", 2023, [https://mc-cd8320d4-36a1-40ac-83cc-3389-cdn-endpoint.azureedge.net/-/media/Files/IRENA/Agency/Publication/2023/Feb/IRENA\\_CPI\\_Global\\_RE\\_finance\\_2023.pdf](https://mc-cd8320d4-36a1-40ac-83cc-3389-cdn-endpoint.azureedge.net/-/media/Files/IRENA/Agency/Publication/2023/Feb/IRENA_CPI_Global_RE_finance_2023.pdf); BloombergNEF, "Wind and Solar Propel...", op. cit. this note.; Teske et. al., "One Earth Climate Model", 2022, <https://doi.org/10.1007/978-3-030-99177-7>.

- 75 **Sidebar 1** based on the following sources: I. Robertson, "Cleaner Is Cheaper", *Innovators*, June 2, 2020, <https://www.innovatorsmag.com/cleaner-is-cheaper>; IRENA, "Record Growth in Renewables Achieved Despite Energy Crisis", March 21, 2023, <https://www.irena.org/News/pressreleases/2023/Mar/Record-9-point-6-Percentage-Growth-in-Renewables-Achieved-Despite-Energy-Crisis>; 900 GW from S. Osaka, "This Little-Known Bottleneck Is Blocking Clean Energy for Millions", *Washington Post*, December 21, 2022, <https://www.washingtonpost.com/climate-environment/2022/12/20/clean-energy-bottleneck-transmission-lines/>; C. Clifford, "Wind and Solar Power Generators Wait in Yearlong Lines to Put Clean Electricity on the Grid, Then Face Huge Interconnection Fees They Can't Afford", *CNBC*, April 6, 2023, <https://www.cnbc.com/2023/04/06/outdated-us-energy-grid-tons-of-clean-energy-stuck-waiting-in-line.html>; 8,100 projects from B. Plumer, "The U.S. Has Billions for Wind and Solar Projects. Good Luck Plugging Them In.", *New York Times*, February 23, 2023, <https://www.nytimes.com/2023/02/23/climate/renewable-energy-us-electrical-grid.html>; Reuters, "Greek Renewables Fully Cover Power Demand for First Time on Record", October 10, 2022, <https://www.reuters.com/business/sustainable-business/greek-renewables-fully-cover-power-demand-first-time-record-2022-10-10/>; H. Aposporis, "Greek Government Adopts Stricter Rules for Renewables Connection", *Balkan Green Energy News*, October 13, 2022, <https://balkangreenenergynews.com/greek-government-adopts-stricter-rules-for-connecting-renewables-to-grid/>; S. O'Farrell, "Australia Invests Billions to Upgrade Grid Infrastructure", *FDI Intelligence*, January 17, 2023, <https://www.fdiintelligence.com/content/news/australia-invests-billions-to-upgrade-grid-infrastructure-81907>; H. Dempsey and G. Plimmer, "Renewables Groups Sound Alarm over UK Grid Connection Delays", *Financial Times*, February 6, 2023, <https://www.ft.com/content/bc200569-cb85-4842-a59a-f04d342805fc>; North Carolina from Clifford, op. cit. this note; N.J. Kurmayer, "German Electricity Grid Upgrade 'Will Be Expensive', Experts Warn – EU-SysFlex", *EU-SysFlex*, February 21, 2022, <https://eu-sysflex.com/german-electricity-grid-upgrade-will-be-expensive-experts-warn/>; BloombergNEF, "Global Net Zero Will Require \$21 Trillion Investment In Power Grids", March 2, 2023, <https://about.bnef.com/blog/global-net-zero-will-require-21-trillion-investment-in-power-grids/>; Thunder Said Energy, "Renewables: How Much Time to Connect to the Grid?" <https://thundersaidenergy.com/downloads/renewables-how-much-time-to-connect-to-the-grid/>, accessed May 2, 2023; Germany from Kurmayer, op. cit. this note; Greece from Aposporis, op. cit. this note; USD 20 billion from US Department of Energy, "Building a Better Grid Initiative", January 12, 2022, <https://www.energy.gov/oe/articles/building-better-grid-initiative>; Japanese Ministry of Economy, Trade and Industry, Agency for Natural Resources and Energy, "Change how to connect to the 'grid' to increase renewable energy", March 25, 2021, [https://www.enecho.meti.go.jp/about/special/johoteikyo/non\\_firm.html](https://www.enecho.meti.go.jp/about/special/johoteikyo/non_firm.html) (using Google Translate); S. Dumitriu, "How Spain Eliminated Environmental Impact Assessments for Most Renewable Projects", *Notes on Growth*, February 17, 2023, <https://samdumitriu.substack.com/p/how-spain-eliminated-environmental>; D. Jordan, "Manchin's Permit Overhaul Falls Short Again", *Roll Call*, December 15, 2022, <https://rollcall.com/2022/12/15/manchins-permit-overhaul-falls-short-again/>; UK from Dempsey and Plimmer, op. cit. this note; Electricity Markets and Policy Group, "Queued Up: Characteristics of Power Plants Seeking Transmission Interconnection", accessed June 5, 2023, <https://emp.lbl.gov/queues>.

## ENDNOTES – BIOENERGY

- 1 International Energy Agency (IEA), "Bioenergy – Analysis", 2022, <https://www.iea.org/reports/bioenergy>
- 2 IEA Bioenergy, "Bioenergy, a Sustainable Solution", <https://www.ieabioenergy.com/bioenergy-a-sustainable-solution>, accessed April 4, 2023.
- 3 IEA, "Technology Roadmap: Delivering Sustainable Bioenergy", 2017, <https://www.iea.org/reports/technology-roadmap-delivering-sustainable-bioenergy>.
- 4 World Health Organization, "Household Air Pollution", <https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health>, accessed April 4, 2023.
- 5 Intergovernmental Panel on Climate Change, "FAQs Chapter 6 – Special Report on Climate Change and Land", <https://www.ipcc.ch/srcccl/faqs/faqs-chapter-6>, accessed April 4, 2023.
- 6 IEA, "Bioenergy – Fuels & Technologies", <https://www.iea.org/fuels-and-technologies/bioenergy>, accessed April 4, 2023.
- 7 IEA, op. cit. note 1.
- 8 **Figure 13** from IEA, "Energy Statistics Data Browser – Data Tools", <https://www.iea.org/data-and-statistics/data-tools/energy-statistics-data-browser>, accessed April 4, 2023.
- 9 Ibid.
- 10 Ibid.
- 11 Ibid.
- 12 Ibid.
- 13 Ibid.
- 14 International Renewable Energy Agency (IRENA), "Bioenergy and Biofuels", <https://www.irena.org/Energy-Transition/Technology/Bioenergy-and-biofuels>, accessed April 4, 2023.
- 15 IEA, op. cit. note 1.
- 16 A. Nyambane et al., "Ethanol as a Clean Cooking Alternative in Sub-Saharan Africa: Insights from Sugarcane Production and Ethanol Adoption Sites in Malawi and Mozambique", in A. Gasparatos et al., *Sustainability Challenges in Sub-Saharan Africa II: Insights from Eastern and Southern Africa*, 2020, pp. 115-44, [https://doi.org/10.1007/978-981-15-5358-5\\_5](https://doi.org/10.1007/978-981-15-5358-5_5); W.M. Champion and A.P. Grieshop, "Pellet-Fed Gasifier Stoves Approach Gas-Stove Like Performance During In-Home Use in Rwanda", *Environmental Science & Technology*, Vol. 53, No. 11 (June 4, 2019), pp. 6570-79, <https://doi.org/10.1021/acs.est.9b00009>; D. Ramsay Njenga Mary, "Five Things to Know About Briquettes and Sustainable Bioenergy in Africa", CIFOR Forests News, May 4, 2021, <https://forestsnews.cifor.org/72344/five-things-to-know-about-briquettes-and-sustainable-bioenergy-in-africa>.
- 17 IEA, op. cit. note 8.
- 18 Ibid.
- 19 Ibid.
- 20 IEA, op. cit. note 8. **Figure 14** from IEA, "Transport Biofuels", in *Renewables 2022*, 2022, <https://www.iea.org/reports/renewables-2022/transport-biofuels>.
- 21 IEA, op. cit. note 8.
- 22 Ibid.
- 23 Bioenergy International, "Hindustan Unilever Switches from Coal to Biomass and Biofuels Across Its Operations", December 3, 2021, <https://bioenergyinternational.com/hindustan-unilever-switches-from-coal-to-biomass-and-biofuels-across-its-operations>; akzente, "The Brewery Using Bush Biomass", <https://akzente.giz.de/en/artikel/brewery-using-bush-biomass>, accessed April 4, 2023; AB Inbev, "Net Zero Executive Summary", [https://www.ab-inbev.com/assets/pdfs/Net%20Zero%20Executive%20Summary\\_FINAL%2012pm.pdf](https://www.ab-inbev.com/assets/pdfs/Net%20Zero%20Executive%20Summary_FINAL%2012pm.pdf), accessed April 14, 2023; Serum Institute of India, "Green Initiatives at SERUM Institute", [https://www.seruminstitute.com/about\\_green\\_initiatives.php](https://www.seruminstitute.com/about_green_initiatives.php), accessed April 4, 2023; S. Seidel, "Wood Gasifier in Germany", Spanner Re2, <https://www.holz-kraft.com/en/references/references-by-countries/germany/836-palets-energy-biomass-power-plant.html>, accessed April 4, 2023.
- 24 Khmer Times, "Heineken Opens Kingdom's Largest Biomass Plant", September 22, 2022, <https://www.khmertimeskh.com/501156393/heineken-opens-kingdoms-largest-biomass-plant>.
- 25 International District Energy Association, "District Heating", <https://www.districtenergy.org/topics/district-heating>, accessed April 4, 2023.
- 26 IEA, "District Heating – Analysis", 2022, <https://www.iea.org/reports/district-heating>.
- 27 Ibid.
- 28 Ibid.
- 29 A. Sherrard, "Groundbreaking Held for Lithuania's Largest Renewable Energy Project", Bioenergy International, February 15, 2018, <https://bioenergyinternational.com/groundbreaking-held-lithuanias-largest-renewable-energy-project>; Fresh Media, "About the Plant | Vilnius Combined Heat and Power Plant", <https://www.vkj.lt/en/about-us/about-the-plant/129>, accessed April 4, 2023.
- 30 SBBA, "SBBA Heating Market Report 2021", 2021, [https://www.sbba.se/wp-content/uploads/sites/11/2021/09/Heating\\_Market\\_Sweden\\_2021\\_V1.0.pdf](https://www.sbba.se/wp-content/uploads/sites/11/2021/09/Heating_Market_Sweden_2021_V1.0.pdf).
- 31 Statistical Database Sweden, "Consumption of Fuels for Steam and Hot Water Production, TJ by Type of Power Plants, Type of Fuel and Year. PxWeb", [https://www.statistikdatabasen.scb.se/pxweb/en/ssd/START\\_\\_EN\\_\\_EN0105\\_\\_EN0105A/BforangaAR/tableViewLayout1](https://www.statistikdatabasen.scb.se/pxweb/en/ssd/START__EN__EN0105__EN0105A/BforangaAR/tableViewLayout1), accessed April 4, 2023.
- 32 Egypt Independent, "Egypt Establishes Its 1st Plant to Convert Waste into Energy", <https://egyptindependent.com/egypt-establishes-its-1st-plant-to-convert-waste-into-energy>.
- 33 EurObserv'ER, "Solid Biofuels Barometer 2022", December 22, 2022, <https://www.eurobserv-er.org/solid-biomass-barometer-2022>.
- 34 Ibid.
- 35 Ibid.
- 36 Ibid.
- 37 Ibid.
- 38 Ibid.
- 39 Ibid.
- 40 World Bank, "Access to Clean Fuels and Technologies for Cooking (% of Population)", <https://data.worldbank.org/indicator/EG.CFT.ACCS.ZS>, accessed April 4, 2023; Sustainable Energy for All, "Clean Cooking", <https://www.seforall.org/clean-cooking>, accessed April 4, 2023; IEA, "Access to Clean Cooking – SDG7: Data and Projections – Analysis", 2019, <https://www.iea.org/reports/sdg7-data-and-projections/access-to-clean-cooking>.
- 41 KOKO Networks, <https://kokonetworks.com>, accessed April 4, 2023; Solar Cookers International, "Why Solar Cooking", <https://www.solarcookers.org/why>, accessed April 4, 2023; SupaMoto, <http://www.supamoto.co.zm>, accessed April 4, 2023; World Bank, "Infographic – Modern Energy Cooking Services", 2020, <https://www.worldbank.org/en/news/infographic/2020/09/24/infographic-modern-energy-cooking-services>.
- 42 See sources in endnote 40.
- 43 Clean Cooking Alliance, "Annual Report 2022", 2022, <https://cleancooking.org/wp-content/uploads/2023/03/CCA-2022-Annual-Report.pdf>.
- 44 Clean Cooking Alliance, "To Stop Climate Catastrophe, Invest in Clean Cooking: Exploring the Lack of Funding – and Signs of Progress – in the Industry", 2019, <https://cleancooking.org/news/to-stop-climate-catastrophe-invest-in-clean-cooking-exploring-the-lack-of-funding-and-signs-of-progress-in-the-industry>.
- 45 European Commission, "Biofuels", [https://energy.ec.europa.eu/topics/renewable-energy/bioenergy/biofuels\\_en](https://energy.ec.europa.eu/topics/renewable-energy/bioenergy/biofuels_en), accessed April 4, 2023.
- 46 IEA, op. cit. note 8.
- 47 European Biogas, "Biomethane in Transport", 2019, <https://www.europeanbiogas.eu/wp-content/uploads/2019/07/Biomethane-in-transport.pdf>.
- 48 Fuel Identifiers, "Fuel Labelling for Road Vehicles", 2021, <https://fuel-identifiers.eu/wp-content/uploads/2021/02/QA-operators-EN.pdf>; European Commission, "EU Fuel Labelling: Clearer Information for Consumers and Operators", [https://ec.europa.eu/commission/presscorner/detail/en/IP\\_18\\_6101](https://ec.europa.eu/commission/presscorner/detail/en/IP_18_6101), accessed April 4, 2023; NITI Aayog, "Expert Committee on Roadmap for Ethanol Blending in India by 2025", <https://www.niti.gov.in/expert-committee-roadmap-ethanol-blending-india-2025>, accessed April 4, 2023; B. Christina, "Indonesia Assures B35 Biodiesel Won't Squeeze Cooking Oil Supply", Reuters, January 31, 2023, <https://www.reuters.com/markets/commodities/indonesia-estimates-2-bl-needed-biodiesel-subsidies-2023-01-31>.
- 49 Sekab, "ED95", <https://www.sekab.com/en/products-services/product/ed95>, accessed April 4, 2023; f3 centre, "B100 (Biodiesel)", August 14, 2017, <https://f3centre.se/en/fact-sheets/b100-biodiesel>.
- 50 IEA, "Transport Biofuels – Renewables 2022 – Analysis", 2022, <https://www.iea.org/reports/renewables-2022/transport-biofuels>. **Figure 15** from IRENA, "Renewable Capacity Statistics 2023", 2023, <https://www.irena.org/Publications/2023/Mar/Renewable-capacity-statistics-2023>.
- 51 Ibid.
- 52 Ibid.
- 53 IEA, op. cit. note 50.



- 54 ACI World, "Positive and Immediate Impact on Global Air Travel Demand as Restrictions Relax", June 28, 2022, <https://aci.aero/2022/06/28/positive-and-immediate-impact-on-global-air-travel-demand-as-restrictions-relax>.
- 55 Ibid.
- 56 IEA, op. cit. note 50.
- 57 IEA, op. cit. note 8.
- 58 US Energy Information Administration (EIA), International: Biofuels, <https://www.eia.gov/international/data/world/biofuels/biofuels-production>, accessed April 4, 2023.
- 59 Alternative Fuels Data Center, "Ethanol Blends", [https://afdc.energy.gov/fuels/ethanol\\_blends.html](https://afdc.energy.gov/fuels/ethanol_blends.html), accessed April 4, 2023; S. Kelly, J. Renshaw and S. Kelly, "EPA Proposes Expanded Sales of Higher Ethanol Blend Gasoline in US Midwest", Reuters, March 1, 2023, <https://www.reuters.com/markets/commodities/us-epa-proposes-expanded-sales-higher-ethanol-gasoline-midwest-states-2023-03-01>.
- 60 Transport Policy, "Brazil: Fuels: Biofuels", <https://www.transportpolicy.net/standard/brazil-fuels-biofuels>, accessed April 4, 2023; SugarCane, "Renovabio", <https://www.sugarcane.org/sustainability-the-brazilian-experience/renovabio>, accessed April 4, 2023.
- 61 EPure, "Overview of Biofuels Policies and Markets Across the EU", 2023, <https://www.epure.org/wp-content/uploads/2023/02/230227-DEF-REP-Overview-of-biofuels-policies-and-markets-across-the-EU-February-2023-1.pdf>.
- 62 European Commission Joint Research Centre, "Renewable Energy – Recast to 2030 (RED II)", [https://joint-research-centre.ec.europa.eu/welcome-jec-website/reference-regulatory-framework/renewable-energy-recast-2030-red-ii\\_en](https://joint-research-centre.ec.europa.eu/welcome-jec-website/reference-regulatory-framework/renewable-energy-recast-2030-red-ii_en), accessed April 4, 2023; IEA, op. cit. note 50; European Parliament, "EU Ban on Sale of New Petrol and Diesel Cars from 2035 Explained", March 11, 2022, <https://www.europarl.europa.eu/news/en/headlines/economy/20221019STO44572/eu-ban-on-sale-of-new-petrol-and-diesel-cars-from-2035-explained>.
- 63 Ethanol Producer, "China's Fuel Ethanol Consumption Expected to Fall in 2022", 2022, <https://ethanolproducer.com/articles/19622/chinaundefineds-fuel-ethanol-consumption-expected-to-fall-in-2022>.
- 64 Ibid.
- 65 ETEnergyworld.com, "India Achieved 10 per Cent Ethanol Blending Target Ahead of Schedule: PM Modi – ET EnergyWorld," ETEnergyworld.com, August 15, 2022, <https://energy.economictimes.indiatimes.com/news/oil-and-gas/india-achieved-10-per-cent-ethanol-blending-target-ahead-of-schedule-pm-modi/93568825>.
- 66 PIB, "Prime Minister Launches E20 Fuel & Flags Off Green Mobility Rally in Bengaluru Today", 2022, <https://pib.gov.in/pib.gov.in/Pressreleaseshare.aspx?PRID=1896729>.
- 67 Environmental and Energy Study Institute, "Is Cellulosic Ethanol Dead? Despite Setbacks, Signs of Progress", November 9, 2017, <https://www.eesi.org/articles/view/is-cellulosic-ethanol-dead-despite-setbacks-signs-of-progress>.
- 68 Shell Global, "Shell and Raízen Sign Large Cellulosic Ethanol Deal", November 7, 2022, <https://www.shell.com/business-customers/trading-and-supply/trading/news-and-media-releases/shell-and-raizen-sign-large-cellulosic-ethanol-deal.html>; Biofuels Digest, "The Big Launch: PM Modi Inaugurates India's First 2G Ethanol Project, Using Praj Technology", August 11, 2022, <https://www.biofuelsdigest.com/bdigest/2022/08/11/the-big-launch-pm-modi-inaugurates-indias-first-2g-ethanol-project-using-praj-technology>; Clariant Ltd Basel, "Clariant Produces First Commercial Sunliquid® Cellulosic Ethanol at New Plant in Podari, Romania", 2022, <https://www.clariant.com/en/Corporate/News/2022/06/Clariant-produces-first-commercial-sunliquid-cellulosic-ethanol-at-new-plant-in-Podari-Romania>.
- 69 IEA, op. cit. note 50.
- 70 US Department of Agriculture, "Biofuels Annual", 2022, [https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Biofuels%20Annual\\_The%20Hague\\_European%20Union\\_E42022-0048.pdf](https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Biofuels%20Annual_The%20Hague_European%20Union_E42022-0048.pdf).
- 71 Ibid.
- 72 F. Nangoy, "Indonesia May Start Using B35 Biodiesel from Jan 2023 – Energy Ministry", Reuters, December 9, 2022, <https://www.reuters.com/business/energy/indonesia-may-start-using-b35-biodiesel-jan-2023-energy-ministry-2022-12-09>.
- 73 Biofuels International, "B20 Mandate Could Boost Biodiesel Production in Malaysia", March 10, 2023, <https://biofuels-news.com/news/b20-mandate-could-boost-biodiesel-production-in-malaysia>.
- 74 V. Hari, "Asia Needs to Face Up to the Downsides of Biofuels", Nikkei Asia, March 22, 2023, <https://asia.nikkei.com/Opinion/Asia-needs-to-face-up-to-the-downsides-of-biofuels>; Oils & Fats International, "Thailand Puts 5% Limit on Biodiesel Blending to Counter Rising Oil Prices", February 15, 2022, <https://www.ofimagazine.com/news/thailand-puts-5-limit-on-biodiesel-blending-to-counter-rising-oil-prices>.
- 75 Vilnius Kogeneracinė Jėgainė, "About the Plant | Vilnius Combined Heat and Power Plant", <https://vkt.lt/en/about-us/about-the-plant/129>, accessed April 4, 2023.
- 76 f3 centre, "HEFA/HVO, Hydroprocessed Esters and Fatty Acids", August 9, 2016, <https://f3centre.se/sv/faktblad/hefa-hvo-hydroprocessed-esters-and-fatty-acids>.
- 77 Neste, "Neste's High-Quality Products Are Manufactured in Finland, the Netherlands and Singapore", April 27, 2020, <https://www.neste.com/about-neste/who-we-are/production>; Eni, "The Biorefineries of Venice and Gela", <https://www.eni.com/en-IT/operations/energy-evolution/biorefineries.html>, accessed April 4, 2023; Total Energies, "La Mède: A Multipurpose Facility for the Energies of Tomorrow", April 3, 2023, <https://totalenergies.com/energy-expertise/projects/bioenergies/la-mede-a-forward-looking-facility>; BP, "BP Acquires 30% Stake in the UK's Largest Provider of Low Emission Hydrogenated Vegetable Oil Fuels", 2022, <https://www.bp.com/en/global/corporate/news-and-insights/press-releases/bp-acquires-30-per-cent-stake-in-the-uks-largest-provider-of-low-emission-hydrogenated-vegetable-oil-fuels.html>.
- 78 World Bioenergy, "Biomethane Vision Document", 2022, <https://www.worldbioenergy.org/uploads/221216%20Biomethane%20vision%20document.pdf>; California Energy Commission, "Biofuels: Biomethane", <https://www.energy.ca.gov/programs-and-topics/programs/clean-transportation-program/clean-transportation-funding-areas-2-1>, accessed April 4, 2023; Government of Brazil, "Brazil Roadmap for Natural Gas and Biomethane Heavy Duty Trucks & Buses Part 1 Strengths, Weaknesses, Opportunities & Challenges (SWOC)", 2021, <https://www.gov.br/mme/pt-br/assuntos/noticias/1.BrazilHDNGVRoadmapPart14.pdf>.
- 79 L. Klackenberg, "Biomethane in Sweden – Market Overview and Policies", 2019, <https://www.energygas.se/media/wm10sxc/biomethane-in-sweden-230112.pdf>.
- 80 Ibid.
- 81 L. Losson, "Global Biomethane Market 2022 Assessment + Database", Cedigaz, May 2, 2022, <https://www.cedigaz.org/global-biomethane-market-2022-assessment>; Planete Energies, "Global Natural Gas Consumption", <https://www.planete-energies.com/en/media/figures/global-natural-gas-consumption>, accessed May 9, 2023.
- 82 P. Serfass, "American Biogas Council Applauds Passage of Inflation Reduction Act and Historic Investment in Clean Energy", American Biogas Council, August 12, 2022, <https://americanbiogascouncil.org/american-biogas-council-applauds-passage-of-inflation-reduction-act-and-historic-investment-in-clean-energy>; Fluence, "Inflation Reduction Act to Boost Biogas", November 3, 2022, <https://www.fluencecorp.com/inflation-reduction-act-to-boost-biogas>; European Commission, "Biomethane", [https://energy.ec.europa.eu/topics/renewable-energy/bioenergy/biomethane\\_en](https://energy.ec.europa.eu/topics/renewable-energy/bioenergy/biomethane_en), accessed April 4, 2023.
- 83 ETIP Bioenergy, "Air", <https://www.etipbioenergy.eu/value-chains/products-end-use/end-use/air>, accessed April 4, 2023.
- 84 International Air Transport Association, "Fact Sheet Climate Change", <https://www.iata.org/contentassets/713a82c7fbf84947ad536df18d08ed86/fact-sheet-climate-change.pdf>, accessed April 4, 2023.
- 85 Climate Champions, "SAF pocket guide for corporate customers", 2022, [https://climatechampions.unfccc.int/wp-content/uploads/2022/11/heathrow\\_smi\\_saf-pocket-guide.pdf](https://climatechampions.unfccc.int/wp-content/uploads/2022/11/heathrow_smi_saf-pocket-guide.pdf).
- 86 US Department of Energy, "Sustainable Aviation Fuel: Review of Technical Pathways", 2020, <https://www.energy.gov/eere/bioenergy/articles/sustainable-aviation-fuel-review-technical-pathways-report>.
- 87 L. Harper, "European SAF Development 'Put Back a Decade' by US IRA Measures", Flight Global, March 30, 2023, <https://www.flightglobal.com/airlines/european-saf-development-put-back-a-decade-by-us-ira-measures/152690.article>.
- 88 Stillwater Associates, "Inflation Reduction Act Sustainable Aviation Fuel Credit", <https://stillwaterassociates.com/inflation-reduction-act-sustainable-aviation-fuel-credit-carbon-intensity-matters>, accessed April 6, 2023.
- 89 European Parliament, "ReFuelEU Aviation Initiative: Sustainable Aviation Fuels and the Fit for 55 Package", 2022, [https://www.europarl.europa.eu/thinktank/en/document/EPRS\\_BRI\(2022\)698900](https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI(2022)698900).

- 90 UNCTAD, "Decarbonizing the Maritime Sector: Mobilizing Coordinated Action in the Industry Using an Ecosystems Approach", June 8, 2022, <https://unctad.org/news/decarbonizing-maritime-sector-mobilizing-coordinated-action-industry-using-ecosystems-approach>.
- 91 International Maritime Organization, "IMO's Work to Cut GHG Emissions from Ships", <https://www.imo.org/en/MediaCentre/HotTopics/Pages/Cutting-GHG-emissions.aspx>, accessed April 4, 2023.
- 92 European Maritime Safety Agency, "Update on Potential of Biofuels for Shipping", October 18, 2022, <https://www.emsa.europa.eu/newsroom/latest-news/item/4834-update-on-potential-of-biofuels-for-shipping.html>; M. Patrakka, "Cleaner Marine Fossil Fuels – Do They Exist?" Elomatic, June 10, 2020, <https://blog.elomatic.com/en/cleaner-marine-fossil-fuels-do-they-exist>.
- 93 T.I. Simonsen et al., "Progress towards Biofuels for Marine Shipping", December 2021, [https://www.ieabioenergy.com/wp-content/uploads/2021/11/Progress-towards-biofuels-for-marine-shippingT39-report\\_June-2021\\_Final.pdf](https://www.ieabioenergy.com/wp-content/uploads/2021/11/Progress-towards-biofuels-for-marine-shippingT39-report_June-2021_Final.pdf).
- 94 Valmet, "Asia's Largest Biomass Power Plant Operates with Valmet DNA", January 6, 2016, <https://www.valmet.com/insights/articles/all-articles/asias-largest-biomass-power-plant-operates-with-valmet-dna>; UNIDO, "Promoting Small Scale Biomass Power Plants in Rural Thailand", 2021, [https://www.unido.org/sites/default/files/files/2021-09/GEF\\_Biomass\\_Gasification\\_thailand\\_screen.pdf](https://www.unido.org/sites/default/files/files/2021-09/GEF_Biomass_Gasification_thailand_screen.pdf).
- 95 Ember, "Global Electricity Review 2023", April 11, 2023, <https://ember-climate.org/insights/research/global-electricity-review-2023>.
- 96 Ibid.
- 97 IEA, op. cit. note 8.
- 98 Ibid.
- 99 IRENA, "Renewable Capacity Statistics 2022", 2022, [https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Apr/IRENA\\_RE\\_Capacity\\_Statistics\\_2022.pdf](https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Apr/IRENA_RE_Capacity_Statistics_2022.pdf).
- 100 Ibid. **Figure 15** from Ibid.
- 101 Ibid.
- 102 Ember, op. cit. note 95; Government of China, "Biomass Energy to Provide Heat, Fuel", 2021, [http://english.www.gov.cn/news/topnews/202104/15/content\\_WS60778ff2c6d0df57f98d7d92.html](http://english.www.gov.cn/news/topnews/202104/15/content_WS60778ff2c6d0df57f98d7d92.html); IEA Bioenergy, "Implementation of Bioenergy in China – Country Report", 2021, [https://www.ieabioenergy.com/wp-content/uploads/2021/11/CountryReport2021\\_China\\_final.pdf](https://www.ieabioenergy.com/wp-content/uploads/2021/11/CountryReport2021_China_final.pdf).
- 103 Government of Brazil, "Monthly Energy Bulletin – Brazil", 2022, <https://www.gov.br/mme/pt-br/assuntos/secretarias/spe/publicacoes/boletins-mensais-de-energia/2022-2/ingles/3-boletim-mensal-de-energia-marco-2022>.
- 104 R. Ireland, "The Rise of Utility Wood Pellet Energy in the Era of Climate Change", 2022; US International Trade Commission, [https://www.usitc.gov/publications/332/working\\_papers/wood\\_pellets\\_final\\_060622.pdf](https://www.usitc.gov/publications/332/working_papers/wood_pellets_final_060622.pdf); PIB, "Ministry of Power Decides to Set Up a National Mission on Use of Biomass in Coal Based Thermal Power Plants", 2021, [https://www.usitc.gov/publications/332/working\\_papers/wood\\_pellets\\_final\\_060622.pdf](https://www.usitc.gov/publications/332/working_papers/wood_pellets_final_060622.pdf).
- 105 PIB, op. cit. note 104.
- 106 Renewable Watch, "Inter-Ministerial Meeting to Review Progress of Biomass Co-Firing in Thermal Power Plants Held in New Delhi Today", October 6, 2022, <https://renewablewatch.in/2022/10/06/inter-ministerial-meeting-reviews-the-progress-of-biomass-co-firing-in-thermal-power-plants/>.
- 107 K. Harris, "Section 1: UK Total Energy", March 30, 2023, [https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment\\_data/file/1147249/Energy\\_Trends\\_March\\_2023.pdf](https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1147249/Energy_Trends_March_2023.pdf).
- 108 EurObserv'ER, "21st Annual Overview Barometer", February 28, 2023, <https://www.eurobserv-er.org/21st-annual-overview-barometer>.
- 109 Ibid.
- 110 Ibid.
- 111 F. Simon, "Biomass Fight Leaves EU Renewable Energy Talks in a Deadlock", Euractiv, February 16, 2023, <https://www.euractiv.com/section/biomass/news/biomass-fight-leaves-eu-renewable-energy-talks-in-a-deadlock>.
- 112 European Commission, "Accelerate the Rollout of Renewable Energy", March 30, 2023, [https://ec.europa.eu/commission/presscorner/detail/en/ip\\_23\\_2061](https://ec.europa.eu/commission/presscorner/detail/en/ip_23_2061).
- 113 **Figure 16** from F. Mathews, "Industrial Pellet Market Update", Hawkins Wright, 2022, [https://www.svebio.se/wp-content/uploads/2022/05/Mathews\\_Fiona\\_NPC2022.pdf](https://www.svebio.se/wp-content/uploads/2022/05/Mathews_Fiona_NPC2022.pdf) and Food and Agriculture Organization of the United Nations, (FAO), "FAOSTAT", <https://www.fao.org/faostat/en/#data/FO>, accessed April 4, 2023.
- 114 FAO, op. cit. note 113.
- 115 World Bio Market Insights, "Ban on Russian Wood Pellet Exports Would Have Consequences on Waste", July 4, 2022, <https://worldbiomarketinsights.com/ban-on-russian-wood-pellet-exports-would-have-consequences-on-waste>; S. Hong and D. Sun, "Viewpoint: Asian Wood Pellet Demand to Diverge", Argus Media, January 6, 2023, <https://www.argusmedia.com/en/news/2406850-viewpoint-asian-wood-pellet-demand-to-diverge>.
- 116 Ibid.

## ENDNOTES – GEOTHERMAL POWER AND HEAT

- 1 Estimates based on the following sources: power capacity data for Iceland, Indonesia, Kenya, Philippines, Türkiye and the United States from sources noted elsewhere in this section; for New Zealand from New Zealand Ministry of Business, Innovation and Employment, "Electricity Statistics", <https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/electricity-statistics>, accessed April 2023; capacity data for other countries from International Renewable Energy Agency (IRENA), "Renewable Capacity Statistics 2023", March 2023, <https://www.irena.org/Publications/2023/Mar/Renewable-capacity-statistics-2023>; estimated electricity generation in 2022 based on International Energy Agency (IEA), "Renewables 2022 Data Explorer", December 6, 2022, <https://www.iea.org/data-and-statistics/data-tools/renewables-data-explorer>. Heat capacity and output in 2022 are extrapolations based on five-year average annualised growth from 2015 through 2019, from J.W. Lund and A.N. Toth, "Direct Utilization of Geothermal Energy 2020 Worldwide Review", October 2020, <https://www.geothermal-energy.org/pdf/IGAStandard/WGC/2020/01018.pdf>.
- 2 For heat applications, geothermal fluid can be used directly or via heat exchangers, where the fluid is re-injected into the crust. For electricity generation, geothermal steam is used directly to drive turbines (either dry or flash steam), or, in the case of binary-cycle plants, geothermal fluid is used to heat a secondary working fluid that powers the turbine. Sub-surface geothermal fluid undergoes flash evaporation to steam as pressure drops ascending a wellbore and at the power plant.
- 3 End-2021 capacity data and capacity additions in 2022 from sources in endnote 1.
- 4 Renewable Energy Policy Network for the 21st Century (REN21), "Renewables Global Status Report", 2018-2022 editions, <https://www.ren21.net/reports/global-status-report>.
- 5 See sources in endnote 1. **Figure 17** based on end-2021 capacity data and capacity additions in 2022 from sources in endnote 1 and from sources noted elsewhere in this section. For the purpose of this figure, end-2021 capacity is assumed to be equal to end-2022 capacity less new capacity installed (or capacity expansion) during 2022.
- 6 End-2021 capacity data from sources in endnote 1; capacity additions in 2022, by country, from sources noted elsewhere in this section.
- 7 In some instances, the effective geothermal generating capacity (achievable or running capacity) may be lower than indicated values, due to gradual degradation of the steam-generating capability of geothermal fields or to insufficient drilling of make-up wells to replenish steam flow over time. If a geothermal power plant extracts heat and steam from the reservoir at a rate that exceeds the rate of replenishment across all its boreholes, additional wells may be drilled over time to tap additional steam flow, provided that the geothermal field overall is capable of supporting additional steam flow. For example, the effective net generation capacity in the United States was 2.6 GW at the end of 2022, as resource depletion in particular has limited the effective output far below the stated gross nameplate capacity of 3.9 GW. This resource-limited capability of a geothermal plant defines its dependable running capacity, as opposed to the total nameplate capacity of its generator(s). For the United States, most of the difference between nameplate and running capacity (about 800 MW) results from plant de-rating at the Geysers geothermal field in California, which is not able to produce enough steam, due to productivity decline, to operate at nameplate capacity. Net summer capacity from US Energy Information Administration (EIA), "Electric Power Monthly", February 2022, Table 6.2.B, <https://www.eia.gov/electricity/monthly>; nameplate capacity from US EIA, "Form EIA-860M (Preliminary Monthly Electric Generator Inventory)", December 2021, <https://www.eia.gov/electricity/data/eia860m>; US Department of Energy, Office of Scientific and Technical Information, "GeoVision: Harnessing the Heat Beneath Our Feet", June 2019, <https://www.energy.gov/eere/geothermal/downloads/geovision-harnessing-heat-beneath-our-feet>. In general, a power plant's net capacity equals gross capacity less the plant's own power requirements and any seasonal de-rating. In the case of geothermal plants, net capacity also would reflect the effective power capability of the plant as determined by the current steam production of the geothermal field.
- 8 Kenya Generating Company (KenGen), "Good News for Kenya as KenGen Completes Construction of Olkaria I Unit 6 Geothermal Power Plant", March 29, 2022, <https://www.kengen.co.ke/index.php/information-center/news-and-events-3/good-news-for-kenya-as-kengen-completes-construction-of-olkaria-i-unit-6-geothermal-power-plant.html>; KenGen, "Good News for Kenyans as President Uhuru Kenyatta Switches on KenGen's 86MW Olkaria Geothermal Power Plant", July 26, 2022, <https://www.kengen.co.ke/index.php/information-center/news-and-events-3/good-news-for-kenyans-as-president-uhuru-kenyatta-switches-on-kengen%E2%80%99s-86mw-olkaria-geothermal-power-plant.html>.
- 9 Energy & Petroleum Regulatory Authority, "Biannual Energy and Petroleum Statistics Report for the Financial Year 2022/2023", April 25, 2023, <https://www.epra.go.ke/biannual-energy-and-petroleum-statistics-report-for-the-financial-year-2022-2023/>.
- 10 KenGen, "Olkaria 1 Units 1, 2 & 3 Rehabilitation Project", <https://www.kengen.co.ke/index.php/business/projects/ongoing.html>, accessed April 2023; KenGen, "KenGen Reports 11% Revenue Growth for the First Half of 2022 (2)", March 1, 2023, <https://www.kengen.co.ke/index.php/information-center/news-and-events/kengen-reports-11-revenue-growth-for-the-first-half-of-2023.html>.
- 11 KenGen, "KenGen Reports 11% Revenue Growth for the First Half of 2022 (2)", op. cit. note 10.
- 12 Net capacity and generation for years 2016 and 2021 from US EIA, "Electric Power Monthly", February 2018 and February 2023, Table 1.1.A and Table 6.2.B, <https://www.eia.gov/electricity/monthly>.
- 13 Ibid.
- 14 Ormat Technologies, "Ormat Technologies Reports First Quarter 2022 Financial Results", May 2, 2022, <https://investor.ormat.com/news-events/news/news-details/2022/Ormat-Technologies-Reports-First-Quarter-2022-Financial-Results/default.aspx>. Reported as 13 MW by the developer, the addition has recorded nameplate capacity of 25.5 MW and net summer capacity of 17 MW, from US EIA, "Electric Power Monthly", op. cit. note 7, Table 6.2.B, <https://www.eia.gov/electricity/monthly>; and from US EIA, "Form EIA-860M (Preliminary Monthly Electric Generator Inventory)", December 2022, <https://www.eia.gov/electricity/data/eia860m>.
- 15 Ormat Technologies, "Ormat Commences Commercial Operation of the 30 MW CD4 Geothermal Project", July 18, 2022, <https://investor.ormat.com/news-events/news/news-details/2022/Ormat-Commences-Commercial-Operation-of-the-30MW-CD4-Geothermal-Project/default.aspx>.
- 16 Generation for 2022 from US EIA, "Electric Power Monthly", op. cit. note 7, Tables ES1.B, 1.1 and 1.1.A.
- 17 C. Augustine et al., "Enhanced Geothermal Shot Analysis for the Geothermal Technologies Office", National Renewable Energy Laboratory, January 2023, <https://www.nrel.gov/docs/fy23osti/84822.pdf>.
- 18 KS Orka, "News Stream", <https://ksorka-sorikmarapi.com>, accessed April 2022; Pertamina Geothermal Energy, "Accelerating the energy transition, PGE completes the binary organic rankine cycle geothermal power plant project in North Sulawesi", December 8, 2022, <https://www.pge.pertamina.com/en/press-release/accelerating-the-energy-transition-pge-completes-the-binary-organic-rankine-cycle-geothermal-power-plant-project-in-north-sulawesi>; Pertamina Geothermal Energy, "PGE soon to operate PLTP utilizing geothermal wet steam", February 18, 2022, <https://www.pge.pertamina.com/en/press-release/pge-soon-to-operate-pltp-utilizing-geothermal-wet-steam>; Pertamina Geothermal Energy, "PGE's Journey", <https://www.pge.pertamina.com/en/pge-history>, accessed May 2023.
- 19 Ibid.
- 20 Ibid.
- 21 Capacity at year-end 2018-2022 from ESDM, "Capaian Kinerja Sektor ESDM Tahun 2022 & Target Tahun 2023", January 30, 2023, <https://www.esdm.go.id/assets/media/content/content-capaian-kinerja-sektor-esdm-tahun-2021-dan-rencana-tahun-2022.pdf>.
- 22 ESDM, "Handbook of Energy & Economic Statistics of Indonesia", April 2022, <https://www.esdm.go.id/id/publikasi/handbook-of-energy-economic-statistics-of-indonesia>.
- 23 ESDM, "Capaian Kinerja Sektor ESDM Tahun 2022 & Target Tahun 2023", January 30, 2023, <https://www.esdm.go.id/id/media-center/arsip-berita/pnbp-lampau-target-menteri-esdm-sampaikan-rincian-torehan-esdm-di-tahun-2022->.
- 24 ESDM, "Rencana Pengembangan Pembangkit Nasional Berti Porsi EBT Lebih Besar", February 1, 2023, <https://www.esdm.go.id/id/media-center/arsip-berita/rencana-pengembangan-pembangkit-nasional-beri-porsi-ebt-lebih-besar>; ESDM, "Pemerintah Perkuat Komitmen Transisi Energi Melalui Peraturan Presiden

- Pengembangan EBT", October 8, 2022, <https://www.esdm.go.id/id/media-center/arsip-berita/pemerintah-perkuat-komitmen-transisi-energi-melalui-peraturan-presiden-pengembangan-ebt>.
- 25 C. Cariaga, "Binary Unit at San Jacinto Geothermal Project, Nicaragua Commences Operations", January 3, 2023, <https://www.thinkgeoenergy.com/binary-unit-at-san-jacinto-geothermal-project-nicaragua-commences-operations>.
- 26 A. Richter, "The San-Jacinto-Tizate Geothermal Power Plant in Nicaragua", Think Geoenergy, May 31, 2020, <https://www.thinkgeoenergy.com/the-san-jacinto-tizate-geothermal-power-plant-in-nicaragua>.
- 27 A.D. Fronda et al., "Geothermal energy development: The Philippines country update", *Proceedings World Geothermal Congress 2020*, <https://www.geothermal-energy.org/pdf/IGASTandard/WGC/2020/01065.pdf>; Republic of the Philippines, Department of Energy, "Grid-connected capacity as of December 31, 2022", 2022, [https://www.doe.gov.ph/sites/default/files/pdf/electric\\_power/04\\_LVM%20Grid%20Summary.pdf](https://www.doe.gov.ph/sites/default/files/pdf/electric_power/04_LVM%20Grid%20Summary.pdf).
- 28 Fronda et al., op. cit. note 27; Energy Development Corporation, "EDC inaugurates 3.6 MW Mindanao-3 geothermal binary plant today", April 27, 2022, <https://www.energy.com.ph/2022/04/27/edc-inaugurates-3-6-mw-mindanao-3-geothermal-binary-plant-today>.
- 29 Energy Development Corporation, op. cit. note 28.
- 30 M.M. Velasco, "PH to open RE for 100% foreign ownership", Manila Bulletin, July 13, 2020, <https://mb.com.ph/2020/07/12/ph-to-open-re-for-100-foreign-ownership>; M.M. Velasco, "Gov't opens full foreign ownership to integrated geothermal projects", Manila Bulletin, October 28, 2020, <https://mb.com.ph/2020/10/28/govt-opens-full-foreign-ownership-to-integrated-geothermal-projects>; M.M. Velasco, "DOE eyes 100% foreign RE ownership to spur manufacturing investments", Manila Bulletin, August 14, 2022, <https://mb.com.ph/2022/8/14/doe-eyes-100-foreign-re-ownership-to-spur-manufacturing-investments>; M.M. Velasco, "DOJ sustains 40% foreign RE ownership rule", Manila Bulletin, September 30, 2022, <https://mb.com.ph/2022/9/30/doj-sustains-40-foreign-re-ownership-rule>.
- 31 M.M. Velasco, "EDC ramps up geothermal capacity", Manila Bulletin, December 17, 2022, <https://mb.com.ph/2022/12/17/edc-ramps-up-geothermal-capacity>; J.L. Mayuga, "Lack of incentives crimps investments in geothermal", Business Mirror, March 2, 2020, <https://businessmirror.com.ph/2020/03/02/lack-of-incentives-crimps-investments-in-geothermal>; M.M. Velasco, "Geothermal investors seek 'risk insurance perks' for new projects", Manila Bulletin, January 19, 2021, <https://mb.com.ph/2021/01/19/geothermal-investors-seek-risk-insurance-perks-for-new-projects>.
- 32 Climeon, "Case Study: The Sansui Power Plant", <https://climeon.com/case-study-the-sansui-power-plant>, accessed April 2023; Baseload Power, "Sansui geothermal power plant begins operations in Kumamoto – renewable energy made possible with hot spring operator together with local and global partners", April 26, 2022, <https://www.baseloadpower.jp/en/sansui-geothermal-power-plant-begins-operations-in-kumamoto>.
- 33 Ibid.
- 34 Turkish Energy Market Regulatory Authority (EMRA/EPDK), "Electricity Market Sector Report", <http://www.emra.org.tr>, accessed April 2023; Turkish Electricity Transmission Company (TEİAŞ), <http://www.teias.gov.tr>, accessed April 2023.
- 35 Ibid.
- 36 Ibid.
- 37 JESDER, "Jeotermal Enerjide Yatırımlar Ancak Teşvikle Yapılabilir", March 7, 2022, <http://jesder.org/jeotermal-enerjide-yatirimlar-ancak-tesvikle-yapilabilir>; JESDER, "YEKDEM Güncellenecek JES Yatırımları Başlayacak", February 2, 2023, <https://jesder.org/yekdem-guncellenecek-jes-yatirimlari-baslayacak>.
- 38 JESDER, "YEKDEM güncellemesinde son aşamaya gelindi", March 9, 2023, <https://jesder.org/yekdem-guncellemesinde-son-asamaya-gelindi>.
- 39 Calculation based on Lund and Toth, op. cit. note 1. Growth of 2.7 GW in 2022 based on five-year compound annual growth rate of 7.8% from 2014 through 2019 (total capacity having grown from 20,627 MW in 2014 to 30,080 MW in 2019).
- 40 Ibid.
- 41 Calculation based on Lund and Toth, op. cit. note 1. Growth of 14.2 TWh in 2022 based on differentiated five-year compound annual growth rate across nine end-use categories from 2014 through 2019 (total output having grown from 265,790 TJ in 2014 to 420,906 TJ in 2019).
- 42 **Figure 18** based on Ibid.
- 43 Distribution and calculation of share based on Lund and Toth, op. cit. note 1.
- 44 Lund and Toth, op. cit. note 1.
- 45 Projection based on historical data from T. Tian et al., "Rapid Development of China's Geothermal Industry – China National Report of the 2020 World Geothermal Conference", *Proceedings World Geothermal Congress 2020*, 2020, <http://www.geothermal-energy.org/pdf/IGASTandard/WGC/2020/01068.pdf>.
- 46 Projection based on historical data from Lund and Toth, op. cit. note 1.
- 47 Ministry of Housing and Urban-Rural Development, "'14th Five-Year' Building Energy Efficiency and Green Building Development Plan", March 11, 2022, <https://www.mohurd.gov.cn>.
- 48 O. Mertoglu, "Geothermal Energy Use: Projections and Country Update for Turkey", *Proceedings World Geothermal Congress 2020*, 2020, <http://www.geothermal-energy.org/pdf/IGASTandard/WGC/2020/01049.pdf>; projection based on Lund and Toth, op. cit. note 1.
- 49 Value for 2019 from O. Mertoglu, "Geothermal Energy Use: Projections and Country Update for Turkey", *Proceedings World Geothermal Congress 2020*, 2020, <http://www.geothermal-energy.org/pdf/IGASTandard/WGC/2020/01049.pdf>; value for 2020 from O. Mertoglu et al., "Geothermal Energy Use, Country Update for Türkiye – 2022", European Geothermal Congress 2022, Berlin, 17-21 October 2022, <https://www.europeangeothermalcongress.eu>.
- 50 Lund and Toth, op. cit. note 1.
- 51 National Energy Authority, "Orkustofnun Data Repository OS-2021-T012-01", September 10, 2021, <https://orkustofnun.is/orkustofnun/gagnasofn/talnaefni>; National Energy Authority, "Orkustofnun Data Repository OS-2022-T002-01" April 22, 2022, <https://orkustofnun.is/orkustofnun/gagnasofn/talnaefni>; Á. Ragnarsson, B. Steingrímsson and S. Thorhallsson, "Geothermal Energy Use, Country Update for Iceland", European Geothermal Congress 2022, Berlin, October 17-21, 2022, <https://www.europeangeothermalcongress.eu>.
- 52 National Energy Authority, "Orkustofnun Data Repository OS-2021-T012-01", op. cit. note 51.
- 53 Ragnarsson, Steingrímsson and Thorhallsson, op. cit. note 51.
- 54 RARIK, "Ný Hitaveita RARIK á Höfn í Hornafirði", December 18, 2020, <https://www.hornafjordur.is/stjornsysla/sveitarfelagid/frettasafn/ny-hitaveita-i-hornafirdi>; RARIK, "Mikilvægt Framfaraskref Fyrir Byggðina í Hornafirði", October 21, 2021, <https://www.rarik.is/frettir/mikilvaegt-framfaraskref-fyrir-byggdina-i-hornafirdi>.
- 55 Growth percentage from Geothermie Nederland, "Productiecijfers aardwarmte 2022 opnieuw gestegen, maar groei blijft achter", February 23, 2023, <https://geothermie.nl/actueel/nieuws/productiecijfers-aardwarmte-2022-opnieuw-gestegen-maar-groei-blijft-achter>; number of projects and capacity from M. Provoost and F. Agterberg, "Geothermal Energy Use, Country Update for The Netherlands", European Geothermal Congress 2022, Berlin, October 17-21, 2022, <https://www.europeangeothermalcongress.eu>.
- 56 Geothermie Nederland, op. cit. note 55.
- 57 Provoost and Agterberg, op. cit. note 55.
- 58 Ibid.
- 59 Ibid.
- 60 V. Schmidlé-Bloch et al., "Geothermal Energy Use, Country Update for France", European Geothermal Congress 2022, Berlin, October 17-21, 2022, <https://www.europeangeothermalcongress.eu>.
- 61 Ville de Meudon / Engie Solutions, "ENGIE Solutions et la Ville de Meudon accélèrent la transition énergétique du territoire meudonnais grâce à la SAS LTE GéoMeudon", October 28, 2022, [https://www.engie-solutions.com/sites/default/files/assets/2022-11/cp\\_signature\\_de\\_la\\_convention\\_geomeudon\\_vf.pdf](https://www.engie-solutions.com/sites/default/files/assets/2022-11/cp_signature_de_la_convention_geomeudon_vf.pdf); C. Bentzmann, "Inauguration de GéoMarne: La Géothermie Sur Le Territoire de Paris – Vallée de La Marne", ENGIE Solutions, October 19, 2021, <https://www.engie-solutions.com/sites/default/files/assets/2021-12/2021.12.07%20CP%20Mise%20en%20service%20Ve%CC%81lige%CC%81o.pdf>; C. Bentzmann, "Mise En Service de La Géothermie de Vélizy-Villacoublay Pour Un Chauffage Urbain Propre et Durable", ENGIE Solutions, December 7, 2021, <https://www.engie-solutions.com/fr/actualites/cp-veligeo>; GENYO, "Mise En Service Du Réseau de Chaleur Géno: Les Villes de Bobigny et Drancy Chauffées à La Géothermie", March 9, 2021, <https://genyo.fr/wp-content/uploads/2021/03/CP-GENYO-09.03.2021-VF.pdf>.
- 62 Ville de Meudon/ Engie Solutions, op. cit. note 61.
- 63 Bundesverband Geothermie, "Tiefe Geothermieprojekte in Deutschland", February 2023, <https://www.geothermie.de/geothermie/geothermie-in-zahlen.html>.

- 64 Bundesministerium für Wirtschaft und Klimaschutz, "Geothermie für die Wärmewende – Bundeswirtschaftsministerium startet Konsultationsprozess", November 11, 2022, <https://www.bmwk.de/Redaktion/DE/Pressemitteilungen/2022/11/20221111-geothermie-fuer-die-waermewende.html>.
- 65 Bayerisches Staatsministerium für Wirtschaft, Landesentwicklung und Energie, "Glauber: Bayern Beschleunigt Ausbau der Geothermie", December 9, 2022, <https://www.stmuv.bayern.de/aktuell/presse/pressemitteilung.htm?PMNr=200/22>.
- 66 S. Fuchs, A. Förster and B. Norden, "Evaluation of the terrestrial heat flow in Germany: A case study for the reassessment of global continental heat-flow data", *Earth-Science Reviews*, Vol. 235 (December 2022), <https://www.sciencedirect.com/science/article/pii/S0012825222003154>.
- 67 See, for example, M. Schreib, "Grünwald baut neue Fernwärmeleitung durch den Forst", *Merkur.de*, January 17, 2023, <https://www.merkur.de/lokales/muenchen-lk/gruenwald-ort28770/geothermie-gruenwald-fernwaerme-energie-energiekrise-ausbau-laufzorn-ewg-forst-92030984.html>.
- 68 Wien Energy, "Die erste Tiefengeothermie-Anlage für Wien", <https://www.wienenergie.at/tiefengeothermie-aspersn>, accessed April 2023.
- 69 Ibid.
- 70 Alpine Geothermal Power Production, "Premier projet suisse de géothermie hydrothermale visant à produire électricité et chaleur", <https://www.agepp.ch>, accessed May 2023.
- 71 R. McRae, "Aus für Geothermieprojekt in Kirchanschöring", Informationsportal Tiefe Geothermie, June 10, 2022, <https://www.tiefengeothermie.de/news/aus-fuer-geothermieprojekt-kirchanschoring>; R. McRae, "Rückschlag für Geothermieprojekt in Wilhelmsburg?" September 2, 2022, <https://www.tiefengeothermie.de/news/rueckschlag-fuer-geothermieprojekt-wilhelmsburg>.

## ENDNOTES – HEAT PUMPS

- 1 International Energy Agency (IEA), "The Future of Heat Pumps", November 2022, <https://www.iea.org/reports/the-future-of-heat-pumps>.
- 2 Ibid.
- 3 Ibid.
- 4 IEA, "Heat Pumps – Analysis", 2022, <https://www.iea.org/reports/heat-pumps>.
- 5 IEA, op. cit. note 1.
- 6 IEA, op. cit. note 4.
- 7 IEA, op. cit. note 1.
- 8 Y. Monschauer, C. Delmastro and R. Martinez-Gordon, "Global Heat Pump Sales Continue Double-Digit Growth – Analysis", IEA, 2023, <https://www.iea.org/commentaries/global-heat-pump-sales-continue-double-digit-growth>.
- 9 Ibid.
- 10 IEA, op. cit. note 1.
- 11 AHRI, "AHRI Releases December 2022 U.S. Heating, Cooling Equipment Shipment Data", February 10, 2023, <https://www.ahrinet.org/news-events/news/ahri-releases-december-2022-us-heating-cooling-equipment-shipment-data>. **Figure 19** from IEA, op. cit. note 8.
- 12 Ibid.
- 13 M.V. Olano, "Chart: Americans Bought More Heat Pumps than Gas Furnaces Last Year", Canary Media, February 10, 2023, <https://www.canarymedia.com/articles/heat-pumps/chart-americans-bought-more-heat-pumps-than-gas-furnaces-last-year>.
- 14 J. Rosenow and D. Gibb, "Guest Post: How the Energy Crisis Is Boosting Heat Pumps in Europe", Carbon Brief, March 21, 2023, <https://www.carbonbrief.org/guest-post-how-the-energy-crisis-is-boosting-heat-pumps-in-europe>.
- 15 Ibid.
- 16 Ibid.
- 17 Ibid.
- 18 Polska Organizacja Rozwoju Technologii Pomp Ciepła (PORT PC), "Ponad dwukrotny wzrost sprzedaży powietrznych pomp ciepła w I poł. 2022 roku!" August 17, 2022, <https://portpc.pl/ponad-dwukrotny-wzrost-sprzedazy-powietrznych-pomp-ciepala-w-i-pol-2022-roku>. **Snapshot: Poland** from the following sources: PORT PC, op. cit. this note; Rosenow and Gibb, op. cit. note 14; PORT PC, "PORT PC: 2022 – the year of heat pumps in Poland", February 8, 2023, <https://portpc.pl/port-pc-2022-rok-pomp-ciepala-w-polsce>; <https://www.gov.pl/web/climate/clean-air-20-programme-launched> (using Google Translate); D. Gibb and M. Morawiecka, "Cleaning up Heat: The Changing Economics for Heat Pumps in Poland", Regulatory Assistance Project, November 2022, <https://www.raonline.org/knowledge-center/cleaning-up-heat-the-changing-economics-for-heat-pumps-in-poland>; L. Sunderland and D. Gibb, "Taking the Burn Out of Heating for Low-Income Households", Regulatory Assistance Project, December 15, 2022, <https://www.raonline.org/knowledge-center/taking-burn-out-of-heating-low-income-households>; SolarPower Europe, "EU Market Outlook for Solar Power 2022-2026", 2022, <https://www.solarpowereurope.org/insights/market-outlooks/eu-market-outlook-for-solar-power-2022-2026-2>; International Renewable Energy Agency (IRENA), "Renewable Capacity and Generation Statistics 2022", 2022, <https://www.irena.org/publications/2022/Apr/Renewable-Capacity-Statistics-2022>. **Figure 20** from PORT PC, op. cit. this note, and from IRENA, op. cit. this note.
- 19 European Heat Pump Association (EHPA), "Heat Pump Record: 3 Million Units Sold in 2022, Contributing to REPowerEU Targets", February 20, 2023, [https://www.ehpa.org/press\\_releases/heat-pump-record-3-million-units-sold-in-2022-contributing-to-repowereu-targets](https://www.ehpa.org/press_releases/heat-pump-record-3-million-units-sold-in-2022-contributing-to-repowereu-targets).
- 20 IEA, op. cit. note 1.
- 21 Y. Monschauer, IEA, personal communication with REN21, March 15, 2023.
- 22 J. Rosenow, Regulatory Assistance Project, personal communication with REN21, March 18, 2023.
- 23 T. DiChristopher and A. Duquiatan, "States that outlaw gas bans account for 31% of US residential/commercial gas use", S&P Global June 9, 2022, <https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/states-that-outlaw-gas-bans-account-for-31-of-us-residential-commercial-gas-use-70749584>.
- 24 IEA, op. cit. note 4.
- 25 IRENA, "Renewable Solutions in End-Uses: Heat Pump Costs and Markets", November 28, 2022, <https://www.irena.org/Publications/2022/Nov/Renewable-solutions-in-end-uses-Heat-pump-costs-and-markets>.
- 26 Ibid.; IEA, op. cit. note 1.
- 27 BASF, "A Heatpump as Big as a Soccer Field", <https://www.basf.com/global/en/who-we-are/change-for-climate/heatpump.html>, accessed April 10, 2023; P. Hockenkos, "In Europe's Clean Energy Transition, Industry Turns to Heat Pumps", Greenbiz, February 1, 2023, <https://www.greenbiz.com/article/europes-clean-energy-transition-industry-turns-heat-pumps>; American Council for an Energy-Efficient Economy, "Industrial Heat Pumps: Electrifying Industry's Process Heat Supply", 2022, <https://www.aceee.org/research-report/ie2201>; A. Ivanova, "BASF Plans 120-MW Heat Pump to Decarbonise Ludwigshafen Site", Renewables Now, July 4, 2022, <https://renewablesnow.com/news/basf-plans-120-mw-heat-pump-to-decarbonise-ludwigshafen-site-790457>.
- 28 IRENA, op. cit. note 25.
- 29 DW, "Can Heat Pumps Replace Fossil Fuels for Heat?" September 16, 2022, <https://www.dw.com/en/heat-pumps-district-heating-decarbonize-energy-crisis-russian-oil-and-gas/a-63053664>.
- 30 E. Townend, "The Enormous Heat Pumps Warming Cities", January 31, 2023, [https://www.bbc.com/future/article/20230131-can-city-dwellers-ever-have-heat-pumps?ocid=global\\_future\\_rss&utm\\_source=flipboard&utm\\_content=user%2Fbbcfuture](https://www.bbc.com/future/article/20230131-can-city-dwellers-ever-have-heat-pumps?ocid=global_future_rss&utm_source=flipboard&utm_content=user%2Fbbcfuture).
- 31 Eneco, "Start of Construction of Largest Heat Pump in the Netherlands", July 5, 2022, <https://news.eneco.com/start-of-construction-of-largest-heat-pump-in-the-netherlands>; Helsingin kaupunki, "Helen rakentaa Eiranrantaan uuden lämpöpumpulaitoksen", December 20, 2022, <https://www.hel.fi/fi/uutiset/helen-rakentaa-eiranrantaan-uuden-lampopumpulaitoksen>; T. Gualtieri and K. Pohjanpalo, "How Cold Seawater Can Heat Helsinki's Homes", Bloomberg, October 18, 2022, <https://www.bloomberg.com/news/articles/2022-10-18/helsinki-utility-finds-a-surprising-heat-source-icy-seawater>; DerStandard.at, "Europas Größte Wärmepumpe Holt Energie Aus Wiens Abwasser", February 2, 2023, <https://www.derstandard.at/story/2000143180017/europas-groesste-waermepumpe-holt-energie-aus-wiens-abwasser>; energie-experten, "Wärmepumpe nutzt Rhein für Mannheimer Fernwärme", <https://www.energie-experten.org/projekte/waermepumpe-nutzt-rhein-fuer-mannheimer-fernwaerme>, accessed April 10, 2023; Vahterus, "40 MW Ammonia Heat Pumps Are Revolutionising District Heating in Sweden", <https://vahterus.com/resources/cases/40-mw-ammonia-heat-pumps-are-revolutionising-district-heating-in-sweden>, accessed March 29, 2023.
- 32 IEA, op. cit. note 1, p. 43.
- 33 IEA, op. cit. note 1, p. 79; T. Nowak, EHPA, personal communication with REN21, May 8, 2023.
- 34 Daikin Europe, "Daikin Europe Invests €300 Million in New Polish Heat Pump Heating Factory", July 7, 2022, [https://www.daikin.eu/en\\_us/press-releases/daikin-europe-invests-300-million-in-new-polish-heat-pump-heatin.html](https://www.daikin.eu/en_us/press-releases/daikin-europe-invests-300-million-in-new-polish-heat-pump-heatin.html); IEA, op. cit. note 1.
- 35 IEA, op. cit. note 1; Vaillant Group, "Vaillant Group Opens Mega Factory for Heat Pumps", March 10, 2023, <https://www.vaillant-group.com/news-stories/vaillant-group-opens-mega-factory-for-heat-pumps.html>.
- 36 Energie und Management, "Wärme: Wärmepumpenbauer steckt 600 Mio. Euro in die Produktion", August 30, 2022, <https://www.energie-und-management.de/nachrichten/energietechnik/detail/waermepumpenbauer-steckt-600-mio.-euro-in-die-produktion-162386>.
- 37 A. Mannweiler, "Wer stellt die Wärmepumpen her?" tagesschau, August 12, 2022, <https://www.tagesschau.de/wirtschaft/waermepumpen-hersteller-deutschland-international-101.html>; BDR Therma Group, "BDR Therma Group ramps up heat pump production to meet rising market demand", October 11, 2022, <https://www.bdrthermeagroup.com/en/stories/bdr-therma-group-ramps-up-heat-pump-production-to-meet-rising-market-demand>; I. Haluza, "Slovakia is becoming a new heat pump paradise. In a short time, a second large investor wants to produce them here", Dennik, July 9, 2020, <https://e.dennik.sk/2926736/slovensko-sa-stava-novym-rajom-tepelnych-cerpadiel-v-kratkom-case-ich-tu-chce-vyrabat-uz-druhy-velky-investor>; T. Nowak, "Heat Pump Investments in Europe – An Overview", September 2022, [https://www.linkedin.com/posts/thomasnowakeu\\_conversation-activity-6970985100586950657-VNc1](https://www.linkedin.com/posts/thomasnowakeu_conversation-activity-6970985100586950657-VNc1); J. Dumez, "Dans le Pas-de-Calais, Atlantic investit 25 millions d'euros dans un centre technique", 1 February 2023, <https://www.>

- lemoniteur.fr/article/dans-le-pas-de-calais-atlantic-investit-25-millions-d-euros-dans-un-centre-technique.2252706; IEA, op. cit. note 1; P. Tisheva, "Panasonic increasing heat pump output at Czech plant", Renewables Now, April 15, 2022, <https://renewablesnow.com/news/panasonic-increasing-heat-pump-output-at-czech-plant-781193>.
- 38 Nowak, op. cit. note 37.
- 39 Rewiring America, "What the IRA Means for Heat Pump Manufacturers", [https://assets.ctfassets.net/v4qx5q5o44nj/E5eXsBxtn4lyCYpKqt6nJ/f4a0d89a8bf6bff9f385d51b6f15e0a9/IRA\\_OEMs\\_Fact\\_Sheet.pdf](https://assets.ctfassets.net/v4qx5q5o44nj/E5eXsBxtn4lyCYpKqt6nJ/f4a0d89a8bf6bff9f385d51b6f15e0a9/IRA_OEMs_Fact_Sheet.pdf), accessed May 5, 2023; US Department of Energy, "Biden-Harris Administration Announces \$250 Million Investment from Inflation Reduction Act for Domestic Heat Pump Manufacturing", November 2, 2022, <https://www.energy.gov/articles/biden-harris-administration-announces-250-million-investment-inflation-reduction-act>.
- 40 B. Santos, "LG reveals plans for US heat pump factory", pv magazine, April 5, 2023, <https://www.pv-magazine.com/2023/04/05/lg-reveals-plans-for-us-heat-pump-factory>.
- 41 R. Lowes et al., "A Policy Toolkit for Global Mass Heat Pump Deployment", Regulatory Assistance Project, November 14, 2022, <https://www.raonline.org/knowledge-center/policy-toolkit-global-mass-heat-pump-deployment>.
- 42 IRENA, op. cit. note 25; IEA, op. cit. note 1.
- 43 IEA, op. cit. note 1.
- 44 Lowes et al., op. cit. note 41.
- 45 J. Rosenow et al., "Levelling the Playing Field: Aligning Heating Energy Taxes and Levies in Europe with Climate Goals", Regulatory Assistance Project, July 12, 2022, <https://www.raonline.org/knowledge-center/aligning-heating-energy-taxes-levies-europe-climate-goals>.
- 46 Ibid.
- 47 For example, in 2022 the electric utility Electric Ireland introduced a night-time rate around half the price of its day rate to encourage heat pump users to operate their devices during the night, from IEA, op. cit. note 1. In early 2023, Ontario (Canada) introduced an "ultra-low" overnight tariff that significantly improved the running costs for heat pumps compared to fossil fuel systems. See CBC, "Ontario rolls out 'ultra low' overnight hydro rate to encourage demand shift", April 11, 2023, <https://www.cbc.ca/news/canada/toronto/ontario-ultra-low-overnight-hydro-rate-1.6806693>.
- 48 IEA, op. cit. note 1.
- 49 Ibid.
- 50 Ibid.
- 51 Ibid.
- 52 European Parliament, "Fluorinated Gases: Reinforced EU Action to Cut Emissions", March 30, 2023, <https://www.europarl.europa.eu/news/en/press-room/20230327IPR78543/fluorinated-gases-reinforced-eu-action-to-cut-emissions>; EHPA, "F-Gas Ban Jeopardises REPowerEU Targets", [https://www.ehpa.org/press\\_releases/f-gas-ban-jeopardises-repowereu-targets](https://www.ehpa.org/press_releases/f-gas-ban-jeopardises-repowereu-targets), accessed March 30, 2023; IEA, op. cit. note 1; Nowak, personal communication, op. cit. note 33.
- 53 Nowak, personal communication, op. cit. note 33.

## ENDNOTES – HYDROGEN

- 1 International Renewable Energy Agency (IRENA), "Global Hydrogen Trade to Meet 1.5°C Climate Goal", 2022, [https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Jul/IRENA\\_Global\\_hydrogen\\_trade\\_part\\_1\\_2022\\_.pdf](https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Jul/IRENA_Global_hydrogen_trade_part_1_2022_.pdf).
- 2 International Energy Agency (IEA), "Global Hydrogen Review 2022", 2022, <https://www.iea.org/reports/global-hydrogen-review-2022>.
- 3 A. de Pee, "The clean hydrogen opportunity for hydrocarbon-rich countries", McKinsey & Company, November 23, 2023, <https://www.mckinsey.com/industries/oil-and-gas/our-insights/the-clean-hydrogen-opportunity-for-hydrocarbon-rich-countries>; A. Holland, "Can Green Hydrogen Be Cost Competitive?" IDTechEx, March 17, 2023, <https://www.idtechex.com/en/research-article/can-green-hydrogen-be-cost-competitive/28876>; P. Day, "Hydrogen as a backup for renewables remains a distant proposition", Reuters, February 1, 2023, <https://www.reuters.com/business/energy/hydrogen-backup-renewables-remains-distant-proposition-2023-02-01>.
- 4 R. Davey, "Green Hydrogen's Role in Electrifying the Heavy Industry", AZO CLEANTECH, April 11, 2023, <https://www.azocleantech.com/article.aspx?ArticleID=1676>; T. Casey, "Tiny Mass. Startup Cooks Up Big, Green Hydrogen Plan", CleanTechnica, June 27, 2022, <https://cleantechnica.com/2022/06/27/tiny-mass-startup-cooks-up-big-green-hydrogen-plan/>; J. Walsh and M. DiFelice, "How Much of This Hype for Hydrogen 'Energy' is Just Smoke and Mirrors?" Food & Water Watch, December 13, 2022, <https://www.foodandwaterwatch.org/2022/12/13/hydrogen-energy-hype>.
- 5 IEA, op. cit. note 2.
- 6 Ibid.
- 7 IEA, "Electrolysers", 2022, <https://www.iea.org/reports/electrolysers>.
- 8 IEA, op. cit. note 2.
- 9 A. Habibic, "GlobalData: Hydrogen market to witness growth surge in 2023", Offshore Energy, February 13, 2023, <https://www.offshore-energy.biz/globaldata-hydrogen-market-to-witness-growth-surge-in-2023>.
- 10 Ibid.
- 11 Government of Australia, Department of Climate Change, Energy, the Environment and Water, "State of Hydrogen 2022", 2022, <https://www.dcceew.gov.au/energy/publications/state-of-hydrogen-2022>.
- 12 McKinsey & Company, "Hydrogen Insights 2022: An updated perspective on hydrogen market development and actions required to unlock hydrogen at scale", September 2022, <https://hydrogencouncil.com/wp-content/uploads/2022/09/Hydrogen-Insights-2022-2.pdf>
- 13 L. Wan, "Energy from green hydrogen will be expensive, even in 2050", CRU, February 24, 2023, <https://sustainability.crugroup.com/article/energy-from-green-hydrogen-will-be-expensive-even-in-2050/>; IEA, "Global average levelised cost of hydrogen production by energy source and technology, 2019 and 2050", October 26, 2022, <https://www.iea.org/data-and-statistics/charts/global-average-levelised-cost-of-hydrogen-production-by-energy-source-and-technology-2019-and-2050>.
- 14 **Figure 21** from REN21 Policy Database. See GSR 2023 Data Pack, available at [www.ren21.net/gsr2023-data-pack/supply](http://www.ren21.net/gsr2023-data-pack/supply).
- 15 METI, "Japan's Roadmap to 'Beyond-Zero' Carbon", 2017, [https://www.meti.go.jp/english/policy/energy\\_environment/global\\_warming/roadmap/innovation/thep.html](https://www.meti.go.jp/english/policy/energy_environment/global_warming/roadmap/innovation/thep.html); D. Akimoto, "Japan Looks to Promote a Hydrogen Society", The Diplomat, January 4, 2023, <https://thediplomat.com/2023/01/japan-looks-to-promote-a-hydrogen-society>.
- 16 Renewable Energy Institute, "Re-examining Japan's Hydrogen Strategy", September 22, 2022, <https://www.renewable-ei.org/en/activities/reports/20220922.php>.
- 17 N. Coca, "A half-decade after its first plan, Japan's hydrogen goals remain distant", Energy Monitor, March 29, 2023, <https://www.energymonitor.ai/tech/hydrogen/a-half-decade-after-its-first-plan-japans-hydrogen-goals-remain-distant/>; D. Orf, "Japan Tried to Build a Hydrogen Society. It Backfired Spectacularly", Popular Mechanics, January 26, 2023, <https://www.popularmechanics.com/science/green-tech/a42665011/japan-hydrogen-energy-failure/>; A. Cohen, "The Biden Administration Should Learn Japan's Painful Lessons on Hydrogen", Forbes, February 13, 2023, <https://www.forbes.com/sites/arielcohen/2023/02/13/the-biden-administration-should-learn-japans-painful-lessons-on-hydrogen>.
- 18 J. Nakano, "China's Hydrogen Industrial Strategy", Center for Strategic and International Studies, February 3, 2022, <https://www.csis.org/analysis/chinas-hydrogen-industrial-strategy>.
- 19 National Development and Reform Commission, "China Hydrogen National Strategy", March 23, 2022, [https://www.ndrc.gov.cn/xxgk/zcfb/ghwb/202203/t20220323\\_1320038.html](https://www.ndrc.gov.cn/xxgk/zcfb/ghwb/202203/t20220323_1320038.html); Y. Yu, "China's National Hydrogen Development Plan", Energy Iceberg, April 6, 2022, <https://energyiceberg.com/national-hydrogen-development-plan>.
- 20 A. Lee, "Modi pledges massive green hydrogen 'quantum leap' to Indian energy independence", Recharge, August 16, 2021, <https://www.rechargenews.com/energy-transition/modi-pledges-massive-green-hydrogen-quantum-leap-to-indian-energy-independence/2-1-1052701>.
- 21 Ministry of New and Renewable Energy of India, "Budget 2021-22 augments capital of SECI and IREDA to promote development of RE sector", February 9, 2021, <https://pib.gov.in/PressReleasePage.aspx?PRID=1696498>.
- 22 European Commission, "A hydrogen strategy for a climate-neutral Europe", July 8, 2020, <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0301&from=EN>.
- 23 Ibid.
- 24 DW, "Germany to join Mediterranean hydrogen pipeline project", January 22, 2023, <https://www.dw.com/en/germany-to-join-mediterranean-hydrogen-pipeline-project/a-64483071>; I. Shumkov, "EU to deepen clean hydrogen cooperation with Japan", Renewables Now, December 2, 2022, <https://renewablesnow.com/news/eu-to-deepen-clean-hydrogen-cooperation-with-japan-807033>.
- 25 I. Shine, "Which countries are leading the way with hydrogen?" World Economic Forum, May 16, 2023, <https://www.weforum.org/agenda/2023/03/hydrogen-innovation-patents-technology>.
- 26 BMWK, "National Hydrogen Strategy", June 2020, <https://www.bmwk.de/Redaktion/EN/Publikationen/Energie/the-national-hydrogen-strategy.pdf>.
- 27 Bundesregierung, "Relief for electricity consumers", April 27, 2022, <https://www.bundesregierung.de/breg-en/news/renewable-energy-sources-act-levy-abolished-2011854>; BMBF, "National Hydrogen Strategy: Green hydrogen as energy source of the future", May 6, 2022, <https://www.bmbf.de/bmbf/en/news/national-hydrogen-strategy.html>.
- 28 The Maritime Executive, "Germany Signs Landmark Deal to Buy Denmark's Green Hydrogen", March 26, 2023, <https://maritime-executive.com/article/germany-signs-landmark-deal-to-buy-denmark-s-green-hydrogen>.
- 29 Government of France, "National strategy for the development of decarbonised and renewable hydrogen in France", 2020, <https://www.bdi.fr/wp-content/uploads/2020/03/PressKitProvisionalDraft-National-strategy-for-the-development-of-decarbonised-and-renewable-hydrogen-in-France.pdf>.
- 30 K. Abnett, "France leads push for EU to boost nuclear-produced hydrogen", Reuters, February 3, 2023, <https://www.reuters.com/business/energy/france-leads-push-eu-boost-nuclear-produced-hydrogen-2023-02-03/>; A. Nussbaum, "France's Hydrogen Pipeline With Spain Is at Risk Over Green Rules", Bloomberg, February 14, 2023, <https://www.bloomberg.com/news/articles/2023-02-14/france-s-hydrogen-pipeline-with-spain-at-risk-over-green-rules>.
- 31 Consejo de Ministros, "El Gobierno aprueba la 'Hoja de Ruta del Hidrógeno: una apuesta por el hidrógeno renovable'", October 6, 2020, <https://www.miteco.gob.es/es/prensa/ultimas-noticias/el-gobierno-aprueba-la-hoja-de-ruta-del-hidr%C3%B3geno-una-apuesta-por-el-hidr%C3%B3geno-renovable/tcm:30-513814>.
- 32 Ibid.
- 33 BP, "BP launches plans for low-carbon green hydrogen cluster in Spain's Valencia region", February 28, 2023, <https://www.bp.com/en/global/corporate/news-and-insights/press-releases/bp-launches-plans-for-low-carbon-green-hydrogen-cluster-in-spains-valencia-region.html>; M. Wetselaar, "7 reasons why Spain and Portugal are about to become a green hydrogen powerhouse", World Economic Forum, January 11, 2023, <https://www.weforum.org/agenda/2023/01/spain-portugal-green-hydrogen-powerhouse-davos23>.
- 34 US Department of Energy, "Clean Hydrogen Strategy Roadmap", September 2022, <https://www.hydrogen.energy.gov/pdfs/clean-hydrogen-strategy-roadmap.pdf>; L. Collins, "US unveils draft national clean hydrogen strategy and roadmap – with three key priorities", Recharge, September 23, 2022, <https://www.rechargenews.com/energy-transition/analysis-us-unveils-draft-national-clean-hydrogen-strategy-and-roadmap-with-three-key-priorities/2-1-1308355>; Warner, "U.S. Department of Energy Announces History \$7 Billion Funding Opportunity to Jump-Start America's Clean Hydrogen Economy", September 26, 2022, <https://www.warner.senate.gov/public/index.cfm/2022/9/u-s-department-of-energy-announces-history-7-billion-funding-opportunity-to-jump-start-america-s-clean-hydrogen-economy>.



- 35 Katy Jane, "Hydrogen production to increase in 2023 as global interest continues.", Dolphin N2, January 4, 2023, <https://dolphin-n2.com/hydrogen-production-to-increase-in-2023-as-global-interest-continues>.
- 36 J. Wood, "Which countries could become the world's hydrogen superpowers?" World Economic Forum, February 14, 2022, <https://www.weforum.org/agenda/2022/02/clean-hydrogen-energy-low-carbon-superpowers>.
- 37 Australian Government, op. cit. note 11.
- 38 Ibid.
- 39 Brazilian Government, "Brazil publishes National Hydrogen Program", August 29, 2022, <https://www.gov.br/en/government-of-brazil/latest-news/2022/brazil-publishes-national-hydrogen-program>.
- 40 Ibid.
- 41 P. Sánchez Molina, "Brazil sets up secretariat to develop green hydrogen", pv magazine, August 9, 2022, <https://www.pv-magazine.com/2022/08/09/brazil-sets-up-secretariat-to-develop-green-hydrogen>; A. Čučuk, "Unigel and ThyssenKrupp to increase capacity of Brazil hydrogen plant", OffShore Energy, March 13, 2023, <https://www.offshore-energy.biz/unigel-and-thyssenkrupp-to-increase-capacity-of-brazil-hydrogen-plant>.
- 42 Ministry of Energy, Government of Chile, "National Green Hydrogen Strategy", November 2020, [https://energia.gob.cl/sites/default/files/national\\_green\\_hydrogen\\_strategy\\_-\\_chile.pdf](https://energia.gob.cl/sites/default/files/national_green_hydrogen_strategy_-_chile.pdf).
- 43 HIF Global, <https://www.hifglobal.com>, accessed May 2023.
- 44 Unigel, "Unigel installs the first industrial-scale green hydrogen production site in Brazil using thyssenkrupp nucera technology", PR News Wire, July 26, 2022, <https://www.prnewswire.com/news-releases/unigel-installs-the-first-industrial-scale-green-hydrogen-production-site-in-brazil-using-thyssenkrupp-nucera-technology-301593261.html>.
- 45 H. Regensburg, "Haru Oni e-fuels demo plant in Chile officially opens", Green Car Congress, December 21, 2022, <https://www.greencarcongress.com/2022/12/haru-oni-e-fuels-demo-plant-in-chile-officially-opens.html>.
- 46 F. La Camera, "The Geopolitics of the Energy Transformation: The Hydrogen Factor", IRENA, January 15, 2021, [https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Jan/12A\\_Geopolitics\\_MS.pdf](https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Jan/12A_Geopolitics_MS.pdf).
- 47 S. Matalucci, "Hydrogen is changing power dynamics in energy sector", DW, December 28, 2022, <https://www.dw.com/en/is-hydrogen-changing-the-power-dynamics-in-the-energy-world/a-64224508>; G. Cantini, "Hydrogen in the MENA region: Priorities and steps forward", EnergySource, February 14, 2023, <https://www.atlanticcouncil.org/blogs/energysource/hydrogen-in-the-mena-region-priorities-and-steps-forward>. **Snapshot:** Chile based on the following sources: V. Eckert, "Germany and Chile sign accord to boost hydrogen cooperation", Reuters, June 29, 2021, <https://www.reuters.com/business/energy/germany-chile-sign-accord-boost-hydrogen-cooperation-2021-06-29>; Government of the Netherlands, "Joint statement of Chile and The Netherlands on collaboration in the field of green hydrogen import and export", July 1, 2021, <https://www.government.nl/documents/diplomatic-statements/2021/07/01/joint-statement-of-chile-and-the-netherlands-on-collaboration-in-the-field-of-green-hydrogen-import-and-export>; S. Pekic, "Belgian ports and Chile to collaborate on green hydrogen", Offshore Energy, November 5, 2021, <https://www.offshore-energy.biz/belgian-ports-and-chile-to-collaborate-on-green-hydrogen>.

## ENDNOTES – HYDROPOWER

- 1 International Hydropower Association (IHA) and International Renewable Energy Agency (IRENA), through personal communications with the Renewable Energy Policy Network for the 21<sup>st</sup> Century (REN21) during April – May 2023, unless otherwise stated.
- 2 Hydropower generation data in 2022 for all countries from IHA and Ember, personal communications with REN21, April – May 2023, unless otherwise stated. **China** generated 1,352 TWh in 2022, from National Bureau of Statistics of China, “China’s Economic and Social Development Statistics”, February 27, 2023, [http://www.stats.gov.cn/english/PressRelease/202302/t20230227\\_1918979.html](http://www.stats.gov.cn/english/PressRelease/202302/t20230227_1918979.html); United States from US EIA, op. cit. note 1; 2021 global generation from REN21, “Renewables 2022 Global Status Report”, 2022, <https://www.ren21.net/gsr-2022>.
- 3 IHA, “Slow Hydropower Growth Is a Stark Wake-Up Call to Governments on Climate”, May 7, 2022, <https://www.hydropower.org/news/slow-hydropower-growth-is-a-stark-wake-up-call-to-governments-on-climate>.
- 4 Shares of hydropower capacity and generation in the global energy mix based on total renewable energy capacity of 3,372 GW, and total renewable energy generation of 4,311 TWh; see endnotes in respective sections of this report. Ember, “Global Electricity Review 2023”, 2023, <https://ember-climate.org/insights/research/global-electricity-review-2023/#supporting-material>; IRENA, “Renewable Capacity Statistics 2023”, 2023, <https://www.irena.org/Publications/2023/Mar/Renewable-capacity-statistics-2023>.
- 5 See endnotes throughout this section on regional drought levels and their effects on water levels.
- 6 E. Martin, “World’s Largest Man-Made Dam Has Less Than 1% of Usable Water”, Bloomberg, January 3, 2023, <https://www.bloomberg.com/news/articles/2023-01-03/world-s-largest-man-made-dam-has-less-than-1-of-usable-water>.
- 7 X. Zhou, S&P Global Commodity Insights, personal communication with REN21, March 24, 2023.
- 8 The Conversation, “Hydropower’s Future Is Clouded by Droughts, Floods, and Climate Change. It’s Also Essential to the US Electric Grid.” May 17, 2022, <https://theconversation.com/hydropowers-future-is-clouded-by-droughts-floods-and-climate-change-its-also-essential-to-the-us-electric-grid-182314>. **Sidebar 2** based on the following sources: P. Bogaart, “The potential for sustainable hydropower”, *Nature Water*, Vol. 1 (2023), pp. 22–23, <https://doi.org/10.1038/s44221-022-00018-9>; International Energy Agency, “The Role of Critical Minerals in Clean Energy Transitions: Mineral Requirements for Clean Energy Transitions”, 2021, <https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/mineral-requirements-for-clean-energy-transitions>; between infrastructure, supply chain emissions and life-cycle emissions (maintenance and repair), materials represent 33% of total emissions per kWh over the lifetime of hydropower projects, from S. Schlömer et al., “Annex III: Technology-specific cost and performance parameters”, in O. Edenhofer et al., eds., *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, 2014, [https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc\\_wg3\\_ar5\\_annex-ii.pdf](https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_annex-ii.pdf); M. Barnard, “Hydroelectric dams have environmental challenges”, *The Future Is Electric*, September 1, 2018, <https://medium.com/the-future-is-electric/hydroelectric-dams-have-environmental-challenges-901a6dbdb53>; emissions based on estimate of 24 g of CO<sub>2</sub> equivalent per kWh, from IPCC’s Fifth Assessment Report; Schlömer et al., op. cit. this note, and on 103 million tonnes of CO<sub>2</sub> from Ember, “Electricity Data Explorer”, <https://ember-climate.org/data/data-tools/data-explorer>, accessed 26 May 2023; Climate Bonds Initiative, “Hydropower Criteria: The Hydropower Criteria for the Climate Bonds Standard & Certification Scheme”, March 2021, <https://www.climatebonds.net/files/files/Hydropower-Criteria-doc-March-2021-release3.pdf>; IHA, “Climate Bonds for Hydropower”, <https://www.hydropower.org/iha/climate-bonds>, accessed May 25, 2023; USD 150 million from Climate Bonds Initiative, “Certified Bonds Database”, <https://www.climatebonds.net/certification/certified-bonds>, accessed May 25, 2023; International Hydropower Association (IHA), “HESG Fund”, accessed May 27, 2023, <https://www.hydrosustainability.org/hesg-fund>; United Nations Department of Economic and Social Affairs, “Good Practice Hydropower: The Key to Sustainability”, [https://www.un.org/esa/sustdev/sdissues/energy/op/hydro\\_lochergoodpracticepaper.pdf](https://www.un.org/esa/sustdev/sdissues/energy/op/hydro_lochergoodpracticepaper.pdf), accessed May 24, 2023; assessments vary from Y. Liu, X. Li and Y. Chen, “Exploring the impact of COVID-19 on global tourism through online review analysis”, *Tourism Management*, Vol. 89 (2022), p. 104892, <https://doi.org/10.1016/j.tourman.2021.104892>; M. Hariyadi, “Central Java, arrests at Bener dam protests”, *Asia News*, October 2, 2022, <https://www.asianews.it/news-en/Central-Java,-arrests-at-Bener-dam-protests-55117.html>; Z. Trkanjec, “Germany’s KfW bank drops financing of BiH hydropower project”, Euractiv, January 30, 2022, [https://www.euractiv.com/section/politics/short\\_news/germanys-kfw-bank-drops-financing-of-bih-hydropower-project/](https://www.euractiv.com/section/politics/short_news/germanys-kfw-bank-drops-financing-of-bih-hydropower-project/); [https://www.euractiv.com/section/politics/short\\_news/germanys-kfw-bank-drops-financing-of-bih-hydropower-project/](https://www.euractiv.com/section/politics/short_news/germanys-kfw-bank-drops-financing-of-bih-hydropower-project/); IHA, “How investors can avoid funding the wrong hydropower projects”, March 22, 2022, <https://www.hydropower.org/blog/how-investors-can-avoid-funding-the-wrong-hydropower-projects/>; Reuters, “China’s Three Gorges Dam, Already Troubled, Faces New Tests”, August 22, 2012, <https://www.reuters.com/article/us-china-threegorges-idUSBRE87L0ZW20120822>; <https://www.reuters.com/article/us-china-threegorges-idUSBRE87L0ZW20120822>; D. Gelles, “Hydro-Québec Finds a New Export Market: Clean Energy for Maine”, *New York Times*, May 6, 2022, <https://www.nytimes.com/2022/05/06/climate/hydro-quebec-maine-clean-energy.html>; Hydropower Sustainability Council, “Hydropower Sustainability Standard”, June 2021, [https://static1.squarespace.com/static/5c1978d3ee1759dc44fbd8ba/t/60ddb3a844b5887d18fe2341/1625142194189/HS+Standard\\_July+2021.pdf](https://static1.squarespace.com/static/5c1978d3ee1759dc44fbd8ba/t/60ddb3a844b5887d18fe2341/1625142194189/HS+Standard_July+2021.pdf); Power Magazine, “Indian Hydropower Project an Example of Good Practice in Sustainability”, August 7, 2019, <https://www.powermag.com/press-releases/indian-hydropower-project-an-example-of-good-practice-in-sustainability/>; <https://www.powermag.com/press-releases/indian-hydropower-project-an-example-of-good-practice-in-sustainability/>; Water Power & Dam Construction, “World first as Sebzor project certified against hydropower sustainability standard”, March 22, 2023, <https://www.waterpowermagazine.com/news/newsworld-first-as-sebzor-project-certified-against-hydropower-sustainability-standard-10695971>; Hydropower Sustainability Assessment Council, “Certified User Training – November 2023”, <https://training.hydr sustainability.org/courses/certified-user-training-november-2023>; IHA, “Nepal to Become a Centre of Excellence in Sustainable Hydropower”, March 25, 2021, <https://www.hydropower.org/news/nepal-to-become-a-centre-of-excellence-in-sustainable-hydropower>.
- 9 Capacities for Brazil, the United States, Canada, the Russian Federation and India based on IHA, op. cit. note 1. **Figures 22 and 23** from IHA, op. cit. note 1. **China** added 13 GW of hydropower, bringing the total to 368 GW of installed capacity in 2022, from National Energy Administration (NEA), “Record of the press conference of the National Energy Administration in the first quarter of 2023”, February 13, 2023, [http://www.nea.gov.cn/2023-02/13/c\\_1310697149.htm](http://www.nea.gov.cn/2023-02/13/c_1310697149.htm) (using Google Translate); **United States** data on added capacity and total capacity are from US Energy Information Administration, “Electric Power Monthly with Data for December 2022”, February 2023, Tables 6.2.B and 6.3, <https://www.eia.gov/electricity/monthly/index.php>; **Türkiye** data are from IRENA, personal communication with REN21, and from Energy Market Regulatory Authority of Türkiye, “Elektrik Piyasası Aylık Sektör Raporu (Monthly Electricity Market Sector Report)”, 2023, <https://www.epdk.gov.tr/Detay/Icerik/3-0-23/elektrikaylik-sektor-raporlar>; **France** total and added capacity are from Réseau de Transport d’Électricité (RTE), “Production Installed Capacity”, <https://www.services-rte.com/en/view-data-published-by-rte/production-installed-capacity.html>, accessed May 2023.
- 10 NEA, op. cit. note 1; US EIA, “How much of U.S. energy consumption and electricity generation comes from renewable energy sources?” October 28, 2022, <https://www.eia.gov/tools/faqs/faq.php?id=427&t=3>; IHA, op. cit. note 1.
- 11 Instituto Costarricense de Electricidad, División Operación y Control del Sistema Eléctrico, “Generación y Demanda (Informe Anual)”, 2022, [apps.grupoice.com/CenceWeb/documentos/3/3008/19/Informe%20Anual%20DOCSE%202022.pdf](https://apps.grupoice.com/CenceWeb/documentos/3/3008/19/Informe%20Anual%20DOCSE%202022.pdf); IHA, op. cit. note 1.
- 12 NEA, op. cit. note 1.
- 13 Norwegian Energy and Environment Consortium, “State Energy Administration held press conference to release renewable energy in 2022”, January 10, 2022, <https://nec.no/国家能源局举行新闻发布会，发布2022年可再生能源>; E. Ingram, “Twelve of 16 units now operating at 16-GW Baihetan hydropower station in China”, *Hydro Review*, June 29, 2022, <https://www.hydroreview.com/hydro-industry-news/twelve-of-16-units-now-operating-at-16-gw-baihetan-hydropower-station-in-china>.
- 14 Reuters, “China’s Surging Hydropower a Boon for Its Climate Goals, Energy Bills”, July 12, 2022, <https://www.reuters.com/world/china/chinas-surging-hydropower-boon-its-climate-goals-energy-bills-2022-07-12/>; National Bureau of Statistics of China, op. cit. note 1.
- 15 A. Hirtenstein and K. Blunt, “Global Drought Saps Hydropower, Complicating Clean Energy Push”, *Wall Street Journal*, July 20, 2022, <https://www.wsj.com/articles/global-drought-saps-hydropower-complicating-clean-energy-push-11662758968>; H. Davidson, “China Drought Causes Yangtze River to Dry Up, Sparking Shortage of

- Hydropower", The Guardian (UK), August 22, 2022, <https://www.theguardian.com/world/2022/aug/22/china-drought-causes-yangtze-river-to-dry-up-sparking-shortage-of-hydropower>.
- 16 Green Finance and Development Center, "Countries of the Belt and Road Initiative (BRI)", <https://greenfdc.org/countries-of-the-belt-and-road-initiative-bri>, accessed April 9, 2023.
- 17 Boston University Global Development Policy Center, "China's Global Energy Finance Database", <http://www.bu.edu/cgef>, accessed April 11, 2023.
- 18 Boston University Global Development Policy Center, "China's Global Power Database", <https://www.bu.edu/cgp>, accessed April 11, 2023.
- 19 "China Global Mega-Projects' Infrastructure Falling Apart", Wall Street Journal, November 25, 2021, <https://www.wsj.com/articles/china-global-mega-projects-infrastructure-falling-apart-11674166180>; Human Rights Watch, "Cambodia: China's 'Belt and Road' Dam a Rights Disaster", August 10, 2021, <https://www.hrw.org/news/2021/08/10/cambodia-chinas-belt-and-road-dam-rights-disaster>.
- 20 IHA, IRENA and Ember, personal communications with REN21, op. cit. notes 1 and 2.
- 21 Ibid.
- 22 L. Morais, "Renewables Account for 92% of Brazil's Power Production in 2022", Renewables Now, February 2, 2023, <https://renewablesnow.com/news/renewables-account-for-92-of-brazils-power-production-in-2022-813298>.
- 23 IHA, IRENA and Ember, personal communications with REN21, op. cit. notes 1 and 2.
- 24 Global Energy Monitor, "Romaine 4 hydroelectric plant", [https://www.gem.wiki/Romaine\\_4\\_hydroelectric\\_plant](https://www.gem.wiki/Romaine_4_hydroelectric_plant), accessed May 25, 2023; IHA and IRENA, op. cit. note 1
- 25 M. Lowrie, "Quebec's Hydropower Era Ends as Last Big Megaproject Nears Completion", The Energy Mix, January 3, 2022, <https://www.theenergymix.com/2022/01/03/quebecs-hydropower-era-ends-as-last-big-megaproject-nears-completion>.
- 26 US EIA, op. cit. note 1.
- 27 N. Rott, "Study Finds Western Megadrought Is the Worst in 1,200 Years", NPR, February 14, 2022, <https://www.npr.org/2022/02/14/1080302434/study-finds-western-megadrought-is-the-worst-in-1-200-years>; J. Plautz, "What the Western Drought Reveals About Hydropower", E&E News, September 13, 2022, <https://www.eenews.net/articles/what-the-western-drought-reveals-about-hydropower>.
- 28 Western Area Power Administration, "Power Projects", <https://www.wapa.gov/About/Pages/power-projects.aspx>, accessed April 9, 2023; Plautz, op. cit. note 27.
- 29 J. Ryan, "Hydropower in the Western U.S. Bounced Back Last Year After a 20-Year Low", KUOW, April 29, 2022, <https://www.kuow.org/stories/hydropower-in-the-western-u-s-bounced-back-last-year-after-a-20-year-low>; Drought.gov, "Current Conditions", <https://www.drought.gov/current-conditions>, accessed May 8, 2023; E. Bush, "Snow Brings Needed Water to the West", NBC News, April 8, 2022, <https://www.nbcnews.com/science/environment/snow-brings-needed-water-west-rcna72786>.
- 30 US EIA, "Hydroelectric (Conventional) Power by State by Sector, Year-to-Date", Electric Power Monthly, February 2023, <https://www.eia.gov/electricity/monthly/archive/february2023.pdf>.
- 31 US EIA, "New Utility Scale Generating Units by Operating Company, Plant, and Month, 2023", Electric Power Monthly, February 2023, [https://www.eia.gov/electricity/monthly/epm\\_table\\_grapher.php?t=table\\_6\\_03](https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=table_6_03); US EIA, "Retired Utility Scale Generating Units by Operating Company, Plant, and Month, 2023", Electric Power Monthly, February 2023, [https://www.eia.gov/electricity/monthly/epm\\_table\\_grapher.php?t=table\\_6\\_04](https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=table_6_04).
- 32 US EIA, "Planned U.S. Electric Generating Unit Additions", Electric Power Monthly, February 2023, [https://www.eia.gov/electricity/monthly/epm\\_table\\_grapher.php?t=table\\_6\\_05](https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=table_6_05).
- 33 US EIA, op. cit. note 1.
- 34 Ember, "European Electricity Review 2023. Supporting Material", 2023, <https://ember-climate.org/insights/research/european-electricity-review-2023/#supporting-material>.
- 35 S&P Global, "Droughts rattle Europe's hydropower market, intensifying energy crisis", August 5, 2022, <https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/electric-power/080522-droughts-rattle-europes-hydropower-market-intensifying-energy-crisis>; Plautz, op. cit. note 27.
- 36 Ember, "European Electricity Review 2023", January 2023, <https://ember-climate.org/insights/research/european-electricity-review-2023>.
- 37 Ibid.
- 38 Ibid.
- 39 IHA and IRENA, op. cit. note 1.
- 40 Enerdata, "Pakistan's 720 MW Karot hydropower plant starts commercial operation", February 7, 2022, <https://www.enerdata.net/publications/daily-energy-news/pakistans-720-mw-karot-hydropower-plant-starts-commercial-operation.html>; Hydro Review, "720-MW Karot hydropower project in Pakistan begins operating. Hydro Review", January 28, 2022, <https://www.hydroreview.com/dams-and-civil-structures/720-mw-karot-hydropower-project-in-pakistan-begins-operating>.
- 41 Government of India, Press Information Bureau, "Power Ministry organises a power ministers' conference to discuss electricity sector reforms and initiatives", May 5, 2022, <https://pib.gov.in/PressReleasePage.aspx?PRID=1877233>.
- 42 P. Man Shrestha, "Nepal reduces power export to India as production dips", Kathmandu Post, November 15, 2022, <https://kathmandupost.com/national/2022/11/15/nepal-reduces-power-export-to-india-as-production-dips>; REN21, op. cit. note 2.
- 43 Energy Market Regulatory Authority of Türkiye, op. cit. note 1.
- 44 I. Todorović, "Erdogan inaugurates 34 hydropower plants", Balkan Green Energy News, December 11, 2020, <https://balkangreenenergynews.com/erdogan-inaugurates-34-hydropower-plants>.
- 45 I. Todorović, "Turkey completes world's fifth highest arch dam with hydropower plant", Balkan Green Energy News, November 28, 2022, <https://balkangreenenergynews.com/turkey-completes-worlds-fifth-highest-arch-dam-with-hydropower-plant>.
- 46 S. Kullab, "Climate politics double threat as Tigris, Euphrates shrivels", ABC News, November 11, 2022, <https://abcnews.go.com/International/wireStory/climate-politics-double-threat-tigris-euphrates-shrivels-93540084>.
- 47 Ember, "Türkiye Electricity Review 2023", 2022, <https://ember-climate.org/insights/research/turkiye-electricity-review-2023/#supporting-material-downloads>.
- 48 IHA and IRENA, op. cit. note 1.
- 49 IHA, "Africa", <https://www.hydropower.org/region-profiles/africa>, accessed April 9, 2023; A. Wasti et al., "Climate change and the hydropower sector: A global review", *Wiley Interdisciplinary Reviews: Climate Change*, Vol. 13, No. 2 (2022), p. e757, <https://doi.org/10.1002/wcc.757>.
- 50 D. Dunne, "Analysis: Africa's unreported extreme weather in 2022 and climate change", Carbon Brief, October 26, 2022, <https://www.carbonbrief.org/analysis-africas-unreported-extreme-weather-in-2022-and-climate-change>; NASA Earth Observatory, "Worst Drought on Record Parches Horn of Africa", December 14, 2022, <https://earthobservatory.nasa.gov/images/150712/worst-drought-on-record-parches-horn-of-africa>.
- 51 J. Gavin, "Kenya seeks to maximise benefits from baseload renewables", African Business, July 7, 2022, <https://african.business/2022/07/energy-resources/kenya-seeks-to-maximise-benefits-from-baseload-renewables>; IHA, op. cit. note 49.
- 52 African Energy Portal, "Largest hydropower project in Africa, GERD, to be fully operational in 2023", August 17, 2022, <https://africa-energy-portal.org/news/largest-hydropower-project-africa-gerd-be-fully-operational-2023>.
- 53 G. Paravicini, "Ethiopia completes third phase filling of giant Nile dam", Reuters, August 12, 2022, <https://www.reuters.com/world/africa/ethiopia-completes-third-phase-filling-giant-nile-dam-2022-08-12>.
- 54 P. Ndawi, "Tanzania: Julius Nyerere hydroelectric dam impoundment launched", Afrik21, April 7, 2022, <https://www.afrik21.africa/en/tanzania-julius-nyerere-hydroelectric-dam-impoundment-launched>.
- 55 R.J. Kuhudzai, "Tanzania starts filling the Julius Nyerere Dam for 2,115 MW hydropower plant", CleanTechnica, December 26, 2022, <https://cleantechnica.com/2022/12/26/tanzania-starts-filling-the-julius-nyerere-dam-for-2115-mw-hydropower-plant>.
- 56 US Department of Commerce, "Tanzania – Energy", Country Commercial Guides, June 2, 2021, <https://www.trade.gov/country-commercial-guides/tanzania-energy>.
- 57 IHA, "Hydropower Status Report 2022", 2022, <https://www.hydropower.org/publications/2022-hydropower-status-report>; Global Energy Monitor, "Zungeru hydroelectric plant", [https://www.gem.wiki/Zungeru\\_hydroelectric\\_plant](https://www.gem.wiki/Zungeru_hydroelectric_plant), accessed April 9, 2023.
- 58 Bureau of Public Enterprises Nigeria, "Zungeru Hydropower Project", <https://www.bpe.gov.ng/zungeru-hydropower-project>, accessed April 9, 2023.
- 59 IHA, op. cit. note 57.

- 60 IHA and IRENA, op. cit. note 1.
- 61 C. Sass, J. Oberg and M. Hiller, hosts, "The role of hydropower in the energy transition", Insider's Guide to Energy, March 2022, <https://open.spotify.com/episode/2j0eYVMGvynNv1AXpd9EZz?si=541a3ddf96794240>.
- 62 Ibid.
- 63 Africa Hydropower and Renewable Energy Partnership, <https://www.ahmpafrica.org>, accessed April 27, 2023.
- 64 IHA, "Sustainable Hydropower Is the Solution to Delivering Latin American and Caribbean Clean Energy Goals", February 14, 2023, <https://www.hydropower.org/news/sustainable-hydropower-is-the-solution-to-delivering-latin-american-and-caribbean-clean-energy-goals>.

## ENDNOTES – OCEAN POWER

- 1 International Energy Agency Ocean Energy Systems (IEA-OES), "Vision 2017", 2017, <https://www.ocean-energy-systems.org/ocean-energy/international-vision-for-ocean-energy>.
- 2 Ocean Energy Europe (OEE), "Ocean Energy Key Trends and Statistics 2022", March 2023, <https://www.oceanenergy-europe.eu/wp-content/uploads/2023/03/Ocean-Energy-Key-Trends-and-Statistics-2022.pdf>.
- 3 Ibid.
- 4 Renewable Energy Policy Network for the 21st Century (REN21), "Renewables 2021 Global Status Report", 2021, [https://www.ren21.net/wp-content/uploads/2019/05/GSR2021\\_Full\\_Report.pdf](https://www.ren21.net/wp-content/uploads/2019/05/GSR2021_Full_Report.pdf); IEA-OES, "Annual Report: An Overview of Ocean Energy Activities in 2022", March 2023, <https://www.ocean-energy-systems.org/publications/oes-annual-reports/document/oes-annual-report-2022/>; OEE, op. cit. note 2.
- 5 OEE, op. cit. note 2.
- 6 Ibid.
- 7 European Commission, "Study on Lessons for Ocean Energy Development", 2017, <https://doi.org/10.2777/389418>.
- 8 OEE, op. cit. note 2.
- 9 For example for use in the oil and gas industry, aquaculture, and defence. OEE, "Ocean Energy: Key Trends and Statistics 2019", March 2020, [https://www.oceanenergy-europe.eu/wp-content/uploads/2020/03/OEE\\_Trends-Stats\\_2019\\_Web.pdf](https://www.oceanenergy-europe.eu/wp-content/uploads/2020/03/OEE_Trends-Stats_2019_Web.pdf).
- 10 OEE, op. cit. note 2.
- 11 Ibid.
- 12 Ibid.
- 13 Seetao, "Zhejiang Zhoushan Tidal Energy Power Station Successfully Launched", February 28, 2023, <https://www.facebook.com/sharer/sharer.php?u=https%3A%2F%2Fwww.seetao.com%2Fdetails%2F141111.html>.
- 14 E. Bellini, "Floating Solar, Tidal Energy Plant Goes Online in China", pv magazine, May 31, 2022, <https://www.pv-magazine.com/2022/05/31/floating-solar-tidal-energy-plant-goes-online-in-china>.
- 15 "Minesto Launches Dragon Tidal Power Plant in Faroe Islands", Hydro Review, May 25, 2022, <https://www.hydroreview.com/hydro-industry-news/minesto-launches-dragon-tidal-power-plant-in-faroe-islands>.
- 16 A. Garanovic, "Minesto's Tidal Energy Kite Reaches New Heights in Faroe Islands", Offshore Energy, March 7, 2023, <https://www.offshore-energy.biz/minestos-tidal-energy-kite-reaches-new-heights-in-faroe-islands>.
- 17 IEA-OES, op. cit. note 4.
- 18 Ibid.
- 19 Ibid.
- 20 OEE, "Sabella and Nova Innovation Celebrate Tidal Success in Wales", January 27, 2022, <https://www.oceanenergy-europe.eu/industry-news/sabella-and-nova-innovation-celebrate-tidal-success-in-wales>.
- 21 Akuo Energy and SABELLA, "Akuo Energy and SABELLA sign a partnership agreement within the framework of the PHARES project", May 22, 2019, [https://www.sabella.bzh/wp-content/uploads/cp\\_renouvellement\\_accord\\_de\\_partenariat\\_akuo\\_sabella.pdf](https://www.sabella.bzh/wp-content/uploads/cp_renouvellement_accord_de_partenariat_akuo_sabella.pdf).
- 22 A. Frangoul, "The World's Most Powerful Tidal Turbine Just Got a Major Funding Boost", CNBC, July 4, 2022, <https://www.cnbc.com/2022/07/05/the-worlds-most-powerful-tidal-turbine-just-got-a-major-funding-boost.html>.
- 23 A. Garanovic, "MeyGen Set for Additional 28MW of Tidal Energy", Offshore Energy, July 7, 2022, <https://www.offshore-energy.biz/meygen-set-for-additional-28mw-of-tidal-energy>.
- 24 OEE, op. cit. note 19.
- 25 IEA-OES, op. cit. note 4.
- 26 Eco Wave Power, "Eco Wave Power Announces Key Milestone, Progresses Toward the Final Stages of the EWP-EDF One Project Installation", January 5, 2022, <https://www.ecowavepower.com/eco-wave-power-announces-key-milestone-progresses-toward-the-final-stages-of-the-ewp-edf-one-project-installation>; OEE, op. cit. note 2.
- 27 OEE, op. cit. note 2.
- 28 IEA-OES, op. cit. note 4.
- 29 A. Garanovic, "Wave-Powered Breakwater DIKWE Starts Sea Trials in France", Offshore Energy, July 12, 2022, <https://www.offshore-energy.biz/wave-powered-breakwater-dikwe-starts-sea-trials-in-france>.
- 30 IEA-OES, "Annual Report: An Overview of Ocean Energy Activities in 2022", op. cit. note 4.
- 31 AWS Ocean Energy, "AWS Waveswing Trials Exceed Expectations", November 1, 2022, <https://awsocan.com/2022/11/aws-waveswing-trials-exceed-expectations>.
- 32 Ibid.
- 33 IEA-OES, op. cit. note 4.
- 34 Ibid.
- 35 A. Garanovic, "Spanish Mutriku plant sets record for continuous wave power production", Offshore Energy, July 27, 2021, <https://www.offshore-energy.biz/spanish-mutriku-plant-marks-a-decade-of-continuous-wave-power-production>.
- 36 BIMEP, "Mutriku Site – Services", <https://www.bimep.com/en/mutriku-area/services>, accessed March 2023.
- 37 See REN21, op. cit. note 4. A new IEA-OES white paper concludes that the biggest barrier to OTEC development is financial, as there is a lack of financial support to move beyond small demonstration plants toward pre-commercial prototypes. IEA-OES, "White Paper on Ocean Thermal Energy Conversion (OTEC)", October 2021, <https://www.ocean-energy-systems.org/publications/oes-position-papers/document/white-paper-on-otec>.
- 38 IEA-OES, op. cit. note 4.
- 39 Ibid.
- 40 European Commission, "Market Study on Ocean Energy", 2018, <https://op.europa.eu/en/publication-detail/-/publication/bf225f11-d89d-481a-9643-5af5c8e6a675/language-en>.
- 41 D. Magagna, "Ocean Energy Technology Development Report", European Commission Low Carbon Energy Observatory, 2018, <https://doi.org/10.2760/158132>.
- 42 European Commission, "SET-Plan Ocean Energy Implementation Plan", March 2018, 1-50, [https://setis.ec.europa.eu/implementing-actions/ocean-energy\\_en](https://setis.ec.europa.eu/implementing-actions/ocean-energy_en).
- 43 European Commission, op. cit. note 40.
- 44 Horizon 2020, "Sustainable, Secure and Competitive Energy Supply (HORIZON-CL5-2023-D3-01)", <https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/horizon-cl5-2023-d3-01-08;callCode=HORIZON-CL5-2023-D3-01>, accessed March 2023; OEE, op. cit. note 2.
- 45 Government of the United Kingdom, "UK Government Announces Biggest Investment into Britain's Tidal Power", November 24, 2021, <https://www.gov.uk/government/news/uk-government-announces-biggest-investment-into-britains-tidal-power>.
- 46 P. Tisheva, "Four Tidal Projects to Deliver 41 MW in UK Under CfD Scheme", Renewables Now, July 7, 2022, <https://renewablesnow.com/news/four-tidal-projects-to-deliver-41-mw-in-uk-under-cfd-scheme-790888>.
- 47 IEA-OES, op. cit. note 4.
- 48 Ibid.
- 49 ETIP Ocean, "Ocean Energy and the Environment: Research and Strategic Actions", European Union, 2020, [https://www.etipocean.eu/knowledge\\_hub/ocean-energy-and-the-environment-research-and-strategic-actions](https://www.etipocean.eu/knowledge_hub/ocean-energy-and-the-environment-research-and-strategic-actions).
- 50 A. Copping, "The State of Knowledge for Environmental Effects: Driving Consenting/Permitting for the Marine Renewable Energy Industry", IEA-OES, 2018, <https://tethys.pnnl.gov/sites/default/files/publications/Copping-2018-Environmental-Effects.pdf>.
- 51 A. Copping et al., "An International Assessment of the Environmental Effects of Marine Energy Development", *Ocean & Coastal Management*, April 2014, pp. 1-11, <https://doi.org/10.1016/j.ocecoaman.2014.04.002>.

## ENDNOTES - SOLAR PV

- 1 **Figure 24** from International Energy Agency (IEA) Photovoltaic Power Systems Programme (PVPS), "Snapshot of Global PV Markets 2023", 2023, p. 4, [https://iea-pvps.org/wp-content/uploads/2023/04/IEA\\_PVPS\\_Snapshot\\_2023.pdf](https://iea-pvps.org/wp-content/uploads/2023/04/IEA_PVPS_Snapshot_2023.pdf).
- 2 S. Enkhardt, "Global Solar Capacity Additions Hit 268 GW in 2022, Says BNEF", pv magazine, December 23, 2022, <https://www.pv-magazine.com/2022/12/23/global-solar-capacity-additions-hit-268-gw-in-2022-says-bnef>.
- 3 International Energy Agency (IEA) Photovoltaic Power Systems Programme (PVPS), "Snapshot of Global PV Markets 2023", 2023, p. 7, [https://iea-pvps.org/wp-content/uploads/2023/04/IEA\\_PVPS\\_Snapshot\\_2023.pdf](https://iea-pvps.org/wp-content/uploads/2023/04/IEA_PVPS_Snapshot_2023.pdf); McKinsey & Company, "Renewable energy development in a net-zero world: Disrupted supply chains", February 2023, <https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/renewable-energy-development-in-a-net-zero-world-disrupted-supply-chains>.
- 4 IEA PVPS, op. cit. note 1, p. 14; IEA PVPS, "Snapshot of Global PV Markets 2022", 2022, p. 18, [https://iea-pvps.org/wp-content/uploads/2022/04/IEA\\_PVPS\\_Snapshot\\_2022-vF.pdf](https://iea-pvps.org/wp-content/uploads/2022/04/IEA_PVPS_Snapshot_2022-vF.pdf).
- 5 IEA PVPS, op. cit. note 1, p. 14; IEA PVPS, op. cit. note 4, p. 18.
- 6 Ibid., both references.
- 7 Ember, "European Electricity Review 2023", January 2023, p. 46, <https://ember-climate.org/app/uploads/2023/01/Report-European-Electricity-Review-2023.pdf>.
- 8 IEA PVPS, op. cit. note 1, pp. 10-11.
- 9 **Figure 25** from Ibid., p. 8.
- 10 **Figure 26 and 27** from Ibid., p. 8.
- 11 Ibid., p. 5.
- 12 Ibid., p. 9; IEA PVPS, op. cit. note 4, p. 14.
- 13 IEA PVPS, op. cit. note 1, p. 9.
- 14 E. Bellini, "Norway Increases Support for Residential PV", pv magazine, February 2, 2022, <https://www.pv-magazine.com/2022/02/02/norway-increases-support-for-residential-pv>.
- 15 P. Molina and S. Enkhardt, "Germany Slashes VAT for Residential PV to 0%", pv magazine, December 8, 2022, <https://www.pv-magazine.com/2022/12/08/germany-slashes-vat-for-residential-pv-to-0>.
- 16 E. Bellini, "Belgium Extends VAT Reduction for Residential PV, Heat Pumps", pv magazine, March 24, 2022, <https://www.pv-magazine.com/2022/03/24/belgium-extends-vat-reduction-for-residential-pv-heat-pumps>.
- 17 E. Bellini, "Italy Speeds Up Permits for Solar up to 200 kW, Allocates €267 Million for Rebates", pv magazine, March 4, 2022, <https://www.pv-magazine.com/2022/03/04/italy-speeds-up-permits-for-solar-up-to-200kw-allocates-e267-million-for-rebates>.
- 18 P. Molina, "Portugal Streamlines Permits for Renewables", pv magazine, April 21, 2022, <https://www.pv-magazine.com/2022/04/21/portugal-streamlines-permits-for-renewables>; P. Molina, "Spain Streamlines Permits for Utility Scale Solar, Supports Another 7 GW Under Self-consumption", pv magazine, March 31, 2022, <https://www.pv-magazine.com/2022/03/31/spain-streamlines-permits-for-utility-scale-solar-supports-another-7gw-under-self-consumption>; S. Enkhardt, "Austria Launches €240 Million Rebate Scheme for Rooftop PV", pv magazine, April 7, 2022, <https://www.pv-magazine.com/2022/04/07/austria-launches-e240-million-rebate-scheme-for-rooftop-pv>.
- 19 IEA PVPS, op. cit. note 1, p. 4.
- 20 China National Energy Administration (NEA), "Construction and operation of photovoltaic power generation in 2021", February 17, 2023, [http://www.nea.gov.cn/2023-02/17/c\\_1310698128.htm](http://www.nea.gov.cn/2023-02/17/c_1310698128.htm); China NEA, "Construction and operation of photovoltaic power generation in 2021", March 9, 2022, [http://www.nea.gov.cn/2022-03/09/c\\_1310508114.htm](http://www.nea.gov.cn/2022-03/09/c_1310508114.htm); China NEA, "Transcript of the online press conference of the National Energy Administration in the first quarter of 2023", February 13, 2022, [http://www.nea.gov.cn/2023-02/13/c\\_1310697149.htm](http://www.nea.gov.cn/2023-02/13/c_1310697149.htm) (using Google Translate).
- 21 China NEA, "Construction and operation of photovoltaic power generation in 2021", February 17, 2023, op. cit. note 20.
- 22 Ibid.; China NEA, "Construction and operation of photovoltaic power generation in 2021", March 9, 2022, op. cit. note 20.
- 23 Ember, "Global Electricity Review 2023", April 12, 2023, p. 29, <https://ember-climate.org/insights/research/global-electricity-review-2023>.
- 24 S&P Global Commodity Insights, "China Data: 2022 power demand growth eases to 3.6% in 2022 from 10.3% a year earlier", January 19, 2023, <https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/coal/011923-china-data-2022-power-demand-growth-eases-to-36-in-2022-from-103-a-year-earlier>; Ember, op. cit. note 23, p. 74; China Energy Portal, "2021 electricity & other energy statistics (preliminary)", January 27, 2022, <https://chinaenergyportal.org/en/2021-electricity-other-energy-statistics-preliminary>.
- 25 Ember, op. cit. note 23, p. 63.
- 26 India added 13,955.78 MW (probably all in alternating current, although this is not specified) in 2022 based on end-2021 capacity of 49,346.71 MW and end-2022 capacity of 63,302.49 MW, from Government of India, Ministry of Power, Central Electricity Authority (CEA), "All India Installed Capacity (in MW) of Power Stations (as of 31.12.2021) (utilities)", [https://cea.nic.in/wp-content/uploads/installed/2021/12/installed\\_capacity.pdf](https://cea.nic.in/wp-content/uploads/installed/2021/12/installed_capacity.pdf), accessed March 27, 2023, and at end 2022 from CEA, "All India Installed Capacity (in MW) of Power Stations (as on 31.12.2022) (utilities)" covering data up to December 31, 2022, [https://cea.nic.in/wp-content/uploads/installed/2022/12/IC\\_Dec\\_2022.pdf](https://cea.nic.in/wp-content/uploads/installed/2022/12/IC_Dec_2022.pdf), accessed March 27, 2023. See also the following: U. Gupta, "India Installed 15 GW of Solar in 2022, Says Bridge to India", pv magazine, February 28, 2023, <https://www.pv-magazine.com/2023/02/28/india-installed-15-gw-of-solar-in-2022-says-bridge-to-india>; U. Lee, "Solar and Wind Dominate India's Capacity Additions in 2022", Ember, March 17, 2023, <https://ember-climate.org/insights/research/india-data-story-2023>; J. Gulia, A. Thayillam and V. Garg, "Rooftop Solar Lagging: Why India Will Miss Its 2022 Solar Target", JMK Research & Analytics and Institute for Energy Economics and Financial Analysis, April 2022, [https://ieefa.org/wp-content/uploads/2022/04/Rooftop-Solar-Lagging\\_Why-India-Will-Miss-Its-2022-Solar-Target\\_April-2022.pdf](https://ieefa.org/wp-content/uploads/2022/04/Rooftop-Solar-Lagging_Why-India-Will-Miss-Its-2022-Solar-Target_April-2022.pdf).
- 27 Mercom India Research, "2022 Q4 and Annual India Solar Market Update - 13 GW installed in 2022", <https://www.mercomindia.com/product/q4-2022-india-solar-market-update>.
- 28 IEA PVPS, op. cit. note 1, p. 8.
- 29 Gulia, Thayillam and Garg, op. cit. note 26.
- 30 Ibid., op. cit. note 26.
- 31 I. Kaizuka, "Still Big in Japan?" pv magazine, March 14, 2023, <https://www.pv-magazine.com/2023/03/14/still-big-in-japan>.
- 32 E. Bellini, "Tokyo Introduces Mandatory PV Requirements for New Buildings, Homes", pv magazine, December 16, 2022, <https://www.pv-magazine.com/2022/12/16/tokyo-introduces-mandatory-pv-requirements-for-new-buildings-homes>.
- 33 R. Efrogmson and J. Scurlock, "The International Landscape of Solar Farms and Agrivoltaics", AgriSolar Clearinghouse, November 9, 2022, <https://www.agrisolarclearinghouse.org/the-international-landscape-of-solar-farms-and-agrivoltaics>.
- 34 E. Bellini, "Japan on Track to Hit 90 GW of PV Capacity by 2023", pv magazine, December 6, 2022, <https://www.pv-magazine.com/2022/12/06/japan-on-track-to-hit-90-gw-of-pv-capacity-by-end-2023>.
- 35 IEA PVPS, op. cit. note 1, p. 8.
- 36 Solar Energy Industries Association (SEIA) and Wood Mackenzie, "U.S. Solar Market Insight Report 2022 Year in Review", March 9, 2023, <https://www.seia.org/research-resources/solar-market-insight-report-2022-year-review>.
- 37 Ibid.
- 38 US Energy Information Administration, "What Is U.S. Electricity Generation by Source?" February 2023, <https://www.eia.gov/tools/faqs/faq.php?id=427&t=4>.
- 39 T. Sylvia, "US Government to Move Forward with PV Anti-circumvention Investigation", pv magazine, March 29, 2022, <https://www.pv-magazine.com/2022/03/29/us-government-to-move-forward-with-pv-anti-circumvention-investigation>; P. Dvorak and K. Blunt, "The Most-Hated Solar Company in America", Wall Street Journal, May 5, 2022, <https://www.wsj.com/articles/the-most-hated-solar-company-in-america-11651752180>.
- 40 A. Fischer, "After a Suppressed First Quarter the US Solar Market Is Buoyed by Tariff Suspension", pv magazine, June 8, 2022, <https://www.pv-magazine.com/2022/06/08/after-a-suppressed-first-quarter-the-us-solar-market-is-buoyed-by-tariff-suspension>.
- 41 R. Kennedy, "More Than 3 GW of Solar Panels Held by US Customs Under Forced Labor Law", pv magazine, August 16, 2022, <https://www.pv-magazine.com/2022/08/16/more-than-3-gw-of-solar-panels-held-by-us-customs-under-forced-labor-law>.
- 42 U.S. Congress, "H.R.5376 - inflation Reduction Act of 2022", 2022, <https://www.congress.gov/bills/117th-congress/house-bill/5376>; SEIA, "Impact of the Inflation Reduction Act", <https://www.seia.org/research-resources/impact-inflation-reduction-act>, accessed May 24, 2023.

- 43 J. Weaver, "What's the Inflation Reduction Act for the Solar Industry?" pv magazine, August 15, 2022, <https://www.pv-magazine.com/2022/08/15/whats-in-the-inflation-reduction-act-for-the-solar-industry>.
- 44 ABSOLAR, "Energia solar fotovoltaica no Brasil – Infográfico ABSOLAR", February 7, 2023, <https://www.absolar.org.br/mercado/infografico>.
- 45 Ibid.
- 46 L. Neves, "Brazil May Add Another 12 GW of PV This Year", pv magazine, January 14, 2022, <https://www.pv-magazine.com/2022/01/14/brazil-may-add-another-12-gw-of-pv-this-year>.
- 47 L. Neves, "Brazil Introduces New Rules for Distributed Generation, Net Metering", pv magazine, January 10, 2022, <https://www.pv-magazine.com/2022/01/10/brazil-introduces-new-rules-for-distributed-generation-net-metering>.
- 48 P. Molina, "Central America's Largest PV Plant Goes Online", pv magazine, January 27, 2022, <https://www.pv-magazine.com/2022/01/07/central-americas-largest-pv-plant-goes-online>.
- 49 SolarPower Europe, "EU Market Outlook for Solar Power 2022-2026", December 2022, p. 7, <https://www.solarpowereurope.org/insights/market-outlooks/eu-market-outlook-for-solar-power-2022-2026-2>.
- 50 IEA PVPS, op. cit. note 1, p. 11.
- 51 M. Hall, "The EU Plan to Drastically Ramp Renewables to Replace Russian Gas", pv magazine, March 9, 2022, <https://www.pv-magazine.com/2022/03/09/eu-plan-to-drastically-ramp-renewables-to-replace-russian-gas>; European Commission, "REPowerEU: New Industrial Alliance to boost the EU's solar power and energy security", December 9, 2022, [https://ec.europa.eu/commission/presscorner/detail/en/IP\\_22\\_7617](https://ec.europa.eu/commission/presscorner/detail/en/IP_22_7617).
- 52 SolarPower Europe, op. cit. note 49, p. 7.
- 53 Ibid, p. 7.
- 54 IEA PVPS, op. cit. note 1, p. 8.
- 55 SolarPower Europe, op. cit. note 49, p. 56.
- 56 Ibid., p. 57; S. Enkhardt, "Germany Installed 7.19 GW of New Solar in 2022", pv magazine, February 2, 2023, <https://www.pv-magazine.com/2023/02/02/germany-installed-7-19-gw-of-new-solar-in-2022>.
- 57 Energy-Charts, "Annual Solar Share of Public Net Electricity Generation in Germany", March 26, 2023, [https://energy-charts.info/charts/renewable\\_share/chart.htm?l=en&c=DE&share=solar\\_share&interval=year](https://energy-charts.info/charts/renewable_share/chart.htm?l=en&c=DE&share=solar_share&interval=year).
- 58 German Federal Ministry for Economic Affairs and Climate Action, "Federal minister Robert Habeck says Easter package is accelerator for renewable energy as the Federal Cabinet adopts key amendment to accelerate the expansion of renewables", April 6, 2022, <https://www.bmwk.de/Redaktion/EN/Pressemitteilung/gen/2022/04/20220406-federal-minister-robert-habeck-says-easter-package-is-accelerator-for-renewable-energy.html>.
- 59 SolarPower Europe, op. cit. note 49, p. 7.
- 60 P. Molina, "Spain Installed 6.93 GW of PV in 2022", pv magazine, March 6, 2023, <https://www.pv-magazine.com/2023/03/06/spain-installed-6-93-gw-of-pv-in-2022>.
- 61 P. Molina, "Spain Installed 2.5 GW of Distributed PV systems in 2022", pv magazine, January 23, 2023, <https://www.pv-magazine.com/2023/01/23/spain-installed-2-5-gw-of-distributed-pv-systems-in-2022>.
- 62 SolarPower Europe, op. cit. note 49, p. 59.
- 63 Molina, op. cit. note 60.
- 64 SolarPower Europe, op. cit. note 49, pp. 62-63; M. Maisch, "Shifting Sands of the Polish PV Market", pv magazine, March 27, 2023, <https://www.pv-magazine.com/2023/03/27/shifting-sands-of-the-polish-pv-market>; IEA PVPS, op. cit. note 1, p. 8.
- 65 SolarPower Europe, op. cit. note 49, pp. 62-63; Maisch, op. cit. note 64.
- 66 SolarPower Europe, op. cit. note 49, p. 63.
- 67 IEA PVPS, op. cit. note 1, p. 5.
- 68 K. Taylor and S. Leeson, "The Netherlands 'Unquestionable Solar Energy Leader' of 2022: Study", Euractiv, January 31, 2023, <https://www.euractiv.com/section/politics/news/the-netherlands-unquestionable-solar-energy-leader-of-2022-study>.
- 69 Ember, op. cit. note 7, p. 46; preliminary data from IEA PVPS, "Snapshots of Global PV Markets 2023", op. cit. note 4, p. 17.
- 70 IEA PVPS, op. cit. note 1, p. 8.
- 71 Clean Energy Council, "Clean Energy Australia Report 2023", April 2023, p. 7, <https://assets.cleanenergycouncil.org.au/documents/Clean-Energy-Australia-Report-2023.pdf>.
- 72 B. Peacock, "Australia Hits New Rooftop Solar Record", pv magazine, March 28, 2023, <https://www.pv-magazine.com/2023/03/28/australia-hits-new-rooftop-solar-record>.
- 73 Clean Energy Council, op. cit. note 71, p. 7.
- 74 Ibid., pp. 7-9.
- 75 D. Carroll, "Western Australia Rolls Out New Rules to Manage Rooftop Solar Sector", pv magazine, February 18, 2022, <https://www.pv-magazine.com/2022/02/18/western-australia-rolls-out-new-rules-to-manage-booming-rooftop-solar-sector>.
- 76 IEA PVPS, op. cit. note 1, p. 11.
- 77 African Solar Industry Association (AFSIA), "Annual Solar Outlook 2023", January 2023, [http://afsiasolar.com/wp-content/uploads/2023/01/AFSIA-Annual-Outlook-Report-2023-Full-digital-final\\_compressed-1.pdf](http://afsiasolar.com/wp-content/uploads/2023/01/AFSIA-Annual-Outlook-Report-2023-Full-digital-final_compressed-1.pdf).
- 78 Ibid.
- 79 IEA PVPS, "Trends in PV Applications 2021", 2021, p. 21, [https://iea-pvps.org/trends\\_reports/trends-in-pv-applications-2021](https://iea-pvps.org/trends_reports/trends-in-pv-applications-2021).
- 80 Y. Jin et al., "Energy Production and Water Savings from Floating Photovoltaics on Global Reservoirs", pv magazine, March 2023, [https://www.researchgate.net/publication/369201558\\_Energy\\_production\\_and\\_water\\_savings\\_from\\_floating\\_solar\\_photovoltaics\\_on\\_global\\_reservoirs](https://www.researchgate.net/publication/369201558_Energy_production_and_water_savings_from_floating_solar_photovoltaics_on_global_reservoirs).
- 81 U. Gupta, "India's Largest Floating PV Plant Goes Online", pv magazine, June 27, 2022, <https://www.pv-magazine.com/2022/06/27/indias-largest-floating-pv-plant-goes-online>; E. Bellini, "Czechia's First Floating Photovoltaic Plant", pv magazine, January 24, 2022, <https://www.pv-magazine.com/2022/01/24/czechias-first-floating-photovoltaic-plant>.
- 82 SolarPower Europe, op. cit. note 49, p. 56-57.
- 83 J. Gifford, "Agrivoltaics to Shine in France After Presidential Recognition", pv magazine, February 21, 2022, <https://www.pv-magazine.com/2022/02/21/agrivoltaics-to-shine-in-france-after-presidential-recognition>; E. Bellini, "France Defines Standards for Agrivoltaics", pv magazine, April 28, 2022, <https://www.pv-magazine.com/2022/04/28/france-defines-standards-for-agrivoltaics>; ADEME Libraire, "Characterizing photovoltaic projects on agricultural land and agrivoltaism", 2021, <https://librairie.ademe.fr/energies-renouvelables-reseaux-et-stockage/4992-caracteriser-les-projets-photovoltaiques-sur-terrains-agricoles-et-l-agrivoltaisme.html>.
- 84 E. Bellini, "Italian Solar Sector Defines Standards for Agrivoltaics", pv magazine, March 11, 2022, <https://www.pv-magazine.com/2022/03/11/italian-solar-sector-defines-standards-for-agrivoltaics>.
- 85 V. Shaw and M. Hall, "Chinese PV Industry Brief: 50 GW Plan for Rooftop, BIPV", pv magazine, March 11, 2022, <https://www.pv-magazine.com/2022/03/11/chinese-pv-industry-brief-50-gw-plan-for-rooftop-bipv>.
- 86 E. Bellini, "Seoul Launches BIPV Incentive Scheme", pv magazine, May 2, 2022, <https://www.pv-magazine.com/2022/05/02/seoul-launches-bipv-incentive-scheme>.
- 87 IEA, "Special Report on Solar PV Global Supply Chains", July 2022, <https://iea.blob.core.windows.net/assets/2d18437f-211d-4504-beeb-570c4d139e25/SpecialReportonSolarPVGlobalSupplyChains.pdf>.
- 88 IEA, "Special Report on Solar PV Global Supply Chains", July 2022, <https://iea.blob.core.windows.net/assets/2d18437f-211d-4504-beeb-570c4d139e25/SpecialReportonSolarPVGlobalSupplyChains.pdf>.
- 89 J. Gifford, "Higher PV Module Prices May Point to Stable Demand and More Sustainable Pricing Trends", pv magazine, January 4, 2022, <https://www.pv-magazine.com/2022/01/04/higher-pv-module-prices-may-point-to-stable-demand-and-more-sustainable-pricing-trends>.
- 90 V. Shaw, "Chinese Industry Brief: Polysilicon Price Reaches a New High at USD 45.4/kg, Government Takes Action", pv magazine, August 26, 2022, <https://www.pv-magazine.com/2022/08/26/chinese-pv-industry-brief-polysilicon-price-reaches-new-high-at-45-4-kg-government-takes-action>.
- 91 J. Weaver, "Solar Power Prices Rising with Demand", pv magazine, February 15, 2022, <https://www.pv-magazine.com/2022/02/15/solar-power-prices-rising-with-demand>.
- 92 D. Carroll, "Shipping Costs Remain Key Challenge for Solar Sector", pv magazine, July 14, 2022, <https://www.pv-magazine.com/2022/07/14/shipping-costs-remain-key-challenge-for-solar-sector>.
- 93 U. Gupta, "India Targets Domestic Production with 40% PV Import Duty, Boost to Manufacturing-linked Incentive", pv magazine, February 3, 2022, <https://www.pv-magazine.com/2022/02/03/india-targets-domestic-production-with-40-pv-import-duty-boost-to-manufacturing-linked-incentive>.

- 94 European Commission, "Commission Moves to Ban Products Made with Forced Labour on the EU Market", September 14, 2022, [https://ec.europa.eu/commission/presscorner/detail/en/ip\\_22\\_5415](https://ec.europa.eu/commission/presscorner/detail/en/ip_22_5415).
- 95 M. Hutchins, "Germany Launched Feasibility Study on PV Manufacturing", pv magazine, March 28, 2023, <https://www.pv-magazine.com/2023/03/28/germany-launches-feasibility-study-on-pv-manufacturing>.
- 96 N. Groom, "Exclusive: U.S. blocks more than 1,000 solar shipments over Chinese slave labor concerns", Reuters, November 11, 2022, <https://www.reuters.com/world/china/exclusive-us-blocks-more-than-1000-solar-shipments-over-chinese-slave-labor-2022-11-11>.
- 97 R. Kennedy and Tim Sylvia, "Biden Halts Solar Tariffs for Two Years. What's Next?" pv magazine, June 15, 2022, <https://www.pv-magazine.com/2022/06/15/biden-halts-solar-tariffs-for-two-years-whats-next>.
- 98 US Department of Energy, "Biden-Harris Administration Announces USD 56 Million to Advance U.S. Solar Manufacturing and Lower Energy Costs", July 14, 2022, <https://www.energy.gov/articles/biden-harris-administration-announces-56-million-advance-us-solar-manufacturing-and-lower>.
- 99 J. Gifford, "2022 Review in Trends: Modules (Part I)", pv magazine, December 28, 2022, <https://www.pv-magazine.com/2022/12/28/2022-review-in-trends-modules-part-i>.
- 100 Ibid.
- 101 J. Gifford, "2022 Review in Trends: Modules (Part II)", pv magazine, December 29, 2022, <https://www.pv-magazine.com/2022/12/29/2022-review-in-trends-modules-part-ii>.



## ENDNOTES – CONCENTRATING SOLAR THERMAL POWER

- 1 Data are compiled from SolarPACES, "CSP Projects Around the World", <https://www.solarpaces.org/csp-technologies/csp-projects-around-the-world>, accessed throughout April and May 2023, and from R. Thonig, A. Glimanova and J. Lilliestam, "CSP. guru 2023-01-01", 2023, <https://doi.org/10.5281/zenodo.1318151>. In some cases, information from these sources was verified against additional country-specific sources, as cited in the endnotes for this section. **Figure 28** from sources in this note and throughout this section, as well as previous editions of the Renewables Global Status Report. Global CSP data are based on commercial facilities only; demonstration and pilot facilities as well as facilities of 5 MW or less are excluded from capacity data, except for certain plants in China that are described as "demonstration" plants by government but are nonetheless large (utility-scale), grid-connected plants that are operating or will operate commercially. Data discrepancies between REN21 and other reference sources are due primarily to differences in categorisation and thresholds for inclusion of specific CSP facilities in overall global totals.
- 2 REN21, "Renewables 2022 Global Status Report", 2022, <https://www.ren21.net/gsr-2022>.
- 3 See sources in endnote 1.
- 4 Ibid.
- 5 Zawya Projects, "Dubai's Concentrated Solar Power Project Starts Supplying Electricity to the Grid – Statement", November 29, 2022, <https://www.zawya.com/en/projects/utilities/dubais-concentrated-solar-power-project-starts-supplying-electricity-to-the-grid-statement-hv2el4px>; Zawya Projects, "Dubai Solar Power Plant's 100MW Central Tower Is Operational – ACWA Power", February 23, 2023, <https://www.zawya.com/en/projects/utilities/dubai-solar-power-plants-100mw-central-tower-is-operational-acwa-power-p6zwwkq3>.
- 6 Zawya Projects, "Dubai's Concentrated Solar Power Project ...", op. cit. note 5.
- 7 J. Santamarta, "Dubai installs world's tallest concentrated solar power tower", HELIOSCSP, June 12, 2020, <https://helioscsp.com/dubai-installs-worlds-tallest-concentrated-solar-power-tower>; China National Solar Thermal Alliance, "Dubai's Concentrated Solar Power Project Starts Supplying Electricity to the Grid", December 5, 2022, <http://en.cnste.org/html/news/2022/1205/1360.html>; ewind, "Dubai's Concentrated Solar Power Project Starts Supplying Electricity to the Grid", November 30, 2022, <https://www.ewind.es/2022/11/30/dubais-concentrated-solar-power-project-starts-supplying-electricity-to-the-grid/89005>; Sina Finance, "Shanghai Electric Dubai CSP Project Trough Unit No. 1 Connected to the Grid", November 30, 2022, <https://finance.sina.cn/2022-11-30/detail-imqmmthc6493662.d.html>.
- 8 SolarPACES, "China Now Has 30 CSP Projects with Thermal Energy Storage Underway", October 8, 2022, <https://www.solarpaces.org/china-now-has-30-csp-projects-with-thermal-energy-storage-underway>.
- 9 China Solar Thermal Alliance (CSTA), "Blue Book of China's Concentrating Solar Power Industry 2022", 2023, <https://www.solarpaces.org/wp-content/uploads/Blue-Book-on-Chinas-CSP-Industry-2022.pdf>.
- 10 CSTA, "50 MW Hami Tower Concentrated Solar Power Project with Novel STELLIO Heliostats Commissioned in China", February 13, 2023, <http://en.cnste.org/html/news/2023/0213/1387.html>.
- 11 HELIOSCSP, "What Is Behind China's Concentrated Solar Power Records and Growth?" May 7, 2022, <https://helioscsp.com/what-is-behind-chinas-concentrated-solar-power-records-and-growth>; CSTA, op. cit. note 9.
- 12 CSTA, op. cit. note 9.
- 13 Ibid.
- 14 Ibid.
- 15 Ibid.
- 16 Thonig, Glimanova and Lilliestam, op. cit. note 1.
- 17 Ibid.
- 18 J. Regan, "Australian Solar Thermal Technology Wins US Backing to Cut Industrial Emissions", RenewEconomy, October 11, 2022, <https://reneweconomy.com.au/australian-solar-thermal-technology-wins-us-backing-to-cut-industrial-emissions>.
- 19 SolarPACES, "Auction Failure Curtails CSP in Spain's Ecological Transition", November 19, 2022, <https://www.solarpaces.org/auction-failure-curtails-csp-in-spains-ecological-transition>.
- 20 C. Dolz, "La falta de entendimiento entre Ribera y la industria termosolar compromete el plan de energía del Gobierno", Economía Digital, November 14, 2022, <https://www.economiadigital.es/economia/falta-entendimiento-gobierno-termosolar-compromete-pniec.html>; SolarPACES, op. cit. note 19.
- 21 Ministerio de Transición Ecológica, "Plan Nacional Integrado de Energía y Clima 2021-2030", 2020, p. 241, [https://www.miteco.gob.es/images/es/pniec/completo\\_tcm30-508410.pdf](https://www.miteco.gob.es/images/es/pniec/completo_tcm30-508410.pdf); Thonig, Glimanova and Lilliestam, op. cit. note 1.
- 22 International Renewable Energy Agency (IRENA), "Renewable Power Generation Costs in 2021", 2022, <https://www.irena.org/publications/2022/Jul/Renewable-Power-Generation-Costs-in-2021>; Thonig, Glimanova and Lilliestam, op. cit. note 1.
- 23 C. Moraes, "Redstone concentrated solar power project on track in South Africa", HELIOSCSP, June 3, 2023, <https://helioscsp.com/redstone-concentrated-solar-power-project-on-track-in-south-africa>.
- 24 HELIOSCSP, "Four bidders shortlisted for 200 MW concentrated solar power plant in Botswana", November 24, 2022, <https://helioscsp.com/four-bidders-shortlisted-for-200-mw-concentrated-solar-power-plant-in-botswana>; HELIOSCSP, "Lethakane Concentrated Solar Power Plant in Botswana", August 9, 2022, <https://helioscsp.com/lethakane-concentrated-solar-power-plant>; HELIOSCSP, "NamPower starts feasibility study for Concentrated Solar Power plant", April 26, 2022, <https://helioscsp.com/nampower-starts-feasibility-study-for-concentrated-solar-power-plant>.
- 25 J. Purtil, "Concentrated Solar Power Is an Old Technology Making a Comeback. Here's How It Works", ABC News, April 5, 2023, <https://amp-abc-net-au.cdn.ampproject.org/c/s/amp.abc.net.au/article/102184372>; HELIOSCSP, "Vast Solar to build world-leading solar thermal project in South Australia", April 29, 2022, <https://helioscsp.com/vast-solar-to-build-world-leading-solar-thermal-project-in-south-australia>.
- 26 See sources in endnote 1.
- 27 IRENA, op. cit. note 22.
- 28 Ibid.
- 29 Ibid.
- 30 R. Thonig, IASS Potsdam, personal communication with REN21, April 19, 2023.
- 31 IRENA, op. cit. note 22.
- 32 CSTA, op. cit. note 9.
- 33 C. Hernández Moris et al., "Comparison Between Concentrated Solar Power and Gas-Based Generation in Terms of Economic and Flexibility-Related Aspects in Chile", *Energies*, Vol. 14, No. 4 (2021), p. 1063, <https://doi.org/10.3390/en14041063>.
- 34 Advanced Energy Technologies, "Solar Energy Storage Technologies. Patent Analysis", January 9, 2023, <https://aenert.com/news-events/energy-news-monitoring/n/solar-energy-storage-technologies-patent-analysis>.
- 35 US Department of Energy, Office of Energy Efficiency and Renewable Energy, "DOE Breaks Ground on Concentrating Solar Power Pilot Culminating \$100 Million Research Effort", February 17, 2023, <https://www.energy.gov/eere/articles/doe-breaks-ground-concentrating-solar-power-pilot-culminating-100-million-research>.
- 36 CSTA, op. cit. note 9.
- 37 Ibid.

## ENDNOTES – SOLAR THERMAL HEATING

- 1 Based on data from W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2022, Detailed Market Figures 2021, 2023 Edition", International Energy Agency (IEA) Solar Heating and Cooling Programme (SHC), 2023, pp. 6, 58, 60, <https://www.iea-shc.org/solar-heat-worldwide>, and from M. Spörk-Dür, AEE – Institute for Sustainable Technologies (AEE INTEC), personal communication with Renewable Energy Policy Network for the 21<sup>st</sup> Century (REN21), May 2023.
- 2 Additions on the country level were provided to REN21 during January-May 2023 from the following sources: France, Italy and South Africa from Weiss and Spörk-Dür, op. cit. note 1; Greece from C. Trivasaros, Greek Solar Industry Association (EBHE); Germany from A. Liesen, Bundesverband Solarwirtschaft e.V. (BSW Solar); Poland from J. Starościk, Association of Manufacturers and Importers of Heating Appliances (SPIUG).
- 3 Additions on the country level were provided to REN21 during January-May 2023 from the following sources: China from Weiss and Spörk-Dür, op. cit. note 1, and from Spörk-Dür, op. cit. note 1; India from J. Malaviya, Solar Thermal Federation of India (STFI); Portugal from P. Dias, Solar Heat Europe; Spain from P. Polo, Asociación de la Industria Solar Térmica (ASIT).
- 4 J.P. Meyer, "Survey of German solar collector industry: 'daily struggle to procure materials'", Solar Thermal World, August 4, 2022, <https://solarthermalworld.org/news/survey-of-german-solar-collector-industry-daily-struggle-to-procure-materials>. At least in Germany, the situation was particularly challenging for manufacturers of vacuum tube collectors, most of which purchase tubes from China, from idem.
- 5 E. Engelniederhammer, "Gas-free industrial heat with PVT collectors and heat pumps", Solar Thermal World, December 12, 2022, <https://solarthermalworld.org/news/gas-free-industrial-heat-with-pvt-collectors-and-heat-pumps>; Weiss and Spörk-Dür, op. cit. note 1; P. Dias, Solar Heat Europe, personal communication with REN21, March 17, 2023; Epp, "High interest in PV and heat pumps has reduced collector sales in India", Solar Thermal World, March 14, 2023, <https://solarthermalworld.org/news/high-interest-in-pv-and-heat-pumps-has-reduced-collector-sales-in-india>. Small-scale solar water heating systems and solar combi-systems (provide hot water and space heating) for single- and multi-family houses, apartment buildings, hotels and public buildings in large parts of Europe and China have lost market share to solar PV systems and heat pumps in recent years, from Weiss and Spörk-Dür, op. cit. note 1. Utility incentives are used in Portugal, for example, where electric utilities are promoting the installation of heat pumps, from Dias, op. cit. this note; in India's commercial and hospitality markets, heat pumps, which can provide constant hot water, were the technology of choice, from Epp, op. cit. this note; in Australia, heat pumps are challenging solar thermal for both the residential hot water market and for pool heating, from D. Ferrari, Exemplary Energy, personal communication with REN21, May 5, 2023. For additional examples, see text and sources throughout this section.
- 6 Weiss and Spörk-Dür, op. cit. note 1, p. 15. Note that China's small retail market declined in 2022, but the space heating market increased.
- 7 B. Epp, solrico, personal communication with REN21, May 10, 2023. For example, see B. Epp, "Construction imminent on 77 MW solar heat plant for leisure resort", Solar Thermal World, April 30, 2022, <https://solarthermalworld.org/news/construction-imminent-on-77-mw-solar-heat-plant-for-leisure-resort>; B. Epp, "37 MW solar district heating plant in the Netherlands with outstanding features", Solar Thermal World, November 11, 2022, <https://solarthermalworld.org/news/37-mw-solar-district-heating-plant-in-the-netherlands-with-outstanding-features>; B. Epp, "Welcome to a new year and another chance for solar heat to get big", Solar Thermal World, January 17, 2023, <https://solarthermalworld.org/news/welcome-to-a-new-year-and-another-chance-for-solar-heat-to-get-big>.
- 8 See text and sources throughout this section.
- 9 [Solarthermalworld.org](https://solarthermalworld.org) reported on solar thermal sales activities in more than 150 countries worldwide during 2008-2022, based on search of website, accessed April 7, 2023.
- 10 Based on 542 GW<sub>th</sub> at the end of 2022, from Weiss and Spörk-Dür, op. cit. note 1, and on 523 GW<sub>th</sub> at end-2021, from Spörk-Dür, op. cit. note 1. **Figure 29** from the following: global solar thermal capacity for glazed and unglazed water collectors is based on historical data from W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends, Detailed Market Figures", multiple editions, IEA SHC, <https://www.iea-shc.org/solar-heat-worldwide>, and on REN21, "Renewables Global Status Report 2022", data for Figure 40, p. 138, <https://www.ren21.net/reports/global-status-report>; data for 2022 are from Weiss and Spörk-Dür, op. cit. note 1, and are based on the latest market data from the following solar thermal markets – Australia, Austria, Brazil, China, Cyprus, Denmark, Germany, Greece, India, Italy, Mexico, State of Palestine, Poland, South Africa, Spain, Türkiye and the United States – which represented 96% of the cumulative installed capacity in operation in 2021, from Spörk-Dür, op. cit. note 1. Note that the difference between annually installed capacity and net annual additions for most countries is the capacity subtracted each year to account for the assumed collector lifetime (generally 25 years), all from Weiss and Spörk-Dür, op. cit. note 1.
- 11 Figure of 442 TWh from Weiss and Spörk-Dür, op. cit. note 1, pp. 4, 84. Equivalence of 442 TWh and 260 million barrels of oil equivalent from Kyle's Converter, <https://www.kylesconverter.com/energy-work-and-heat/terawatt-hours-to-barrels-of-oil-equivalent>.
- 12 Figure of 73% for China based on data from Weiss and Spörk-Dür, op. cit. note 1, and from Spörk-Dür, op. cit. note 1; top five countries and ranking based on data from Ibid. and on additions and cumulative data for top 20 countries from sources cited throughout this section.
- 13 Top 20 countries and **Figure 30** based on the latest market data available for gross additions of glazed and unglazed water collectors (not including concentrating, photovoltaic-thermal and air collectors), at the time of publication, for countries that together represent around 97% of the world total. Data from original country sources include gross national additions and were provided to REN21 during February-May 2023 from the following sources: Australia from D. Ferrari, Sustainability Victoria; Austria, China, Italy, Mexico and South Africa from Spörk-Dür, op. cit. note 1, and from Weiss and Spörk-Dür, op. cit. note 1; Brazil from D. Johann, Associação Brasileira de Energia Solar Térmica (ABRASOL); Cyprus from P. Kastanias, Cyprus Union of Solar Thermal Industrialists (EBHEK); France from Spörk-Dür, op. cit. note 1, and based on data from Uniclimate, "Dossier de Presse: Bilan 2022 et perspectives 2023 des industries thermiques, aéronautiques et frigorifiques", February 2, 2023, p. 9, and from Agence de la transition écologique (ADEME); Germany from BSW Solar and Federation of German Heating Industry (BDH), cited in J.P. Meyer, "The German solar thermal market only grew slightly in the energy crisis year 2022", February 14, 2023, <https://solarthermalworld.org/news/the-german-solar-thermal-market-only-grew-slightly-in-the-energy-crisis-year-2022>, and from A. Liesen, BSW Solar; Greece from C. Trivasaros, EBHE; India from J. Malaviya, STFI; Israel data are for 2021 and from E. Shilton, Elsol; A. Fadlallah, Lebanese Center for Energy Conservation; for Morocco a 13% decrease in additions in 2022 was estimated based on the import value in million USD for the months January to September 2022, from Trademap, <https://www.trademap.org>, and provided by Epp, solrico (the share of vacuum tube and flat plate collectors for Morocco was not available); Poland from Weiss and Spörk-Dür, op. cit. note 1, and from J. Starościk, SPIUG; Portugal from P. Dias, Solar Heat Europe; Spain from P. Polo, ASIT; Türkiye from K. Ulke, Bural Solar, and from Weiss and Spörk-Dür, op. cit. note 1, Tables 11 and 12; United States from B. Heavner, California Solar & Storage Association (CALSSA), personal communication with REN21, May 2023. For Mexico, data are 2021 installations because 2022 statistics were not available at time of publication.
- 14 Installations in Lebanon were up 385% in 2022 based on data for 2021 additions from Weiss and Spörk-Dür, op. cit. note 1, Table 13, and on a total of 86.3 MW<sub>th</sub> (123,329.8 m<sup>2</sup>) added during 2022, from A. Fadlallah, Lebanese Center for Energy Conservation, personal communication with REN21, May 12, 2023. The Lebanese government removed subsidies for fuel and electricity, causing prices to rise and triggering a drastic increase in solar thermal system installations relative to previous years. Almost all systems are used for domestic hot water in single-family homes, from Fadlallah, op. cit. this note. Data are not yet available for Tunisia, which was included among the top 20 for 2021 in REN21, op. cit. note 10, **Figure 31**; however, it is likely that this country was not among the top 20 installers in 2022.
- 15 Sun Realm Think Tank, "2022 China Solar Thermal Industry Operation Status Report" officially released", March 16, 2023, <https://mp.weixin.qq.com/s/1jXYS-8iMpstP2-3ddSerw> (using Google Translate); H. Cheng, Shandong SunVision Management Consulting, personal communication with B. Epp, solrico, May 2023.
- 16 Based on data from Weiss and Spörk-Dür, op. cit. note 1, and from Spörk-Dür, op. cit. note 1.
- 17 Weiss and Spörk-Dür, op. cit. note 1; Spörk-Dür, op. cit. note 1, May 16, 2023. Installation data are slightly higher (using a different methodology), but still estimated market decline of 12.3%, from Sun Realm Think Tank, op. cit. note 15. Total installed capacity

- reflects an improvement in the quality of most brands of household solar heating systems, with lifespans exceeding 15 years and, in some cases, lasting for more than 20 years, from idem.
- 18 Sun Realm Think Tank, op. cit. note 15. Energy savings amount to an estimated 1,001.66 million tonnes of standard coal, or the equivalent of 27,846 GWh of electricity, from idem.
- 19 Based on data from Weiss and Spörk-Dür, op. cit. note 1, and from Spörk-Dür, op. cit. note 1. Vacuum tube sales in 2022 totalled 17.968 million m<sup>2</sup> and flat plate collector sales were 5.757 million m<sup>2</sup>, with vacuum tubes accounting for 75.7% of total sales, based on data from Sun Realm Think Tank, op. cit. note 15.
- 20 Sun Realm Think Tank, op. cit. note 15. The shares are based on a sample survey of enterprises in several provinces and key regions of China, from idem.
- 21 Ibid.
- 22 Ibid.
- 23 ABRASOL, "Pesquisa de produção e Vendas de Sistemas de Aquecimento Solar 2023, Base 2022", April 2023, p. 2, <https://abrasol.org.br/wp-content/uploads/2023/04/Pesquisa-de-Producao-e-Vendas-de-2023-ano-base-2022.pdf>; E. Engelniederhammer, "Hotel sector is important sales channel for solar industry in Brazil", Solar Thermal World, April 21, 2023, <https://solarthermalworld.org/news/hotel-sector-is-important-sales-channel-for-solar-industry-in-brazil>. Sales rose 28% in 2021, driven by the energy crisis and rising electric rates, which encouraged people to invest in their homes and, as of early 2022, the expectation was that Brazil's market would see an increase of 30% for the year, from ABRASOL, "Produção de aquecedor solar de água cresce 28% em 2021", Boletim 24, February 2022, <https://abrasol.org.br/boletim-i-fevereiro-i-no24-2022-2> (using Google Translate).
- 24 ABRASOL, "Pesquisa de produção...", op. cit. note 23, p. 6.
- 25 D. Johann, ABRASOL, personal communication with REN21, March 2023. Brazil added 920,463 m<sup>2</sup> of unglazed collector area, 821,248 m<sup>2</sup> of glazed collectors and 38,124 m<sup>2</sup> of vacuum tube collectors (bringing total additions to 1,779,835 m<sup>2</sup>), from idem. The residential sector remained the primary market (73%), followed by the commercial sector (19%); the industrial sector represented 6% and social projects only 2%, from ABRASOL, "Pesquisa de produção...", op. cit. note 23, p. 2.
- 26 The residential sector remained the primary market (73%), followed by the commercial sector (19%); the industrial sector represented 6% and social projects only 2%, from ABRASOL, "Pesquisa de produção...", op. cit. note 23, p. 2. Use in hotels and 2-4 year payback, from L.A. dos Santos Pinto, ABRASOL and Solis, cited in Engelniederhammer, op. cit. note 23.
- 27 Figure of 8.5% from ABRASOL, "Pesquisa de produção...", op. cit. note 23, p. 4; cumulative capacity based on 9,066 MW<sub>th</sub> from Spörk-Dür, op. cit. note 1, and from Weiss and Spörk-Dür, op. cit. note 1.
- 28 Based on data from J. Malaviya, Malaviya Solar Energy Consultancy, personal communication with REN21, March 2023.
- 29 Additions in 2022 based on data from J. Malaviya, Malaviya Solar Energy Consultancy, cited in Epp, op. cit. note 5; year-end totals (water collectors only) based on 19,827,079 m<sup>2</sup> (15,246,893 m<sup>2</sup> of vacuum tube collector area and 4,580,186 m<sup>2</sup> of flat plate collector area), from Weiss and Spörk-Dür, op. cit. note 1. The third phase of the Jawaharlal Nehru National Solar Mission required 20 million m<sup>2</sup> of solar thermal collector area to be in operation at the end of 2022, from B. Epp, "India close to the Solar Mission target of 20 million m<sup>2</sup> collector area", Solar Thermal World, February 22, 2022, <https://solarthermalworld.org/news/india-close-to-the-solar-mission-target-of-20-million-m2>.
- 30 Based on data from Malaviya, cited in Epp, op. cit. note 5. A little over 75,000 m<sup>2</sup> of flat plate collector area was installed during 2022, from idem.
- 31 Epp, op. cit. note 5.
- 32 Ibid.
- 33 Importance of small-scale from Y. Akay, Solimpeks Solar Corp, personal communication with B. Epp, solrico, February 2022; second after China for large systems from Weiss and Spörk-Dür, op. cit. note 1. Türkiye had 18 large-scale systems (>350 kW<sub>th</sub>; 500 m<sup>2</sup>) with a total installed capacity of 14.2 MW<sub>th</sub>, from Weiss and Spörk-Dür, op. cit. note 1. India's main solar thermal application continued to be thermosiphon systems for single-family houses, from Epp, op. cit. note 5.
- 34 Akay, op. cit. note 33.
- 35 The parabolic trough system has a cooling capacity of 3.5 MW<sub>th</sub> and is operating at a packaging factory in Izmir, from Weiss and Spörk-Dür, op. cit. note 1. See also B. Epp, "Solar steam to cool production halls in southern Turkey", Solar Thermal World, July 5, 2022, <https://solarthermalworld.org/news/solar-steam-to-cool-production-halls-in-southern-turkey>.
- 36 Estimated additions in 2022 from K. Ulke, Bural Solar, personal communication with REN21, May 16, 2023; estimated market decline based on 2021 additions from Weiss and Spörk-Dür, op. cit. note 1, Tables 11 and 12; end-2022 capacity from Spörk-Dür, op. cit. note 1, and from Weiss and Spörk-Dür, op. cit. note 1.
- 37 Ulke, op. cit. note 36.
- 38 Additions based on data from Heavner, op. cit. note 13 (US new additions of vacuum tube collectors were not available); estimated total capacity from Spörk-Dür, op. cit. note 1.
- 39 Brazil from information and sources in this section; Australia from Ferrari, op. cit. note 5; United States from Heavner, op. cit. note 13.
- 40 US unglazed based on 839,122 m<sup>2</sup> of collector area installed in 2022, accounting for nearly 95% of additions, based on data from Heavner, op. cit. note 13; Australia based on an estimated 350,000 m<sup>2</sup> of unglazed collector area installed in 2022, accounting for 71.5% of the year's installations, from Ferrari, op. cit. note 5.
- 41 B. Epp, solrico, personal communication with REN21, April 2022 and May 2023. For Italy, for example, see R. Battisti, "Conto Termico: Good incentive but with room for improvement", Solar Thermal World, April 25, 2023, <https://solarthermalworld.org/news/conto-termico-good-incentive-but-with-room-for-improvement>.
- 42 Based on preliminary data from L. Mico, Solar Heat Europe / European Solar Thermal Industry Federation, personal communication with REN21, May 5, 2023. The preliminary data show a slight increase in Spain relative to 2021.
- 43 Based on P. Dias, Solar Heat Europe, personal communication with B. Epp, solrico, April 2022. In Germany, more than half of new installations in 2022 were water heating systems on rooftops, with single family houses accounting for the largest share of demand, based on data from A. Liesen, BSW Solar, personal communication with REN21, February 28 and March 2, 2023; estimate by D. Lange, cited in Meyer, op. cit. note 13; and data from German industry associations BSW Solar and BDH, cited in Meyer, op. cit. note 13. In Greece, the market is mostly hot water systems for single-family homes, from C. Travasaros, EBHE, personal communication with REN21, April 11, 2023. In Italy, as of 2020, 76% of solar thermal heat was used by residential customers, from Battisti, op. cit. note 41, and 90% of new collector area in 2021 was to provide hot water, from R. Battisti, "Superbonus has pushed solar heat in Italy", Solar Thermal World, March 9, 2022, <https://solarthermalworld.org/news/superbonus-has-pushed-solar-heat-in-italy>. In Poland, the majority of systems installed in 2022 were for domestic hot water, with 64% for single-family and 20% for multi-family residences, from Weiss and Spörk-Dür, op. cit. note 1. In Spain, most 2022 installations were flat plate collectors (almost 94%) and used by households, from P. Polo, ASIT, personal communication with REN21, March 3, 2023. Flat plate collectors were followed in Spain by vacuum tube collectors (4.8%) and unglazed collectors for swimming pool heating (1.4%); multi-family houses accounted for almost half of demand (45%), with single family houses accounting for 35%, all from Polo, op. cit. this note.
- 44 Based on data and sources throughout this section.
- 45 Data from German industry associations BSW Solar and BDH, cited in Meyer, op. cit. note 13, and from Liesen, op. cit. note 43. The 2022 additions were up from 448 MW<sub>th</sub> in 2021, from Meyer, op. cit. note 13.
- 46 Data from German industry associations BSW Solar and BDH, cited in Meyer, op. cit. note 13. Germany's annual market held even in 2021 relative to 2020, in which the market expanded 26% over 2019, from idem.
- 47 D. Lange, cited in Meyer, op. cit. note 13; Liesen, op. cit. note 43. The government continued to fund residential installations through the Federal Office for Economic Affairs and Export Control (BAFA), from idem. Note that growth was due primarily to the energy crisis because subsidies enacted in 2021 did not have much effect on market in 2022, from Lange, op. cit. this note. Germany saw nearly 77,000 applications for federal funding that included a solar thermal system in 2022, up 75% over 2021; the greatest increase in applications submitted was for heat pumps (up 429%), from Meyer, op. cit. note 13.
- 48 Total capacity in operation at end-2022, from Liesen, op. cit. note 43.
- 49 C. Travasaros, op. cit. note 43, January 29, 2023.
- 50 C. Travasaros, op. cit. note 43, April 11, 2023.
- 51 E. Engelniederhammer, "Greek factories: a new collector every 72 seconds", Solar Thermal World, May 31, 2022, <https://solarthermalworld.org/news/greek-factories-a-new-collector-every-72-seconds>.
- 52 Ibid.

- 53 Travasaros, op. cit. note 43, January 29, 2023.
- 54 Weiss and Spörk-Dür, op. cit. note 1, and from Spörk-Dür, op. cit. note 1.
- 55 Battisti, op. cit. note 43.
- 56 Battisti, op. cit. note 41; R. Battisti, "National Round Table discusses market development and policies in Italy", Solar Thermal World, November 2022, <https://solarthermalworld.org/news/national-round-table-discusses-market-development-and-policies-in-italy/>; Battisti, op. cit. note 43. The market in 2021 also was driven by construction, with 2021 being a record year for the building industry, from idem. The Superbonus was extended in 2022 to be in effect until the end of 2025, with rates decreasing over time, from ANIMA Confindustria Meccanica Varia, "Guida al nuovo Superbonus", <https://www.anima.it/media/news/superbonus/superbonus-anima.kl>, accessed May 8, 2023 (using Google Translate). However, the Superbonus does not cover solar thermal district heating systems, from Battisti, op. cit. this note.
- 57 J. Starościk, SPIUG, personal communication with REN21, February 1, 2023; Weiss and Spörk-Dür, op. cit. note 1. The 210,000 m<sup>2</sup> of solar water collectors included 208,500 m<sup>2</sup> of glazed collectors and 1,500 m<sup>2</sup> of vacuum tube collectors, from idem, both sources.
- 58 Weiss and Spörk-Dür, op. cit. note 1.
- 59 Ibid. Of the total in operation at the end of 2022, 85% were flat plate and the remainder vacuum tube collectors, from idem.
- 60 Confirmed by P. Polo, ASIT, peer review comment, April 2023.
- 61 Figure of 12% and estimated 2022 additions, from Polo, op. cit. note 43; decline for period 2017-2021, from P. Polo, ASIT, cited in A.D. Rosell, "More than EUR 1 billion of incentives available in Spain", Solar Thermal World, October 12, 2022, <https://solarthermalworld.org/news/more-than-eur-1-billion-of-incentives-available-in-spain/>. Flat plate collectors were followed by vacuum tube collectors (4.8%) and unglazed collectors for swimming pool heating (1.4 %); multi-family houses accounted for almost half of demand (45%), with single family houses accounting for 35%, all from Polo, op. cit. note 43.
- 62 Polo, op. cit. note 43.
- 63 Ibid. Spain has five subsidy schemes that support solar thermal (and other renewable technologies and heat pumps), and that were implemented between late 2021 and the end of 2022, with funds available through 2023, from Rosell, op. cit. note 61.
- 64 Weiss and Spörk-Dür, op. cit. note 1.
- 65 Austria extended a large-scale system in Graz, from Weiss and Spörk-Dür, op. cit. note 1; Denmark from D. Trier, PlanEnergi, personal communication with REN21, February 27, 2023; Italy commissioned two solar thermal plants, in the district heating networks of Turin and Verona, from Battisti, op. cit. note 41.
- 66 Weiss and Spörk-Dür, op. cit. note 1, p. 17. Year-end total installations of concentrating collector technologies (linear Fresnel, parabolic trough and dish) were reported by aperture area and converted into solar thermal capacity using the internationally accepted convention for stationary collectors, 1 million m<sup>2</sup> = 0.7 GW<sub>th</sub>.
- 67 Weiss and Spörk-Dür, op. cit. note 1. The figure of 25 is based on an average reported size of 4.86 MW<sub>th</sub> (6,945 m<sup>2</sup>) per facility, from idem. In 2021, China commissioned around 20 large-scale solar heating systems in total, including solar thermal district heating systems; by the end of 2022, 571 large-scale solar thermal systems (>350 kW<sub>th</sub>, 500 m<sup>2</sup>) were in operation (totalling 2,148 MW<sub>th</sub>; 3.1 million m<sup>2</sup>), including district heating systems and those for individual buildings. The total installed capacity of these systems equaled 2,148 MW<sub>th</sub>, corresponding to 3.1 million m<sup>2</sup> collector area, from idem, pp. 4, 17. Note that China's national statistics do not distinguish between the two different uses of large-scale systems, from Sun Realm Think Tank, "2021 Solar Heating Market Yearbook", April 7, 2022, [https://mp.weixin.qq.com/s/o66GAR8KQMK717DB\\_yapPQ](https://mp.weixin.qq.com/s/o66GAR8KQMK717DB_yapPQ).
- 68 Based on data in Figure 9, from Weiss and Spörk-Dür, op. cit. note 1.
- 69 Weiss and Spörk-Dür, op. cit. note 1. See also B. Epp, "Concentrating solar heat capacity quadruples in 2022", Solar Thermal World, August 29, 2022, <https://solarthermalworld.org/news/concentrating-solar-heat-capacity-quadruples-in-2022/>.
- 70 Record year based on data from Steinbeis Research Institute Solites, cited in Solar Wärme Netze, "2022 Rekordjahr für solare Wärmenetze in Deutschland", March 28, 2023, <https://www.solare-waermenetze.de/2023/03/28/solare-waermenetze-in-betrieb-2023> (using Google Translate); data for Germany in 2022 from Meyer, op. cit. note 13, and from Liesen, op. cit. note 43; all Europe in 2021 from Spörk-Dür, op. cit. note 1, April 2022.
- 71 Data from Liesen, op. cit. note 43; and from German industry associations BSW Solar and BDH, cited in Meyer, op. cit. note 13.
- Drivers from H. Huther, district heating association AGFW, cited in Solar Wärme Netze, op. cit. note 70. A growing number of district heating systems in Germany and increased interest among home owners has led to a rapid increase in demand for vacuum tube collectors in recent years, rising from 15% of newly installed collector area in 2020 to 26% in 2022 (130 MW<sub>th</sub>, 185,000 m<sup>2</sup>). Around 130 MW<sub>th</sub> (185,000 m<sup>2</sup>) of vacuum tube collectors were added in 2022 and nearly 367 MW<sub>th</sub> (524,000 m<sup>2</sup>) of flat plate collectors, from Liesen, op. cit. note 43.
- 72 Liesen, op. cit. note 43; E. Augsten, "Will smart district heating bring solar thermal back into focus in Germany?" Solar Thermal World, October 11, 2022, <https://solarthermalworld.org/news/will-smart-district-heating-bring-solar-thermal-back-into-focus-in-germany/>. Other systems that came into operation in 2022 were in Lemgo (9,118 m<sup>2</sup>), Aschersleben (3,717 m<sup>2</sup>), Schönwald (2,860 m<sup>2</sup>), Horb am Neckar (2,416 m<sup>2</sup>), Markt Erlbach (2,400 m<sup>2</sup>), and Dettenhausen and Sigmaringen (both 2,312 m<sup>2</sup>), from Liesen, op. cit. note 43. Lemgo also from Augsten, op. cit. this note.
- 73 M. Berberich, Solites, cited in B. Epp, "Solar district heating solutions providing higher temperatures", Solar Thermal World, December 4, 2022, <https://solarthermalworld.org/news/solar-district-heating-solutions-providing-higher-temperatures/>. Capacity of further 9 plants under construction or in advanced planning is based on gross collector area of 31,200 m<sup>2</sup>, and of the 50 plants in preparation is based on gross collector area of 286,400 m<sup>2</sup>, and sourced from idem. Note that the total collector area for district heating in Germany grew by 30% relative to 2021, from Solites, cited in Weiss and Spörk-Dür, op. cit. note 1.
- 74 F. Stier, "Successful operator models for solar district heating in Germany", Solar Thermal World, January 5, 2023, <https://solarthermalworld.org/news/operator-models-for-solar-district-heating/>; F. Stier, "From LECs to TECs – citizen energy in focus", Solar Thermal World, May 28, 2022, <https://solarthermalworld.org/news/from-lecs-to-tecs-citizen-energy-in-focus/>; policy information from Augsten, op. cit. note 72; B. Epp, "Fund of EUR 3 billion for decarbonising German district heating", Solar Thermal World, August 30, 2022, <https://solarthermalworld.org/news/fund-of-eur-3-billion-for-decarbonising-german-district-heating/>.
- 75 Trier, op. cit. note 65, February 27, 2023. The plant that began operations in 2021 was a 5.6 MW<sub>th</sub> (8,013 m<sup>2</sup>) project in Præstø, from idem.
- 76 World leader in terms of number and installed area of systems and figure of 123, from Weiss and Spörk-Dür, op. cit. note 1. Capacity in operation, from Trier, op. cit. note 65, February 2023. By the end of 2022, Denmark had installed a total of 1,128 MW<sub>th</sub> (1,611,065 m<sup>2</sup>); accounting for decommissioning, a total of 1,125 MW<sub>th</sub> (1,607,015 m<sup>2</sup>) was in operation; in addition, another three projects totalling 8.3 MW<sub>th</sub> (11,910 m<sup>2</sup>) were under construction with plans to come online in 2023, from Trier, op. cit. note 65, February 2023.
- 77 Trier, op. cit. note 65, March 2, 2023.
- 78 A.D. Rosell, "Heat pumps: Competition or complement in district heating?" Solar Thermal World, September 13, 2022, <https://solarthermalworld.org/news/heat-pumps-competition-or-complement-in-district-heating/>.
- 79 Ibid.
- 80 Weiss and Spörk-Dür, op. cit. note 1, p. 13. The Graz extension increased the collector area by 2,134 m<sup>2</sup>, bringing the total to 6,134 m<sup>2</sup>, from idem. Note that another estimate puts the decline in 2022 at 25%, from F. Stier, "Feasibility studies for large solar heat plants totalling almost 1 million m<sup>2</sup> underway", Solar Thermal World, April 6, 2023, <https://solarthermalworld.org/news/feasibility-studies-for-large-solar-heat-plants-totalling-almost-1-million-m2-underway/>.
- 81 Stier, op. cit. note 80.
- 82 Ibid. The studies were support by the national Climate and Energy Fund, and the plants are to supply heat to energy suppliers and industrial companies, from idem.
- 83 B. Bogdanovic, European Bank for Reconstruction and Development, cited in B. Epp, "EUR 65 million provided for solar district heating in Kosovo", Solar Thermal World, July 7, 2022, <https://solarthermalworld.org/news/eur-65-million-provided-for-solar-district-heating-in-kosovo/>.
- 84 Epp, op. cit. note 83. Note that two solar thermal district heating plants were planned for Serbia as of early 2023. The feasibility study for a plant in the city of Pancevo (24.5 MW<sub>th</sub>/35,000 m<sup>2</sup> of collector area) was completed, and a plant in the range of 45-136 MW<sub>th</sub> was planned for Novi Sad, all from Weiss and Spörk-Dür, op. cit. note 1.

- 85 B. Epp, "Big Solar in Kosovo replaces coal-based electric heating", Solar Thermal World, January 25, 2023, <https://solarthermalworld.org/news/big-solar-in-kosovo-replaces-coal-based-electric-heating>; Epp, op. cit. note 83. Planned funds amount to EUR 80 million (USD 85 million); the project will replace a coal-fired heat and power plant, and the heat pumps and storage should enable the network to reach high solar shares, from Epp, op. cit. this note.
- 86 Fraunhofer ISE, PlanEnergi and Chalmers University, cited in "Solar Thermal Shows Highest Energy Yield Per Square Metre", Solar Thermal World, July 31, 2017, <https://solarthermalworld.org/news/solar-thermal-shows-highest-energy-yield-square-metre>. Another sources says up to four times solar PV and 50 times biomass, from Augsten, op. cit. note 72.
- 87 Challenges competing from Augsten, op. cit. note 72; lack of awareness from, for example, Stier, op. cit. note 80, and from B. Epp, "Solar district heating solutions providing higher temperatures", Solar Thermal World, December 4, 2022, <https://solarthermalworld.org/news/solar-district-heating-solutions-providing-higher-temperatures>; permitting processes and suitable sites from F. Stier, "Access to land is one of the key bottlenecks for rolling out renewables", Solar Thermal World, November 22, 2022, <https://solarthermalworld.org/news/access-to-land-is-one-of-the-key-bottlenecks-for-rolling-out-renewables>, and from B. Epp, "Fund of EUR 3 billion for decarbonising German district heating", Solar Thermal World, August 30, 2022, <https://solarthermalworld.org/news/fund-of-eur-3-billion-for-decarbonising-german-district-heating>; bottlenecks also from M. Berberich, Solites, cited Epp, "Solar district heating solutions...", op. cit. this note.
- 88 Temperature ranges from Solar Payback, "Suppliers of Turnkey Solar Process Heat Systems", <https://www.solar-payback.com/suppliers>, accessed 31 January 2023.
- 89 J. Bystrom, Absolicon Solar Collector, personal communication with B. Epp, solrico, February 2022; B. Epp, "Concentrating solar heat capacity quadruples in 2022", Solar Thermal World, August 29, 2022, <https://solarthermalworld.org/news/concentrating-solar-heat-capacity-quadruples-in-2022> (updated in November 2022); energy price stability and volatility from S. Papa, Solar Heat Europe, personal communication with REN21, May 2, 2023.
- 90 Data assessed by a survey among the companies listed in Solar Payback, op. cit. note 88, and cited in B. Epp, "High level of dynamism on the SHIP world market in 2022", Solar Thermal World, March 27, 2023, <https://solarthermalworld.org/news/high-level-of-dynamism-on-the-ship-world-market-in-2022>.
- 91 Ibid. Capacity was calculated by Epp using the factor 0.7 kW/m<sup>2</sup> for all collector types. Figure of 78 in 2021 from Weiss and Spörk-Dür, op. cit. note 1.
- 92 Epp, op. cit. note 90. Capacity was calculated by Epp using the factor 0.7 kW/m<sup>2</sup> for all collector types.
- 93 Weiss and Spörk-Dür, op. cit. note 1.
- 94 Epp, op. cit. note 90. The nine types include flat plate, which accounted for 39% of newly installed collector area, followed by vacuum tube (24%), parabolic trough (12%), air collectors (11%), high temperature flat plate (6%), linear Fresnel (4%), photovoltaic-thermal (3%), unglazed polymer (1%) and concentrating dish (0.4%); concentrating collectors represented a combined 16% in nine projects; the substantial share of air collectors was due mainly to generous funding in Austria, Germany and Spain, all from idem.
- 95 Weiss and Spörk-Dür, op. cit. note 1. Parabolic trough collectors account for the highest installed area, but due primarily to the 330 MW<sub>th</sub> Miraah plant in Oman, which was commissioned in 2017, from idem.
- 96 Epp, op. cit. note 89.
- 97 See, for example, "Two concentrating solar industrial heat plants in operation in Barcelona", Solar Thermal World, June 19, 2022, <https://solarthermalworld.org/news/two-concentrating-solar-industrial-heat-plants-in-operation-in-barcelona>. A linear Fresnel collector field for Givaudan, a Spanish company that produces flavours and fragrances, includes hybrid heat pumps (with electric and thermal compressors), from idem.
- 98 Data assessed by a survey among the companies listed in Solar Payback, op. cit. note 88, and cited in Epp, op. cit. note 90. Leading markets for number of systems installed in 2022 are based on data assessed by a survey among the companies listed on the SHIP Supplier World Map in March/April 2022, from Solar Payback, "SHIP Supplier Map of Turnkey Solar Process Heat Systems", April 2022, <https://www.solar-payback.com/suppliers>. China possibly under-reported from Epp, op. cit. note 90, and from Weiss and Spörk-Dür, op. cit. note 1. The China Academy of Building Research reported that, in 2021 alone, a total of 359 SHIP systems (256,000 m<sup>2</sup>) were added; because detailed data are not available, the systems are not included in data from Weiss and Spörk-Dür, op. cit. note 1, p. 26.
- 99 Epp, op. cit. note 90; B. Epp, "Mood on the SHIP market: High interest but slow decision making", Solar Thermal World, March 28, 2023, <https://solarthermalworld.org/news/mood-on-the-ship-market-high-interest-but-slow-decision-making>.
- 100 Solar Thermal Plants Database, <http://ship-plants.info/solar-thermal-plants>, accessed April 13, 2023.
- 101 Data assessed by a survey among the companies listed in Solar Payback, op. cit. note 88, and cited in Epp, op. cit. note 90.
- 102 Ibid. A key driver in the Netherlands is a national support scheme for solar thermal systems up to 200 m<sup>2</sup>, with a targeted natural gas phase-out also playing a role, from Epp, op. cit. note 99.
- 103 Four new systems from Epp, op. cit. note 90. The country's first solar steam boiler (170 °C) a 2.3 MW<sub>th</sub> (4,000 m<sup>2</sup>) parabolic trough plant for pasteurisation at an almond processing facility, meets 100% of the factory's demand during the daytime, from B. Epp, "2.3 MW solar steam boiler for almond pasteurization in California", Solar Thermal World, March 3, 2022, <https://solarthermalworld.org/news/2-3-mw-solar-steam-boiler-for-almond-pasteurization-in-california>.
- 104 Epp, op. cit. note 89.
- 105 Epp, op. cit. note 99.
- 106 A.D. Rosell, "Heat purchase agreements on the rise in Spain", Solar Thermal World, August 10, 2022, <https://solarthermalworld.org/news/heat-purchase-agreements-on-the-rise-in-spain>.
- 107 Epp, op. cit. note 99.
- 108 Fossil fuel costs from A.D. Rosell, "Zero CAPEX solar heat for Mexican industry", Solar Thermal World, March 18, 2022, <https://solarthermalworld.org/news/zero-capex-solar-heat-for-mexican-industry>; carbon emissions from Epp, op. cit. note 99. The relative decline in the number of systems completed in Mexico in 2022 was due to implementation delays stemming from supply chain issues and delays in payments by clients. A total of 13 projects were completed in 2022, compared with 18 projects in 2021 and 16 in 2020, all from Epp, idem.
- 109 Rosell, op. cit. note 108.
- 110 See, for example: B. Epp, "Welcome to a new year...", op. cit. note 7; Rosell, op. cit. note 108; Rosell, op. cit. note 106.
- 111 Epp, "Welcome to a new year...", op. cit. note 7. Internal decarbonisation targets also have been important factors, from idem. Even where SHIP systems are very competitive with fossil fuels, such as in southern Spain, the lack of awareness about the benefits of solar heat remains a challenge. One company in southern Spain offers heat for EUR 15-20 per MWh, which compares to gas at EUR 80-90 per MWh, from Rosell, op. cit. note 106.
- 112 B. Epp, "Structural changes in solar industrial heat supply industry", Solar Thermal World, July 6, 2022, <https://solarthermalworld.org/news/structural-changes-in-solar-industrial-heat-supply-industry>. A survey of developers showed 25 companies reporting at least one project completed in 2022, up from 19 in 2021, from Epp, op. cit. note 90.
- 113 Epp, op. cit. note 112. Applying for government subsidies slowing rollout of projects, from S. Papa and P. Dias, Solar Heat Europe, personal communication with REN21, May 2023.
- 114 B. Epp, "New Glasspoint announces first 1.5 GW parabolic trough field", Solar Thermal World, June 10, 2022, <https://solarthermalworld.org/news/new-glasspoint-announces-first-1-5-gw-parabolic-trough-field>; GlassPoint, "MA'ADEN and GlassPoint sign a Memorandum of Understanding ("MOU") to develop the world's largest solar process steam plant", June 2, 2022, <https://www.glasspoint.com/maaden-press-release>. The plant is the Ma'aden facility in Ras al Khair, and the SHIP project will be a parabolic trough field, from Epp, op. cit. this note.

## ENDNOTES – WIND POWER

- 1 Global additions in 2022 are gross (not accounting for decommissioned capacity), and all data are based on the following: Global Wind Energy Council (GWEC), "Global Wind Report 2023", March 27, 2023, p. 10, <https://gwec.net/globalwindreport2023>; GWEC, "Global Wind Report 2023", March 2023, unpublished document; American Clean Power (ACP), "Clean Power Quarterly 2022 Q4 – Market Report", February 2023, p. 5, <https://cleanpower.org/resources/clean-power-quarterly-market-report-q4-2022>; WindEurope, "Wind Energy in Europe: 2022 Statistics and the Outlook for 2023-2027", February 2023, pp. 10, 11, <https://windeurope.org/intelligence-platform/product/wind-energy-in-europe-2022-statistics-and-the-outlook-for-2023-2027>; G. Costanzo, WindEurope, Brussels, personal communication with REN21, March 13, 2023. Note that GWEC reports installations with turbines larger than 200 kW; projects with smaller turbines are not included. In addition, GWEC data include installed and fully commissioned capacity. During 2022, 1,860 MW was decommissioned, up from 1,132 MW decommissioned in 2021, from GWEC, "Global Wind Report 2023", March 2023, op. cit. this note. Annual installations reported in this section are gross additions unless otherwise noted (but most countries did not decommission capacity during the year), and year-end totals account for decommissioned capacity. Also, net global additions in 2022 were 74,653 MW for a year-end total of 898,824 MW, based on data from International Renewable Energy Agency (IRENA), "Renewable Capacity Statistics 2023", March 2023, p. 14, <https://www.irena.org/Publications/2023/Mar/Renewable-capacity-statistics-2023>; global additions were 88,631 MW for a year-end total of 934,443 MW (representing the first market decline since 2016), including capacity installed in China but not yet grid-connected by end-2022, from World Wind Energy Association (WWEA), "WWEA Annual Report 2022: Wind power installations 2022 stay below expectations", March 23, 2023, [https://wwindea.org/wp-content/uploads/2023/03/WWEA\\_WPR2022WEB.pdf](https://wwindea.org/wp-content/uploads/2023/03/WWEA_WPR2022WEB.pdf); annual installations were down 15%, following two record years, to 86 GW (with offshore installations down 46% to 9.1 GW), from BloombergNEF, "Goldwind and Vestas in Photo Finish for Top Spot as Global Wind Power Additions Fall", March 23, 2023, <https://about.bnef.com/blog/goldwind-and-vestas-in-photo-finish-for-top-spot-as-global-wind-power-additions-fall>. **Figure 31** based on historical data from GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. this note, pp. 100-102, and from GWEC, "Global Wind Report 2023", March 2023, op. cit. this note; data for 2022 based on sources provided in this note.
- 2 Capacity installed during the year was 88,631 MW, including capacity installed in China but not officially grid-connected by the end of 2022, for a total of 934,443 MW, from WWEA, op. cit. note 1. Capacity that was mechanically installed during 2022 was 90.3 GW for a total of nearly 940 GW, including 13 GW of new installations in (mostly) China and Vietnam that were not grid-connected by year's end, from GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, p. 92, and adjusting for lower installations in Sweden, from Costanzo, op. cit. note 1. The higher global capacity numbers from both WWEA and GWEC include 44.7 GW mechanically installed onshore in China, from Chinese Wind Energy Association (CWEA), cited in GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, p. 98; this number is 12.1 GW higher than the 32.6 GW of grid-connected capacity as reported by China's National Energy Agency (NEA), per GWEC, idem. Previous editions of the *Renewables Global Status Report* used the CWEA data (including mechanically installed and officially grid-connected capacity in China) for China as well as global totals. The CWEA believed these numbers to best reflect the state of the industry in China. See endnotes in previous editions of this section in past GSRs for more details. Starting with the GSR 2023, only NEA data for China are included, except where otherwise noted. The change reflects the fact that many other organisations, including IRENA and now GWEC, report only grid-connected data; in addition, Vietnam also mechanically installed capacity that was not commissioned in 2022 because of grid connection delays, so it made sense to shift to counting only fully commissioned, grid-connected additions and total installations.
- 3 Third largest year from GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, p. 10.
- 4 Market decline was an estimated 17.5% based on additions of 77.2 GW in 2022 and of 93.6 GW in 2021, calculated using data from GWEC, "Global Wind Report 2023", March 2023, op. cit. note 1, from GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, p. 102, from WindEurope, op. cit. note 1, pp. 10, 11, and from Costanzo, op. cit. note 1. Rate of decline in onshore and offshore installations, China, United States and Europe all from GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, pp. 8, 97. Installations were down 17% relative to 2021, from GWEC, idem, p. 10. The largest declines in annual installations were in North America (down 28%, or 3.8 GW), Africa and the Middle East (down 75%, or 1.4 GW) and Latin America and the Caribbean (down 10%, 0.6 GW). Africa and the Middle East connected 453 MW, the lowest level since 2013; Latin America and the Caribbean were stable with 5.2 GW installed (mostly in Brazil), all from GWEC, idem, p. 109.
- 5 M. Dyrholm, Foreword, in GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, p. 2; W. Mathis, R. Beene and J. Saul, "Wind Power's 'Colossal Market Failure' Threatens Climate Fight", Bloomberg, April 25, 2022, <https://www.bnnbloomberg.ca/wind-power-s-colossal-market-failure-threatens-climate-fight-1.1756429>. Despite rising wind costs, wind energy remains cost-competitive due to rising fossil fuel prices, from C. Richard, "Wind turbine maker Vestas expects 2022 loss and 'profit challenge' in 2023", Windpower Monthly, January 27, 2023, <https://www.windpowermonthly.com/article/1811536/wind-turbine-maker-vestas-expects-2022-loss-profit-challenge-2023>; Reve, "The wind power industry's challenging period continued in 2022", EV Wind, January 27, 2023, <https://www.evwind.es/2023/01/27/the-wind-power-industrys-challenging-period-continued-in-2022/89892>. Offshore wind also is cost-competitive with fossil generation in spite of recent cost inflation, from GWEC, "Global Offshore Wind Report 2022", June 29, 2022, p. 5, <https://gwec.net/gwecs-global-offshore-wind-report>.
- 6 GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, pp. 93, 94; F. Zhao, GWEC, personal communication with REN21, May 1, 2023.
- 7 See, for example: A. Symons, "Finland: Wind power increased by 75% last year, boosting energy security and climate goals", Euro News, January 12, 2023, <https://www.euronews.com/green/2023/01/12/finland-wind-power-increased-by-75-last-year-boosting-energy-security-and-climate-goals>; Kyodo News, "Japan aims to speed up start of new offshore wind power plants", March 18, 2022, <https://english.kyodonews.net/news/2022/03/9e13148b7dc4-japan-aims-to-speed-up-start-of-new-offshore-wind-power-plants.html>; A. Morales, "U.K. to ramp up offshore wind targets in energy security push", Bloomberg, March 17, 2022, <https://www.bloomberg.com/news/articles/2022-03-17/u-k-to-ramp-up-offshore-wind-targets-in-energy-security-push>; GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1; WWEA, op. cit. note 1. Cost-competitiveness also from W. Mathis, "Renewable Power's Big Mistake Was a Promise to Always Get Cheaper", Bloomberg, November 7, 2022, <https://www.bloomberg.com/news/articles/2022-11-07/wind-giant-rues-promise-that-renewable-power-could-be-free>. Electricity generation from wind power is cheaper than that from coal in almost every country, even without considering the cost of carbon, from GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, p. 21.
- 8 See, for example, Statista, "Companies with the largest contracted renewable capacity through corporate power purchase agreements (PPAs) worldwide in 2022, by technology", <https://www.statista.com/statistics/1375971/renewable-ppa-capacity-worldwide-by-company-and-technology>, accessed April 1, 2023; 10.9 GW (including 4.8 GW in the Americas; 4.6 GW in Europe, the Middle East and Africa; and 1.5 GW in Asia-Pacific) from BloombergNEF and provided by Zhao, op. cit. note 6. Of this, about 6.6 GW was contracted in Europe, from Costanzo, op. cit. note 1, May 3, 2023.
- 9 Global targets based on data and sources throughout this section; challenges from, for example, C. Mapes, The Lincoln Electric Company, in GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, p. 6; GWEC, idem, p. 16; WindEurope, "EU wind installations up by a third despite challenging year for supply chain", January 11, 2023, <https://windeurope.org/newsroom/press-releases/eu-wind-installations-up-by-a-third-despite-challenging-year-for-supply-chain>; B. Woods, "From GE to Siemens, the wind energy industry hopes billions in losses are about to end", CNBC, April 17, 2023, <https://www.cnbc.com/2023/04/17/from-ge-to-siemens-wind-energy-hopes-its-crisis-is-about-to-end.html>; O. Jenkinson, "Critical risks to European wind supply chain threaten to derail green transition", Windpower Monthly, April 19, 2023, <https://www.windpowermonthly.com/article/1820082/critical-risks-european-wind-supply-chain-threaten-derail-green-transition>.
- 10 J. Saul, W. Mathis and R. Morison, "Planet-Saving Wind Farms Fall Victim to Global Inflation Fight", Bloomberg, March 10, 2023, <https://www.bloomberg.com/news/articles/2023-03-10/offshore-wind-farms-face-fresh-hurdles-around-the-world-because-of-inflation>; W. Mathis, R. Beene and J. Saul, "Wind

- Power's 'Colossal Market Failure' Threatens Climate Fight", Bloomberg, April 25, 2022, <https://www.bloomberg.com/news/articles/2022-04-25/wind-power-s-colossal-market-failure-threatens-climate-fight>; B. Backwell, "We must invest in supply chain to build the next TW", in GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, p. 3; Reuters Events, "Losses mount at turbine makers; U.S. wind installs dive on supply chain woes", November 16, 2022, <https://www.reutersevents.com/renewables/wind/losses-mount-turbine-makers-us-wind-installs-dive-supply-chain-woes>; Reuters Events, "Europe counters U.S. with clean energy package; Inflation hounds turbine suppliers", February 1, 2023, <https://www.reutersevents.com/renewables/wind/europe-counters-us-clean-energy-package-inflation-hounds-turbine-suppliers>.
- 11 Permitting from, for example, Saul, Mathis and Morison, op. cit. note 10; W. Mathis, "Renewable Power's Big Mistake Was a Promise to Always Get Cheaper", Bloomberg, November 7, 2022, <https://www.bloomberg.com/news/articles/2022-11-07/wind-giant-rues-promise-that-renewable-power-could-be-free>; N. Ferris, "What the closure of Germany's only wind blade factory says about its energy transition", Energy Monitor, May 20, 2022, <https://www.energymonitor.ai/tech/renewables/what-the-closure-of-germanys-only-wind-blade-factory-says-about-its-energy-transition>. Projects have stalled or been delayed in much of the world, including countries in Europe, the United States, India, Japan and elsewhere, from B. Backwell, Foreword, in GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, p. 3. Globally, the average time for permitting of wind projects exceeds five years, and permitting is one of the main barriers to achieving climate neutrality through wind power, from S. Gsänger, in WWEA, "WWEA Webinar: Wind Power Markets Around the World 2023", Part 1, April 27, 2023, [https://www.youtube.com/watch?v=VsRW1y\\_FwLk](https://www.youtube.com/watch?v=VsRW1y_FwLk). In many countries it takes significantly longer; for example, in Sweden the permitting process takes 5-8 years, from A. Wickmann, Swedish Wind Power Association, in WWEA, idem. Grid planning from J. Lee and M. Blanch, "Three big barriers stop nations quickly adopting wind power – it's time to break them down", RECharge News, March 13, 2023, <https://www.rechargenews.com/energy-transition/three-big-barriers-stop-nations-quickly-adopting-wind-power-its-time-to-break-them-down-2-1-1418216>; A. Lee, "Bad permitting prime example! Italy in wind industry firing line after green power auction flops", RECharge News, February 1, 2022, <https://www.rechargenews.com/wind/bad-permitting-prime-example-italy-in-wind-industry-firing-line-after-green-power-auction-flops/2-1-1161131>; Reuters Events, "Europe counters...", op. cit. note 10; RenewableUK, cited in M. Mace, "Report: UK 'wasted' enough wind energy to power 1.2 million homes this winter", edie, February 6, 2023, <https://www.edie.net/report-uk-wasted-enough-wind-energy-to-power-1-2-million-homes-this-winter>. Connection queues from, for example, R. Kessler, "US clean-power build tumbles to three-year low amid 'policy and regulatory challenges': ACP", RECharge News, November 2, 2022, <https://www.rechargenews.com/wind/us-clean-power-build-tumbles-to-three-year-low-amid-policy-and-regulatory-challenges-ACP/2-1-1345060>, and from C. Clifford, "Wind and solar power generators wait in yearslong lines to put clean electricity on the grid, then face huge interconnection fees they can't afford", CNBC, April 6, 2023, <https://www.cnbc.com/2023/04/06/outdated-us-energy-grid-tons-of-clean-energy-stuck-waiting-in-line.html>.
  - 12 H. Zaremba, "Europe's wind energy industry has hit a rough patch", <https://www.baystreet.ca/articles/commodities/82836/112822>; WindEurope, op. cit. note 1, p. 54.
  - 13 Downstream price pressures, pandemic challenges and skilled labour from B. Lepic, "Wind industry feeling tight squeeze on supply chain", Rig Zone, August 10, 2022, [https://www.rigzone.com/news/wind\\_industry\\_feeling\\_tight\\_squeeze\\_on\\_supply\\_chain-10-aug-2022-169917-article](https://www.rigzone.com/news/wind_industry_feeling_tight_squeeze_on_supply_chain-10-aug-2022-169917-article). Pandemic challenges and skilled labour also from GWEC, "Global Offshore Wind Report 2022", op. cit. note 5, p. 14; Kessler, op. cit. note 11. Inflation and war in Ukraine from GWEC, "Global Offshore Wind Report 2022", op. cit. note 5, p. 5; A.F. Rochas, "EU wind targets under threat from volatile costs", Reuters Events, November 16, 2022, <https://www.reutersevents.com/renewables/wind/eu-wind-targets-under-threat-volatile-costs>; Reuters Events, "Losses mount...", op. cit. note 10; D. Peterson, "The European wind sector is 'struggling' in the face of escalating costs", Energy News, October 11, 2022, <https://www.energy-news.net/the-european-wind-sector-is-struggling-in-the-face-of-escalating-costs>; GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1; Siemens Gamesa, "European's energy independence impossible unless wind power considered a strategic industry", September 26, 2022, <https://www.siemensgamesa.com/en-int/newsroom/2022/09/092622-siemens-gamesa-press-release-europe-wind-energy-security-white-paper>. Profitability of offshore as well as onshore, from GWEC, "Global Offshore Wind Report 2022", op. cit. note 5, p. 14. For example, the 1.2 GW Commonwealth Wind project near the US coast of Massachusetts was delayed in 2022 for at least a year, and 6 GW of projects off the coast of Germany did not advance, from Saul, Mathis and Morison, op. cit. note 10.
  - 14 Unfavourable policies and regulatory landscape from WWEA, op. cit. note 1; Rochas, op. cit. note 13; Reuters Events, "Losses mount...", op. cit. note 10; Peterson, op. cit. note 13; Kessler, op. cit. note 11; developers from Saul, Mathis and Morison, op. cit. note 10; turbine orders from WindEurope, "Investments in wind energy are down – Europe must get market design and green industrial policy right", January 31, 2023, <https://windeurope.org/newsroom/press-releases/investments-in-wind-energy-are-down-europe-must-get-market-design-and-green-industrial-policy-right>; investment from WindEurope, op. cit. note 1, p. 8, and from WindEurope, "Europe invested €17bn in new wind in 2022, the lowest since 2009", March 29, 2023, <https://windeurope.org/newsroom/press-releases/europe-invested-e17bn-in-new-wind-in-2022-the-lowest-since-2009>.
  - 15 E. Ng, "Chinese wind turbine makers eye Asia, Europe for growth as climate change, energy security take centrestage", South China Morning Post, August 29, 2022, <https://www.scmp.com/business/china-business/article/3190585/chinese-wind-turbine-makers-eye-asia-europe-growth-climate>; Peterson, op. cit. note 13.
  - 16 See, for example: GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, pp. 20, 22; WindEurope, op. cit. note 1, p. 54; Reuters Events, "Losses mount...", op. cit. note 10; Zaremba, op. cit. note 12; Mathis, op. cit. note 11; Mathis, Beene and Saul, op. cit. note 10; S. Mody, "GE is laying off 20% of its U.S. workforce devoted to onshore wind power, costing hundreds of jobs", CNBC, October 6, 2022, <https://www.cnbc.com/2022/10/06/ge-layoff-20percent-of-onshore-wind-workforce-hundreds-of-jobs.html>; A. Lee, "Wind power giant Siemens Gamesa to axe almost 3,000 jobs in turnaround bid", RECharge News, September 29, 2022, <https://www.rechargenews.com/wind/wind-power-giant-siemens-gamesa-to-axe-almost-3-000-jobs-in-turnaround-bid/2-1-1323294>; Nordex Acciona Windpower, "Nordex SE: Nordex Group achieves consolidated sales of EUR 5.7 billion", March 31, 2023, <https://www.nordex-online.com/en/2023/03/nordex-se-nordex-group-achieves-consolidated-sales-of-eur-5-7-billion>; Nordex Group, "Nordex Group generates order intake of 6.3 GW in the fiscal year 2022", January 17, 2023, <https://www.nordex-online.com/en/2023/01/nordex-group-generates-order-intake-of-6-3-gw-in-the-fiscal-year-2022>; A. Lee, "A cyberattack and market headwinds: Loss-making 2022 a year to forget for Nordex", RECharge News, March 9, 2023, <https://www.rechargenews.com/wind/a-cyberattack-and-market-headwinds-loss-making-2022-a-year-to-forget-for-nordex/2-1-1416787>; N. Ferris, "What the closure of Germany's only wind blade factory says about its energy transition", Energy Monitor, May 20, 2022, <https://www.energymonitor.ai/tech/renewables/what-the-closure-of-germanys-only-wind-blade-factory-says-about-its-energy-transition>.
  - 17 See, for example: Mathis, op. cit. note 11; GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, pp. 10, 20, 22; WindEurope, op. cit. note 1, p. 54; Reuters Events, "Losses mount...", op. cit. note 10; Zaremba, op. cit. note 12; Mathis, op. cit. note 11; Mathis, Beene and Saul, op. cit. note 10; Mody, op. cit. note 16; Lee, "Wind power giant...", op. cit. note 16; Nordex Acciona Windpower, "Nordex SE: Nordex Group achieves consolidated sales of EUR 5.7 billion", March 31, 2023, <https://www.nordex-online.com/en/2023/03/nordex-se-nordex-group-achieves-consolidated-sales-of-eur-5-7-billion>; Nordex Group, "Nordex Group generates order intake of 6.3 GW in the fiscal year 2022", January 17, 2023, <https://www.nordex-online.com/en/2023/01/nordex-group-generates-order-intake-of-6-3-gw-in-the-fiscal-year-2022>; Lee, "A cyberattack...", op. cit. note 16; Ferris, op. cit. note 16.
  - 18 Predictable policies and steel from Peterson, op. cit. note 13; eroding profits from Lepic, op. cit. note 13. Goldwind, China's largest firm, saw weaker profits for the first half of 2022 and a profit decline was expected for the full year, from W. Mathis and J. Saul, "Wind Farms Need to Boom to Hit Climate Targets, But Growth Is Stalling", BloombergNEF, March 23, 2023, <https://financialpost.com/pmn/business-pmn/wind-farms-need-to-boom-to-hit-climate-targets-but-growth-is-stalling>. This shift was despite strong growth in sales volume during the year, from Ng, op. cit. note 15.
  - 19 Western manufacturers from Mathis, Beene and Saul, op. cit. note 10. Between late 2020 and late 2022, wind turbine prices (at least in Europe) increased 40% due to inflation in commodity prices and other input costs, from WindEurope, "Investments

- in wind energy...”, op. cit. note 14. Goldwind from Bloomberg News, “China’s wind turbine prices have hit bottom, Goldwind says”, April 8, 2022, <https://www.bloomberg.com/news/articles/2022-04-08/china-s-wind-turbine-prices-have-hit-bottom-goldwind-says>. According to BloombergNEF, turbine prices in China have fallen from about USD 700,000 per MW in early 2020 to about USD 470,000 per MW at the end of 2021, with bids for new projects averaging about USD 370,000 per MW in early 2022, from idem.
- 20 See, for example: GWEC, “Global Wind Report 2023”, March 27, 2023, op. cit. note 1, pp. 11, 22; A. Frangoul, “The energy transition will fail unless industry fixes wind power issues, Siemens Energy CEO says”, CNBC, November 17, 2022, <https://www.cnbc.com/2022/11/17/energy-transition-will-fail-unless-wind-power-fixes-problems-ceo.html>; Ferris, op. cit. note 16; Siemens Gamesa, op. cit. note 13; GWEC, “Global wind industry unites to address climate and energy crises ahead of COP27”, July 15, 2022, <https://gwec.net/global-wind-industry-unites-to-address-climate-and-energy-crises-ahead-of-cop27>.
- 21 In 2022, all successful auctions for offshore wind power in Europe included non-price criteria as part of the evaluation, from GWEC, “Global Wind Report 2023”, March 27, 2023, op. cit. note 1, p. 77. See also WindEurope, “WindEurope position on non-price criteria in auctions”, April 13, 2022, <https://windeurope.org/policy/position-papers/windeurope-position-on-non-price-criteria-in-auctions>.
- 22 S. Gsänger, WWEA, personal communication with REN21, May 2, 2023.
- 23 Based on data from GWEC, “Global Wind Report 2023”, March 2023, op. cit. note 1.
- 24 Ibid.; ACP, op. cit. note 1, p. 5; WindEurope, op. cit. note 1, pp. 10, 11; Costanzo, op. cit. note 1; WWEA, op. cit. note 1.
- 25 Regional shares based on data from GWEC, “Global Wind Report 2023”, March 2023, op. cit. note 1, from ACP, op. cit. note 1, p. 5, from WindEurope, op. cit. note 1, pp. 10, 11, and from Costanzo, op. cit. note 1. Numbers in text are based on regional groupings that include Türkiye as part of Asia, rather than Europe; other regional shares include Pacific with just over 2% of the total added in 2022, and Africa and the Middle East with 1.9%, based on data from idem, all sources.
- 26 The top five markets accounted for 71.9% of global installations in 2022, based on data from GWEC, “Global Wind Report 2023”, March 2023, op. cit. note 1, from ACP, op. cit. note 1, p. 5, from WindEurope, op. cit. note 1, pp. 10, 11, and from Costanzo, op. cit. note 1.
- 27 Based on data from GWEC, “Global Wind Report 2023”, March 2023, op. cit. note 1, from ACP, op. cit. note 1, p. 5, from WindEurope, op. cit. note 1, pp. 10, 11, and from Costanzo, op. cit. note 1. Figure of 1.6 GW to rank among top 10 is based on data from idem, all sources. Figure of 1.4 GW in 2021 (and 1.1 GW in 2020) based on data from GWEC, “Global Wind Report 2022”, April 4, 2022, <https://gwec.net/global-wind-report-2022>, p. 112, and from GWEC, “Global Wind Report 2022”, April 2022, unpublished document. **Figure 32** based on country-specific data and sources provided throughout this section, and drawn largely from the following: GWEC, “Global Wind Report 2023”, March 27, 2023, op. cit. note 1; GWEC, “Global Wind Report 2023”, March 2023, op. cit. note 1; WindEurope, op. cit. note 1, pp. 10, 11; Costanzo, op. cit. note 1; WWEA, op. cit. note 1; ACP, op. cit. note 1.
- 28 Based on data from GWEC, “Global Wind Report 2023”, March 2023, op. cit. note 1, from ACP, op. cit. note 1, p. 5 <https://cleanpower.org/resources/clean-power-quarterly-market-report-q4-2022/>, from WindEurope, op. cit. note 1, pp. 10, 11, and from Costanzo, op. cit. note 1.
- 29 GWEC, “Global Wind Report 2023”, March 27, 2023, op. cit. note 1, p. 52.
- 30 A gross total of 37,631 MW (including 32,579 MW onshore and 5,052 MW offshore) was installed and grid connected in 2022, with 1,1214 MW of onshore capacity decommissioned during the year, from GWEC, “Global Wind Report 2023”, March 27, 2023, op. cit. note 1, pp. 52, 106, from China’s NEA, “National Energy Administration Press Conference”, February 13, 2023, <http://www.nea.gov.cn/xwfb/2023012b/index.htm> (using Google Translate), and from China Daily, “Solar, wind projects to accelerate”, February 21, 2023, [http://english.www.gov.cn/statecouncil/ministries/202302/21/content\\_WS63f41dafc6d0a757729e6fc7.html](http://english.www.gov.cn/statecouncil/ministries/202302/21/content_WS63f41dafc6d0a757729e6fc7.html). The CWEA reported the installation of 44.7 GW onshore, but China’s NEA announced that 32.6 GW was grid-connected in 2022, meaning that 12.1 GW installed were not yet grid-tied at the end of the year, from idem, p. 93, and from NEA, cited in Mathis and Saul, op. cit. note 18. Note that WWEA continues to report data for total mechanically installed capacity, reporting that 48,960 MW was added for a year-end total of 395.6 GW, based on data from the CWEA, cited in WWEA, op. cit. note 1; also note that about 50 GW was added (43.8 GW onshore and 5.16 GW offshore) for year-end total of about 400 GW, from F. Guo, CWEA, participant in WWEA, op. cit. note 11.
- 31 GWEC, “Global Wind Report 2023”, March 27, 2023, op. cit. note 1, pp. 52, 106, and from GWEC, “Global Wind Report 2023”, March 2023, op. cit. note 1.
- 32 Zhao, op. cit. note 6.
- 33 Based on data from GWEC, “Global Wind Report 2023”, March 27, 2023, op. cit. note 1, p. 102, and from GWEC, “Global Wind Report 2023”, March 2023, op. cit. note 1. Also see E. Ng, “Climate change: China sets another solar power installation record while putting the brakes on fossil fuel capacity”, South China Morning Post, January 18, 2023, <https://www.scmp.com/business/article/3207250/climate-change-china-sets-another-solar-power-installation-record-while-putting-brakes-fossil-fuel>.
- 34 Figure of 16.3% based on 762,400 GWh in 2022, and 655,600 GWh in 2021, from China Electricity Council, provided by Zhao, op. cit. note 6. Wind penetration was 8.8% by the end of 2022, up from 7.8% in 2021 and 6.1% in 2020; it passed nuclear power in 2018 to become China’s third largest source of electricity, after coal and hydropower, all from F. Guo, CWEA, in WWEA, op. cit. note 11. Wind energy accounted for 9.3% of China’s electricity mix in 2022, from Ember, cited in SR Bhandari, “China leads, as wind and solar reach record power generation in 2022”, Radio Free Asia, April 12, 2023, <https://www.globalsecurity.org/wmd/library/news/china/2023/04/china-230412-rfa03.htm>.
- 35 Ng, op. cit. note 33.
- 36 GWEC, “Global Wind Report 2023”, March 27, 2023, op. cit. note 1, pp. 11-12, 24.
- 37 Ibid., pp. 25, 54; Ng, op. cit. note 15. More than 15 manufacturers are active in China, and China (including capacity from three western turbine manufacturers) represents 60% of wind turbine manufacturing capacity (nacelle assembly capability) as of early 2023; most of the rest is in Europe (19%), the United States (9%), India (7%) and Latin America (4%), all from GWEC Market Intelligence, February 2023, cited in GWEC, “Global Wind Report 2023”, March 27, 2023, op. cit. note 1.
- 38 GWEC, “Global Wind Report 2023”, op. cit. note 1, pp. 25, 54; Ng, op. cit. note 15. Fierce competition driving down prices also from Mathis and Saul, op. cit. note 18. As of January 2022, the average price of an onshore wind turbine in China was about half that outside of China, while Chinese-made offshore turbines available in the market also cost less than those made elsewhere, from BloombergNEF, “Wind Turbine Price Index”, cited in BloombergNEF, “Wind – 10 predictions for 2022”, January 28, 2022, <https://about.bnef.com/blog/wind-10-predictions-for-2022>. An estimated 4,224 turbines had been exported from China as of end-2022, for a cumulative capacity of 12 GW, from F. Guo, CWEA, in WWEA, op. cit. note 11. Less than 3% of capacity outside of China based on 12 GW and estimate of 540,392 MW installed globally outside of China, based on data from GWEC, “Global Wind Report 2023”, March 2023, unpublished document.
- 39 Six of top 10 from BloombergNEF, “Goldwind and Vestas in Photo Finish for Top Spot as Global Wind Power Additions Fall”, March 23, 2023, <https://about.bnef.com/blog/goldwind-and-vestas-in-photo-finish-for-top-spot-as-global-wind-power-additions-fall>, and from GWEC, “Global Wind Market Development: Supply Side Data 2022”, p. 7, unpublished document. Estimates from BloombergNEF are based on 49 GW of new wind capacity added in China during 2022; not all of this capacity was grid-connected by year’s end. Goldwind supplied 12.7 GW of turbines for projects in 2022, followed closely by Vestas (12.3 GW), and then GE (United States, with 9.3 GW), Envision (China, 8.3 GW), Siemens Gamesa (Spain, 6.8 GW) tied with MingYang (China, 6.8), followed by Windey (China, 6.4 GW), Nordex (Germany, 4.7), Sany (China, 4 GW) and CRRC (China, 3.2 GW), from BloombergNEF, op. cit. this note. GWEC estimates based on total of 89,890 MW installed in 2022 (but not all grid connected by year’s end), with Vestas still in the lead with 12.6 GW, followed by Goldwind (11.8 GW), Siemens Gamesa (9.3 GW), GE Renewable Energy (8.8 GW), Envision (8.4 GW), MingYang (6.5 GW), Windey (6.3 GW), Nordex Group (4.9 GW), SANY (4.5 GW) and CRRC (3.9 GW), from GWEC, op. cit. this note, pp. 3, 7.
- 40 Figure of 3.1 GW from J. Hensley, ACP, Washington, DC, personal communication with REN21, April 20, 2023; other data from ACP, op. cit. note 1, pp. 5, 7. Partial and full repowering from R. Davidson, “American Clean Power Association: Policy vacuum feeds five-year low for US onshore wind”, Windpower Monthly, February 17, 2023, <https://www.windpowermonthly.com/>



- article/1813784/american-clean-power-association-policy-vacuum-feeds-five-year-low-us-onshore-wind.
- 41 GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, p. 93, from ACP, op. cit. note 1, pp. 5, 7, and from Davidson, op. cit. note 40. Note that the Production Tax Credit was extended and increased for projects that begin construction by the end of December 2024; in 2025, the wind credits will be replaced by technology-neutral credits for low-carbon electricity generation, which will phase out in 2032 (or when US power sector greenhouse gas emissions fall to one-quarter of 2022 levels), from GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, p. 108. However, as of early 2023, the US Internal Revenue Service had not issued guidance on how companies can access the tax credits, from Davidson, op. cit. note 40.
- 42 ACP, op. cit. note 1, p. 7.
- 43 Figure of 10.2% based on preliminary data of 434,812 GWh of utility-scale wind generation and 4,243,136 GWh generation from all utility-scale sources during 2022; up from 9.2% based on 378,197 GWh of utility-scale wind generation and 4,108,303 GWh generation from all utility-scale sources during 2021, all from US Energy Information Administration (EIA), "Electric Power Monthly with Data for December 2022", February 2023, Table ES1.B, <https://www.eia.gov/electricity/monthly/archive/february2023.pdf>.
- 44 Down 13%, from ACP, op. cit. note 1, p. 13; advanced development pipeline from Davidson, op. cit. note 40
- 45 Davidson, op. cit. note 40.
- 46 Increased 27% from Ibid.; fell late 2022, from Reuters Events, "EU leaders agree 'targeted' support for clean tech; U.S. wind power prices fall", February 15, 2023, <https://www.reutersevents.com/renewables/wind/eu-leaders-agree-targeted-support-clean-tech-us-wind-power-prices-fall>. Capital expenditure requirements for developing wind farms onshore in the United States also increased, by more than 16% between 2020 and 2022, from Saul, Mathis and Morison, op. cit. note 10.
- 47 Almost half is based on the following: Brazil added around 8.5 GW of new generating capacity in 2022, from S. Djunicic, "Brazil expects 10.3 GW of new capacity in 2023, mainly wind and solar", Renewables Now, January 23, 2023, <https://renewablesnow.com/news/brazil-expects-103-gw-of-new-capacity-in-2023-mainly-wind-and-solar-812111>, and added 8.2 GW from reve, "Brazil hopes to have 10 GW installed in wind power and solar energy by 2023", January 20, 2023, <https://www.evwind.es/2023/01/20/brazil-hopes-to-have-10-gw-installed-in-wind-power-and-solar-energy-by-2023/89813>. Figure of 4.1 GW based on GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, p. 98, and on figure of 4,065 MW (all onshore), from GWEC, "Global Wind Report 2023", March 2023, op. cit. note 1.
- 48 GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, p. 109.
- 49 Ibid., pp. 85, 109. Auctions for the regulated electricity market have been declining in recent years, so PPAs have become the dominant market for wind power, from E. Feitosa, Eolica, Brazil, in WWEA, "WWEA Webinar: Wind Power Markets Around the World 2023", Part 2, April 27, 2023, <https://www.youtube.com/watch?v=-QR-ijAgg9Y>.
- 50 Feitosa, op. cit. note 49.
- 51 GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, p. 102, and from GWEC, "Global Wind Report 2023", March 2023, op. cit. note 1. Total year-end capacity was 25,632 MW, from Feitosa, op. cit. note 49.
- 52 Second largest from GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, p. 84; share of electricity mix from Associação Brasileira de Energia Eólica (ABEEólica), provided by Zhao, op. cit. note 6. This was up from 72.3 TWh, or 11.4% of the mix, in 2021, from EPE, "Brazilian Energy Balance 2022, Base Year 2021 / Empresa de Pesquisa Energética - Rio de Janeiro", 2022, provided by A.R.J. Esparta, peer review comment, undated.
- 53 Based on data for capacity added in 2022, from WindEurope, op. cit. note 1, pp. 10, 11, 13, and from Costanzo, op. cit. note 1; figure of 16 GW added in 2021 based on data from WindEurope, "Wind Energy in Europe: 2021 Statistics and the Outlook for 2022-2026," February 24, 2022, p. 11, <https://windeurope.org/intelligence-platform/product/wind-energy-in-europe-2021-statistics-and-the-outlook-for-2022-2026>, and from I. Komusanac, WindEurope, Brussels, personal communication with REN21, April 2022. Note that the GSR does not include Türkiye as part of Europe, so the country's data are not included in these numbers.
- 54 Based on data from WindEurope, op. cit. note 1, pp. 10, 11, 13, 14, 17, and from Costanzo, op. cit. note 1. All of Europe installed 17,874 MW (15,414 MW onshore and 2,460 MW offshore) in 2022, and decommissioned 454 MW, for a year-end total of 242,432 MW (212,165 MW onshore and 30,267 MW offshore), from idem, both sources. Note that these data do not include Türkiye, which this GSR includes with Asia; they assume pre-2022 capacity for Ukraine and the Russian Federation; and they account for updated statistics for Sweden. Note that Germany was responsible for most decommissioned capacity (266 MW), followed by the Netherlands (80 MW), Austria (39 MW) and Denmark (27 MW), from idem, p. 17.
- 55 Based on data from WindEurope, op. cit. note 1, p. 10, and from Costanzo, op. cit. note 1. EU Member States added 15,761 MW (14,540 MW onshore and 1,221 MW offshore) in 2022 for a year-end total of 204,112 MW (187,829 MW onshore and 16,283 MW offshore), from idem, both sources.
- 56 WindEurope, op. cit. note 1, pp. 8, 9, 44.
- 57 Ibid., pp. 8, 9, 44.
- 58 Ibid., p. 53.
- 59 Figures of 36% and 10.7 GW based on orders of 16.9 GW (less 322 MW in Türkiye) in 2021 and 10.9 GW (less 155 MW in Türkiye) in 2022, from WindEurope, "Wind Turbine Orders Monitoring, 2022 Statistics", January 2023, unpublished document (for members only); WindEurope, "Wind Turbine Orders Monitoring, 2021 statistics", January 2022, unpublished document (for members only); and from Costanzo, op. cit. note 1, May 3 and 4, 2023. Note that there were undisclosed orders totalling 2.1 GW in 2021 and 2.6 GW in 2022, and some of that capacity could have been for Türkiye (which the GSR does not include with Europe), from Costanzo, op. cit. this note. Decline in order capacity also in 2021, from WindEurope, "Wind Turbine Orders Monitoring, 2021 Statistics", op. cit. this note. Investment from WindEurope, op. cit. note 1, p. 8, and from WindEurope, "Europe invested €17bn...", op. cit. note 14. Note that the EUR 17 billion investment reported by WindEurope includes EUR 1 billion in Türkiye and EUR 0.3 billion in Azerbaijan, which this report does not classify as being part of Europe; 87% of the EUR 17 billion were in the EU, from WindEurope, "Financing and Investment Trends: The European Wind Industry in 2022", March 2023, pp. 8, 24, <https://windeurope.org/intelligence-platform/product/financing-and-investment-trends-2022>.
- 60 Figures of 36% and 10.7 GW based on orders of 16.9 GW (less 322 MW in Türkiye) in 2021 and 10.9 GW (less 155 MW in Türkiye) in 2022, from WindEurope, "Wind Turbine Orders Monitoring, 2022 Statistics", January 2023, unpublished document (for members only); WindEurope, "Wind Turbine Orders Monitoring, 2021 Statistics", January 2022, unpublished document (for members only); and from G. Costanzo, WindEurope, personal communications with REN21, May 3 and 4, 2023. Note that there were undisclosed orders totalling 2.1 GW in 2021 and 2.6 GW in 2022, and some of that capacity could have been for Türkiye (which the GSR does not include with Europe), from Costanzo, op. cit. this note. Decline in order capacity also in 2021, from WindEurope, "Wind Turbine Orders Monitoring, 2021 Statistics", op. cit. this note. Investment from WindEurope, op. cit. note 1, p. 8, and from WindEurope, "Europe invested €17bn...", op. cit. note 14. Note that the EUR 17 billion investment reported by WindEurope includes EUR 1 billion in Türkiye and EUR 0.3 billion in Azerbaijan, which this report does not classify as being part of Europe; 87% of the EUR 17 billion were in the European Union, from WindEurope, "Financing and Investment Trends...", op. cit. note 59, pp. 8, 24.
- 61 WindEurope, op. cit. note 1, p. 7, and from Costanzo, op. cit. note 1. The leaders were Finland (added 2.4 GW), the United Kingdom and Germany (both 2.3 GW), Sweden (2 GW), Spain (1.7 GW), and France and Poland (both 1.5 GW), from WWEA, op. cit. note 1.
- 62 Based on data from WindEurope, op. cit. note 1, pp. 10-11, and from Costanzo, op. cit. note 1.
- 63 Based on data from GWEC, "Global Wind Report 2023", March 2023, op. cit. note 1, from WindEurope, op. cit. note 1, pp. 10-11, and from Costanzo, op. cit. note 1.
- 64 WindEurope, op. cit. note 1, pp. 10, 14. Germany added 2,403 MW onshore and 342 MW offshore (and decommissioned 266 MW) for a year-end total of 66,322 MW (including 58,267 MW onshore and 8,055 MW offshore), from idem, pp. 10, 17. Germany added 2,318 MW for a total of 66,242 MW, from WWEA, op. cit. note 1. Germany installed 2.4 GW in 2022, up from 1.9 GW in 2021, with 266 MW decommissioned, resulting in 2.1 GW of net additions and total year-end capacity of 58.1 GW, from Deutsche WindGuard, cited in B. Radowitz, "German wind sector urges to 'overcome permit bottlenecks' despite rise in onshore additions", RECharge News, January 18, 2023, <https://www.rechargenews.com/wind/german-wind-sector-urges-to-overcome-permit-bottlenecks-despite-rise-in-onshore-additions/2-1-1389722>.

- The country also repowered 423 MW, from Bundesverband WindEnergie (BWE), cited in Radowitz, idem.
- 65 Based on data from GWEC, "Global Wind Report 2023", March 2023, op. cit. note 1. Last year of FIT from WindEurope, "Wind in Power 2017: Annual Combined Onshore and Offshore Wind Statistics", February 2018, p. 18, <https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Statistics-2017.pdf>; EurObserv'ER, "Wind Energy Barometer", February 2018, p. 10, <https://www.eurobserv-er.org/wind-energy-barometer-2018>.
- 66 Generation from wind energy was 100.164 TWh onshore and 25.123 TWh offshore, accounting for 18.2% and 4.6% respectively of Germany's gross electricity consumption, from Geschäftsstelle der Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat) and Umweltbundesamt, "Erneuerbare Energien in Deutschland Daten zur Entwicklung im Jahr 2022", February 2023, pp. 9, 19, <https://www.umweltbundesamt.de/publikationen/erneuerbare-energien-in-deutschland-2022>. Germany's generation from wind energy in 2021 was 114.6 TWh, from idem. Generation in 2022 was down relative to 2019 and 2020, from Umweltbundesamt, "Erneuerbare Energien in Zahlen", March 17, 2023, <https://www.umweltbundesamt.de/themen/klima-energie/erneuerbare-energien/erneuerbare-energien-in-zahlen#uberblick>, viewed April 3, 2023; and this relative decline was due to low wind speeds for much of the year, from G. Maguire, "Column: Wind set to ease Germany's power crunch, for now", Reuters, December 13, 2022, <https://www.reuters.com/markets/commodities/wind-set-ease-germanys-power-crunch-now-2022-12-13>.
- 67 G. Rajgor, "Onshore wind breakthrough as Germany green lights 10GW a year from 2025", Windpower Monthly, July 11, 2022, <https://www.windpowermonthly.com/article/1792723/onshore-wind-breakthrough-germany-green-lights-10gw-year-2025>. The new law aims to double onshore capacity to 115 GW by 2030, calls on German states to set aside 2% of land for onshore wind, and sets offshore targets of 30 GW in operation by 2030, 40 GW by 2035 and 70 GW by 2045), from idem. Also see DW, "Germany presents new Ukraine-accelerated renewables plan", April 6, 2022, <https://www.dw.com/en/germany-presents-new-ukraine-accelerated-renewables-plan/a-61383714>.
- 68 Undersubscribed from Saul, Mathis and Morison, op. cit. note 10. During 2022, 3.2 GW of onshore capacity was secured from a total available capacity of 4.6 GW, through technology-specific auctions in Germany with feed-in premiums, from WindEurope, op. cit. note 1, pp. 24, 26. The German levy would take 90% of wind (and solar) power profits above EUR 130/MWh, or above a benchmark based on the FIT assigned to a specific project, from N. Ford, "Germany's windfall tax curtails short-term wind growth", Reuters, December 14, 2022, <https://www.reutersevents.com/renewables/wind/germanys-windfall-tax-curtails-short-term-wind-growth>. Also see Reuters Events, "EU caps wind revenues above costs but national limits could bite", October 5, 2022, <https://www.reutersevents.com/renewables/wind/eu-caps-wind-revenues-above-costs-national-limits-could-bite>.
- 69 Saul, Mathis and Morison, op. cit. note 10.
- 70 Finland added 2,430 MW, all onshore, for a year-end total of 5,678 MW (including 5,607 MW onshore and the rest offshore), from WindEurope, op. cit. note 1, pp. 10, 14; rankings based on data from idem, and from GWEC, "Global Wind Report 2023", March 2023, op. cit. note 1. Finland added 2,421 MW for a total of 5,677 MW, from WWEA, op. cit. note 1.
- 71 Increase over 2021 based on data from GWEC, "Global Wind Report 2023", March 2023, op. cit. note 1; 5.7 GW from WindEurope, op. cit. note 1, pp. 10, 14; net zero and invasion from Symons, op. cit. note 7.
- 72 WindEurope, op. cit. note 1, p. 10.
- 73 Ibid., pp. 10, 14. Record also based on historical data from GWEC, "Global Wind Report 2023", March 2023, op. cit. note 1.
- 74 France added 1,590 MW onshore and 480 MW offshore for a year-end total of 21,135 MW (including 20,653 MW onshore and 482 MW offshore), WindEurope, op. cit. note 1, pp. 10, 14. France added 1,516 MW for a total of 20,600 MW, from WWEA, op. cit. note 1.
- 75 Based on data from ENTSO-E, from WindEurope, op. cit. note 1, p. 19.
- 76 Based on data from WindEurope, op. cit. note 1, p. 10, and on historical data from GWEC, "Global Wind Report 2023", March 2023, op. cit. note 1. Sweden added 2,054 MW for a total of 14,227 MW, from WWEA, op. cit. note 1, and from A. Wickmann, Swedish Wind Power Association, in WWEA, op. cit. note 11.
- 77 Rankings based on data from WindEurope, op. cit. note 1, pp. 10, 11, from GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, and from GWEC, "Global Wind Report 2023", March 2023, op. cit. note 1.
- 78 WindEurope, op. cit. note 1, p. 38.
- 79 F. Jones, "Sweden sets new record for wind energy", Power Technology, March 29, 2023, <https://www.power-technology.com/news/sweden-wind-energy-record>. Sweden's wind generation in 2022 was about 33,000 GWh (up from about 27,100 GWh in 2021), and wind energy accounts for about one-third of the country's electricity generation, or about the same share as hydro- and nuclear power, from A. Wickmann, Swedish Wind Power Association, in WWEA, op. cit. note 11.
- 80 Based on data from WindEurope, op. cit. note 1, p. 11, and from GWEC, "Global Wind Report 2023", March 2023, op. cit. note 1.
- 81 GWEC, "Global Wind Report 2023", March 2023, op. cit. note 1. In 2022, the United Kingdom added 1,682 MW, of which 502 MW was onshore and 1,179 MW was offshore, and decommissioned 1 MW; this is up from 2021 additions of 328 MW onshore (and 2.9 MW decommissioned) and down from 2,316.5 MW offshore, totalling 2,641.6 MW net. The end-2022 total was 28,292.8 MW (including 14,574.9 MW onshore and 13,917.9 MW offshore), all from GWEC, op. cit. this note. The United Kingdom added 2,339 MW for a total of 28,087 MW, from WWEA, op. cit. note 1. The decline in offshore capacity brought online was due to the gap between execution of projects under rounds 2 and 3 of the UK Contracts for Difference, from Zhao, op. cit. note 6. In addition, offshore wind is more cyclical than onshore, with fewer but larger projects, resulting in fluctuations in installations, from Costanzo, op. cit. note 1, May 3, 2023.
- 82 BBC News, "Onshore wind rules to be relaxed after Tory revolt", December 6, 2022, <https://www.bbc.com/news/uk-politics-63880999>; A. Lee, "UK wind power breaks records in 2022 as pressure grows to lift onshore ban", REcharge, January 6, 2023, <https://www.rechargenews.com/wind/uk-wind-power-breaks-records-in-2022-as-pressure-grows-to-lift-onshore-ban/2-1-1384290>.
- 83 Based on data from WindEurope, op. cit. note 1, p. 11, and from GWEC, "Global Wind Report 2023", March 2023, op. cit. note 1. In 2022, the United Kingdom added 1,682 MW, of which 502 MW was onshore and 1,179 MW was offshore, and decommissioned 1 MW; this is up from 2021 additions of 328 MW onshore (and 2.9 MW decommissioned) and 2,316.5 MW offshore, totalling 2,641.6 MW net. The end-2022 total was 14,574.9 MW onshore and 13,917.9 MW offshore, all from GWEC, "Global Wind Report 2023", March 2023, op. cit. note 1.
- 84 W. Mathis, "The UK produced a record amount of wind power in 2022, easing gas crisis", Bloomberg, December 22, 2022, <https://www.bloomberg.com/news/articles/2022-12-22/record-wind-power-spare-uk-even-worse-energy-crisis>.
- 85 Spain added 1,659 MW in 2022, up from 750 MW in 2021, for an end-2022 total of 29,803 MW (all onshore except for 10 MW offshore), from WindEurope, op. cit. note 1, p. 14, and from GWEC, "Global Wind Report 2023", March 2023, op. cit. note 1. Spain added 1,670 MW for a total of 29,813 MW, from WWEA, op. cit. note 1.
- 86 Costanzo, op. cit. note 1, May 3, 2023.
- 87 Preliminary estimates from Red Eléctrica, "La eólica y la fotovoltaica batieron récord de generación eléctrica en España en 2022", December 22, 2022, [https://www.ree.es/sites/default/files/paragraph/2022/12/file/Sistema\\_Electrico\\_Pevision\\_2022.pdf](https://www.ree.es/sites/default/files/paragraph/2022/12/file/Sistema_Electrico_Pevision_2022.pdf) (using Google Translate).
- 88 Ember, "European Electricity Review 2023", January 31, 2023, p. 53.
- 89 WindEurope, op. cit. note 1, pp. 9, 18, 34. For all of Europe, output in 2022 was up over 2021 due to better wind conditions, especially in northern regions and strong installations in some countries; by country, output was up except in Estonia, Hungary, Italy, the Slovak Republic, Slovenia and Spain, all of which generated more electricity from the wind in 2021 than in 2022. Wind energy's share of demand also rose in Europe because demand was down due to high electricity prices and government measures to reduce demand in response to the Russian Federation's invasion of Ukraine. All from idem, pp. 18, 20. Electricity generation from wind energy across the EU and United Kingdom has increased from 370 TWh in 2018 to 489 TWh in 2022, while electricity demand has fallen (from 2,960 TWh in 2018 to 2,830 TWh in 2022) due to the pandemic and the war in Ukraine. The one anomalous year was 2021, when generation fell relative to 2020, from WindEurope, op. cit. note 1, p. 34. Note that wind energy generated an estimated 420 TWh, or 15%, of EU electricity during 2022, and Lithuania met 38% of its demand with wind energy, from Ember, op. cit. note 88, p. 50.

- 90 WindEurope, op. cit. note 1, pp. 9, 19. Note that WindEurope data for national shares of electricity mix in each country represent the average of the share of wind in final electricity demand, captured hourly from ENTSO-E and corrected with data from national transmission system operators and governments, from idem, p. 19. Note that share of wind energy in Britain's electricity mix was 26.8% in 2022, up from 21.8% in 2021, from National Grid, cited in S. Twidale, "Britain produced record amount of wind power in 2022, National Grid says", January 6, 2023, <https://www.reuters.com/business/energy/britain-produced-record-amount-wind-power-2022-national-grid-2023-01-06>.
- 91 Germany ended the year with 66,322 MW, followed by Spain (29,798 MW), the United Kingdom (28,493 MW), France (21,135 MW) and Sweden (14,198 MW), based on data from WindEurope, op. cit. note 1, pp. 10, 11, and from Costanzo, op. cit. note 1.
- 92 Based on total combined capacity in top five countries of 159,946 MW and total regional capacity of 242,432 MW, from WindEurope, op. cit. note 1, pp. 10, 11, and from Costanzo, op. cit. note 1.
- 93 Based on data from GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, p. 102, and from GWEC, "Global Wind Report 2023", March 2023, op. cit. note 1.
- 94 India added 1,458.6 MW in 2021 and added 1,847 MW in 2022 for a total of 41,929.8 MW, all onshore, from GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, p. 102, and from GWEC, "Global Wind Report 2023", March 2023, op. cit. note 1. Note that India added 1,846.71 MW in 2021 based on the country's year-end 2020 total of 40,083 MW, from Government of India, Ministry of Power, "Power Sector at a Glance ALL INDIA", February 11, 2022, <https://powermin.gov.in/en/content/power-sector-glance-all-india>, and on year-end 2020 total of 40,082.7 MW from Government of India, Ministry of New and Renewable Resources (MNRE), cited in Central Electricity Authority, "All India installed capacity (in MW) of power stations (as on 31.12.2021)", [https://cea.nic.in/wp-content/uploads/installed/2021/12/installed\\_capacity.pdf](https://cea.nic.in/wp-content/uploads/installed/2021/12/installed_capacity.pdf). Note that India added 2,183 MW in 2022 for a total of 41,983 MW, from WWEA, op. cit. note 1. Almost 10 GW of wind power capacity has been added since auctions were initiated in 2017, from J. Hossain, WWEA, India, in WWEA, op. cit. note 11. India's reverse bidding policy was halted in 2022; it was considered a reason for the decline in installations because aggressive bidding encouraged by the policy made projects unviable for developers, from G. Mishra, "India's wind installations increased 8% YoY to 229 MW in Q4 2022", January 23, 2023, <https://mercomindia.com/india-wind-installations-increased-8-yoy-q4-2022>. The decline in installations was driven primarily by the cancellation of projects that became unviable as a result of high inflation and delays resulting from lack of grid availability and timeline extensions in scheduled commissioning dates, from Zhao, op. cit. note 6.
- 95 A. Joshi, "India missed 2022 renewables target as rooftop solar and wind fell short", Mercom India, March 24, 2023, <https://www.mercomindia.com/india-missed-2022-renewables-target>.
- 96 Offshore installations were 8,771 MW for an end-2022 total of 64,320 MW, from GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, pp. 92, 95, 102, and from GWEC, "Global Wind Report 2023", March 2023, op. cit. note 1.
- 97 Based on data from GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, pp. 92, 102, from GWEC, "Global Wind Report 2023", March 2023, op. cit. note 1, WindEurope, op. cit. note 1, pp. 10, 11, and from Costanzo, op. cit. note 1.
- 98 Global additions in 2021 amounted to nearly 21.5 GW, with 16.9 GW of that capacity installed in China alone, from GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, pp. 92, 102, and from GWEC, "Global Wind Report 2023", March 2023, op. cit. note 1.
- 99 Figure of 58% based on global 2022 installations of 8,771 MW and installations in China of 5,052 MW; the rest was installed in the United Kingdom (added 1,179 MW), Chinese Taipei (1,175 MW), France (480 MW), the Netherlands (369 MW), Germany (342 MW), Japan (84 MW), Norway (60 MW) and Italy (30 MW), all from GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, p. 102, and from GWEC, "Global Wind Report 2023", March 2023, op. cit. note 1.
- 100 China added 5,052 MW, followed in the region by Chinese Taipei (1,175 MW) and Japan (84 MW), from GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, p. 102, and from GWEC, "Global Wind Report 2023", March 2023, op. cit. note 1. First to achieve commercial operations in Chinese Taipei from C. Hsu, "Offshore wind power leaping forward: officials", Taipei Times, October 18, 2022, <https://www.taipetimes.com/News/biz/archives/2022/10/18/2003787220>. **Snapshot Japan** based on the following sources: M. Lewis, "Japan's First Large-Scale Offshore Wind Farm Just Came Online", Electrek, December 27, 2022, <https://electrek.co/2022/12/27/japan-first-large-scale-offshore-wind-farm/>; A. Memija, "Japan's First Commercial-Scale Offshore Wind Farm Fully Up and Running", Offshore Wind, January 31, 2023, <https://www.offshorewind.biz/2023/01/31/japans-first-commercial-scale-offshore-wind-farm-fully-up-and-running/>; Ministry of Economy, Trade and Industry, "Japan's Roadmap to 'Beyond-Zero' Carbon", [https://www.meti.go.jp/english/policy/energy\\_environment/global\\_warming/roadmap/index.html](https://www.meti.go.jp/english/policy/energy_environment/global_warming/roadmap/index.html), accessed April 28, 2023; EU-Japan Centre for Industrial Cooperation, "Japanese Government Announces Results for First Large-Scale Offshore Windpark Auctions", December 24, 2021, <https://www.eu-japan.eu/news/japanese-government-announces-results-first-large-scale-offshore-windpark-auctions/>; Infolink, "Market Analysis: Japan to Reach 10 GW Offshore Wind Capacity by 2030", November 17, 2021, <https://www.infolink-group.com/energy-article/Market-analysis-Japan-to-reach-10-GW-offshore-wind-capacity-by-2030/>; Japan Wind Development Co. Ltd., "Concluded a cooperation agreement with Akita University regarding local contribution and human resource development through offshore wind power generation business", February 9, 2023, <https://www.jwd.co.jp/info> (using Google Translate); Akita Prefecture, "FY2020 Akita Prefecture Wind Power Generation Related Industry Entry Support Project Subsidy Announcement of Recruitment of Eligible Projects", April 5, 2023, <https://www.pref.akita.lg.jp/pages/archive/71956> (using Google Translate); Kahoku, "Offshore wind power will create 37,000 jobs. Akita Prefecture estimate economic effect is 382 billion yen", March 9, 2022, <https://kahoku.news/articles/20220308khn000025.html> (using Google Translate).
- 101 GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, pp. 8, 95, and from GWEC, "Global Offshore Wind Report 2022", op. cit. note 5, p. 7. Rush to commission in 2021 also from F. Guo, CWEA, in WWEA, op. cit. note 11, and from N. Weekes, "Bumper Year-End for Chinese Offshore Wind as Feed-in Tariff Expires", Windpower Monthly, January 5, 2022, <https://www.windpowermonthly.com/article/1736674/bumper-year-end-chinese-offshore-wind-feed-in-tariff-expires>. Pandemic-related restrictions from GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, pp. 52, 106; other sources blame the end of government subsidies for the decline offshore. For example, see Ng, op. cit. note 33. Provincial-level subsidies (although small compared to the expired federal incentives) may have played a role in ongoing development in 2022, from B. Lepic, "Chinese offshore wind capacity boom driven by state subsidies", Rigzone, November 23, 2022, <https://www.rigzone.com/news/chinese-offshore-wind-capacity-boom-driven-by-state-subsidies-23-nov-2022-171136-article>.
- 102 Global Times, "China's largest unsubsidized offshore wind power project completed", December 21, 2022, <https://www.globaltimes.cn/page/202212/1282301.shtml>.
- 103 GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, p. 102; GWEC, "Global Wind Report 2023", March 2023, op. cit. note 1.
- 104 WindEurope, op. cit. note 1, pp. 10, 11; lowest since 2016 from WindEurope, "Offshore Wind Energy 2022 Statistics", March 2023, p. 4.
- 105 The United Kingdom added 1,179 MW in 2022, from WindEurope, op. cit. note 1, p. 13. The UK commissioned 924 MW at Hornsea Two in 2022; the total project is 1,386 MW, from idem, p. 18.
- 106 J. Timperley, "Floating offshore wind prepares to go commercial", Energy Monitor, May 16, 2022, <https://www.energymonitor.ai/tech/renewables/floating-offshore-wind-prepares-to-go-commercial/>; The Crown Estate, "Government approves 8GW of offshore wind in major milestone for renewable energy", July 19, 2022, <https://www.thecrownestate.co.uk/en-gb/media-and-insights/news/2022-government-approves-8gw-of-offshore-wind-in-major-milestone-for-renewable-energy/>; floating wind can triple the size from GWEC, "Global Offshore Wind Report 2021", 2021, p. 6, <https://gwec.net/global-offshore-wind-report-2021>.
- 107 France from WindEurope, op. cit. note 1, p. 14. This was the 480 MW Saint Nazaire project, from idem; The Netherlands from A. Durakovic, "Subsidy-Free Offshore Wind Power Starts Flowing into Dutch Grid", Offshore Wind Biz, August 2, 2022, <https://www.offshorewind.biz/2022/08/02/subsidy-free-offshore-wind-power-starts-flowing-into-dutch-grid/>; Norway from GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, p. 9. The Hywind Tampen project produced its first power in 2022, from A. Frangoul, "The 'world's largest floating wind farm' produces its first power", CNBC, November 14, 2022, <https://www.cnbc.com/2022/11/14/the-worlds-largest-floating-wind-farm-produces-its-first-power.html>. When completed, it will be the world largest floating offshore wind project, from WindEurope,

- "Offshore Wind Energy 2022 Statistics", op. cit. note 104, p. 47. It was not completed in 2022 due to supply chain issues, from GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, p. 95; Italy from WindEurope, op. cit. note 1, p. 13, and from Maritime Executive, "Italy Inaugurates the First Offshore Wind Farm in the Mediterranean", April 25, 2022, <https://www.maritime-executive.com/article/italy-inaugurates-the-first-offshore-wind-farm-in-the-mediterranean>. New offshore capacities commissioned in 2022 totaled 1,179 MW in the United Kingdom, followed by France (480 MW), the Netherlands (369 MW), Germany (342 MW), Norway (60 MW) and Italy (30 MW), from WindEurope, op. cit. note 1.
- 108 Germany added 342 MW in 2022, following a year in which no new offshore capacity came online, based on data from WindEurope, op. cit. note 1, p. 10, and from GWEC, "Global Wind Report 2023", March 2023, op. cit. note 1.
- 109 WindEurope, op. cit. note 1, p. 10-11, 14; WindEurope, "Offshore Wind Energy 2022 Statistics", op. cit. note 104, pp. 4, 10.
- 110 WindEurope, op. cit. note 1, pp. 51, 53; WindEurope, "Offshore Wind Energy 2022 Statistics", op. cit. note 104, p. 40. UK floating wind target was increased in 10 GW in 2022, from GWEC, "Global Offshore Wind Report 2022", op. cit. note 5, p. 3. For more on offshore wind targets in Europe and developments in 2022, see, for example: Institute for Energy Economics and Financial Analysis, "Netherlands targets 70 gigawatts of offshore wind energy by 2050", September 19, 2022, <https://ieefa.org/articles/netherlands-targets-70-gigawatts-offshore-wind-energy-2050>; RENEWS, "North Sea countries set 260GW offshore wind target North Sea countries set 260GW offshore wind target", September 12, 2022, <https://renews.biz/80395/north-sea-countries-set-260gw-offshore-wind-target>; A. Fine, "New Greek Law Focuses on Reaching 2 GW of Offshore Wind Development by 2030", North American Windpower, August 4, 2022, <https://nawindpower.com/new-greek-law-focuses-on-reaching-2-gw-of-offshore-wind-development-by-2030>; Maritime Executive, "Sweden targets 120 TWh from accelerated offshore wind farm development", February 15, 2022, <https://www.maritime-executive.com/article/sweden-targets-120-twh-from-accelerated-offshore-wind-farm-development>.
- 111 WindEurope, "Offshore Wind Energy 2022 Statistics", op. cit. note 104, pp. 4, 35. Not one project reached final investment decision in 2022, from WindEurope, "The EU built only 16 GW new wind in 2022: must restore investor confidence and ramp up supply chain", February 28, 2023, <https://windeurope.org/newsroom/press-releases/the-eu-built-only-16-gw-new-wind-in-2022-must-restore-investor-confidence-and-ramp-up-supply-chain>.
- 112 reNEWS Biz, "US offshore wind demand doubles in 2022", February 21, 2023, <https://renews.biz/83969/us-offshore-wind-demand-doubles-in-2022>; R. Davidson, "US 'tripled offshore wind investment' to \$10bn in 2022", Windpower Monthly, February 22, 2023, <https://www.windpowermonthly.com/article/1814179/us-tripled-offshore-wind-investment-10bn-2022>. This included USD 4.4 billion for port infrastructure, supply chain development and transmission infrastructure, from reNEWS Biz, op. cit. this note.
- 113 More than 13 GW, from GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, p. 96. Also see: R. Davidson, "Rhode Island utility issues RfP for up to 1GW offshore wind", Windpower Monthly, October 17, 2022, <https://www.windpowermonthly.com/article/1802233/rhode-island-utility-issues-rfp-1gw-offshore-wind>; Renewable Energy World, "The 5 clean energy stories that defined 2022", December 28, 2022, <https://www.renewableenergyworld.com/solar/the-5-clean-energy-stories-that-defined-2022>; D. Kovaleski, "New York Bight offshore wind sale nets largest haul in U.S. history", Daily Energy Insider, March 1, 2022, <https://dailyenergyinsider.com/news/34036-new-york-bight-offshore-wind-sale-nets-largest-haul-in-u-s-history>; A. Fine, "BNOW: U.S. Offshore Wind Industry Finished 2022 on a Strong Note", North American Wind Power, January 12, 2023, <https://nawindpower.com/bnow-reports-u-s-offshore-wind-industry-finished-2022-on-a-strong-note>. In addition, the US government designated areas for offshore wind in the Gulf of Mexico, from OE Digital, "U.S. Designates Offshore Wind Farm Development Areas in Gulf of Mexico", October 31, 2022, <https://www.oedigital.com/news/500593-u-s-designates-offshore-wind-farm-development-areas-in-gulf-of-mexico>.
- 114 ACP, op. cit. note 1, pp. 5, 16. The advanced development pipeline at end-2022 was 16,696 MW, and the first commercial-scale project (806 MW Vineyard Wind) began installing offshore cabling during the year, from idem.
- 115 ACP, op. cit. note 1, p. 29. States included California (25 GW), New Jersey (11 GW), New York (9 GW), North Carolina (8 GW), Massachusetts (5.6 GW), Virginia (5.2 GW), Louisiana (5 GW), Connecticut (2.3 GW), Maryland (1.6 GW) and Rhode Island (1.4 GW), from idem. US offshore official targets increased 79% in 2022, due to a California target (25 GW), Louisiana, New Jersey and Rhode Island all announcing new state level goals, from RENEWS Biz, op. cit. note 112. California also has floating wind power targets of 3 GW by 2030, 15 GW by 2045, and possibly 20 GW by 2050, from reNEWS Biz, "California sets 3GW floater goal for 2030", May 9, 2022, <https://renews.biz/77679/california-sets-3gw-floater-goal-for-2030>. In addition to state procurement targets, the Biden administration targets having 30 GW offshore wind online in the United States by 2030, from H.J. Mai, "Biden's offshore wind plan could create thousands of jobs but challenges remain", Oregon Public Broadcasting, January 24, 2023, <https://www.opb.org/article/2023/01/24/offshore-wind-energy-jobs-biden>; on top of this target, the Administration targets 15 GW of floating wind capacity by 2035, from A. Frangoul, "The U.S. looks to rival Europe and Asia with massive floating offshore wind plan", CNBC, September 16, 2022, <https://www.cnbc.com/2022/09/16/the-us-looks-to-rival-europe-and-asia-with-massive-floating-offshore-wind-plan.html>.
- 116 Figure of 16 governments from GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, p. 70. Governments with new or increased targets were the Republic of Korea, China, Victoria (Australia), Nova Scotia (Canada), Belgium, Denmark, France, Germany, Ireland, Luxembourg, the Netherlands, Norway, Sweden, Portugal, New Jersey and Louisiana (United States), from idem. Nova Scotia set a target to offer leases for 5 GW of offshore wind power by 2030 to address climate change and create local jobs, from A. Fine, "Nova Scotia Sets Offshore Wind Lease Goal of 5 GW", North American Windpower, September 22, 2022, <https://nawindpower.com/nova-scotia-sets-offshore-wind-lease-goal-of-5-gw>. Australia's Victoria State set a target of 9 GW by 2030, from GWEC, "Global Offshore Wind Report 2022", op. cit. note 5, p. 3. The Philippines set a target for 21 GW offshore by 2040, from Pinsent Masons, "Philippines targets 21GW offshore wind by 2040", April 29, 2022, <https://www.pinsentmasons.com/out-law/news/philippines-targets-21gw-offshore-wind-by-2040>. Global targets approaching 380 GW from GWEC, "Global Offshore Wind Report 2022", op. cit. note 5, p. 4.
- 117 Australia from B. Symons, "Federal government declares Australia's first six offshore wind energy zones", ABC Gippsland, August 5, 2022, <https://www.abc.net.au/news/2022-08-05/offshore-windfarms-climate-renewable-energy-turbines/101303944>; India from reNEWS Biz, "India unveils 4GW offshore wind tender plan", November 15, 2022, <https://renews.biz/81829/india-unveils-4gw-offshore-wind-tender-plan>, and from Mercom India, "Bids for 12 GW of Offshore Wind Energy to be Issued in Tamil Nadu and Gujarat in Three Years", June 10, 2022, <https://mercomindia.com/bids-for-12-gw-of-offshore-wind-energy>; Brazil from E. Gannoum, President of ABEÉolica, Forward, in GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, p. 5, and from re, "Abeéolica: Brazil will enter 2023 with regulated offshore wind energy", February 17, 2023, <https://www.evwind.es/2023/02/17/abeolica-brazil-will-enter-2023-with-regulated-offshore-wind-energy/90271>. As of mid-2022, Brazil had a pipeline of 97.4 GW of offshore capacity under development, from C. Richard, "Corio Generation unveils 5GW offshore wind pipeline off Brazil", Windpower Monthly, June 13, 2022, <https://www.windpowermonthly.com/article/1789527/corio-generation-unveils-5gw-offshore-wind-pipeline-off-brazil>. In Australia, construction started in 2022 on the MacIntyre Wind Precinct (1,026 MW), which was expected to come online in 2024, from M. Lewis, "Construction officially starts on the largest wind farm in Australia", Electrek, June 2, 2022, <https://electrek.co/2022/06/02/largest-wind-farm-in-australia>. And yet, Australia's Star of the South (2.2 GW) was still on track to become the country's first operating offshore wind farm, with the first power expected in 2028, from A. Durakovic, "Australia Putting Wind Projects Offshore Victoria on Fast Track", Offshore Wind Biz, October 21, 2022, <https://www.offshorewind.biz/2022/10/21/australia-putting-wind-projects-offshore-victoria-on-fast-track>.
- 118 Global offshore pipeline from renewableUK, "UK offshore wind pipeline reaches nearly 100 gigawatts – while global pipeline hits over 1,100GW", February 15, 2023, <https://www.renewableuk.com/news/632004/UK-offshore-wind-pipeline-reaches-nearly-100-gigawatts---while-global-pipeline-hits-over-1100GW-.htm>; floating wind from GWEC, "Global Offshore Wind Report 2022", op. cit. note 5, p. 96.
- 119 Total of 19 in 2022 includes China, Japan, the Republic of Korea, Chinese Taipei and Vietnam in Asia; Germany, Spain, the United Kingdom, France, Italy, Sweden, Portugal, Denmark, the Netherlands, Ireland, Belgium, Norway and Finland in Europe; and the United States. Same countries in 2021 except for Italy; also, note that France had only 2 MW of capacity and Norway only 5.9 MW at the end of 2021. All based on data from WindEurope, op.

- cit. note 1, p. 10-11, 14, from WindEurope, "Offshore Wind Energy 2022 Statistics", op. cit. note 104, pp. 4, 10, and from GWEC, "Global Wind Report 2023", March 2023, op. cit. note 1.
- 120 Based on data from WindEurope, op. cit. note 1, p. 10-11, 14, from WindEurope, "Offshore Wind Energy 2022 Statistics", op. cit. note 104, pp. 4, 10, and from GWEC, "Global Wind Report 2023", March 2023, op. cit. note 1.
- 121 Shares at the end of 2022 and 2021 based on data from GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, p. 102. At the end of 2021, Europe had slightly more than 50% of global installed offshore wind power capacity; this fell to just over 47% in 2022, based on data from idem.
- 122 GWEC, "Global Offshore Wind Report 2022", op. cit. note 5, p. 14.
- 123 Challenges associated with scaling up from T. Casey, "Wooden towers to help cut the cost of wind turbines, even more", CleanTechnica, May 31, 2022, <https://cleantechnica.com/2022/05/31/wooden-towers-to-help-cut-the-cost-of-wind-turbines-even-more/>; I. Griggs, "Firms to produce wooden turbine blades to give wind industry 'sustainable future'", Windpower Monthly, November 15, 2022, <https://www.windpowermonthly.com/article/1805271/firms-produce-wooden-turbine-blades-give-wind-industry-sustainable-future/>; T. Casey, "No more excuses: spiral welding can bring taller wind turbines to US southeast", CleanTechnica, May 16, 2022, <https://cleantechnica.com/2022/05/16/no-more-excuses-spiral-welding-can-bring-taller-wind-turbines-to-us-southeast/>; H. Everett, "New GE facility focuses on R&D of 3D printed wind turbine towers", 3D Printing Industry, April 25, 2022, <https://3dprintingindustry.com/news/new-ge-facility-focuses-on-rd-of-3d-printed-wind-turbine-towers-208125/>; T. Casey, "Taller wind turbines to get TLC from 3D printing", CleanTechnica, April 21, 2022, <https://cleantechnica.com/2022/04/21/taller-wind-turbines-to-get-tlc-from-3d-printing/>; C. Richard and I. Griggs, "2022: Innovations that could shape the wind industry", Windpower Monthly, December 22, 2022, <https://www.windpowermonthly.com/article/1808918/2022-innovations-shape-wind-industry>. For offshore, see also, for example, GWEC, "Global Offshore Wind Report 2022", op. cit. note 5, p. 14. For China specifically, see, for example: D. Snieckus, "'New global milestone' | China's CSSC Haizhuang rolls out world's largest wind turbine", REcharge News, January 9, 2023, <https://www.rechargenews.com/wind/new-global-milestone-chinas-cssc-haizhuang-rolls-out-worlds-largest-wind-turbine/2-1-1384424>. Also, see sources for information provided in endnotes below.
- 124 Reddie & Grose, cited in M. Ahmad, "China leads global increase in wind power generation patents", Energy Digital, January 18, 2023, <https://energydigital.com/renewable-energy/china-leads-global-increase-in-wind-power-generation-patents>. Over the past decade, Chinese firms have filed for far more patents than have those in any other region: Chinese firms accounted for 23,737 patent filings, followed by Europe (16,396), the United States (16,074), the Republic of Korea (6,611) and Japan (3,809), from idem.
- 125 See, for example, US Department of Energy (US DOE), "Land-Based Wind Market Report: 2022 Edition", August 2022, p. viii, [https://www.energy.gov/sites/default/files/2022-08/land\\_based\\_wind\\_market\\_report\\_2202.pdf](https://www.energy.gov/sites/default/files/2022-08/land_based_wind_market_report_2202.pdf), and Lepic, op. cit. note 101; M. Lewis, "GE is developing a massive 18 MW offshore wind turbine", Electrek, March 13, 2023, <https://electrek.co/2023/03/13/ge-is-developing-a-massive-18-mw-offshore-wind-turbine>. Benefits of Larger, higher-efficiency turbines from, for example, B. Backwell, GWEC, "Taking offshore wind global", March 4, 2020, slide 10, [https://www.renewable-ei.org/pdfdownload/activities/11\\_BenBackwell.pdf](https://www.renewable-ei.org/pdfdownload/activities/11_BenBackwell.pdf); US DOE, "Land-Based Wind Market Report...", op. cit. this note, p. 43; US DOE, "Wind turbines: the bigger, the better", August 16, 2022, <https://www.energy.gov/eere/articles/wind-turbines-bigger-better>.
- 126 Preliminary data from GWEC, "Global Wind Market Development: Supply Side Data 2022", p. 25, unpublished document, provided by Zhao, op. cit. note 6.
- 127 Ibid. The regions with the largest average turbine sizes were Latin America (4,482 MW), followed by Asia Pacific (4,343 MW), with both regions passing Europe (4,313 MW); the region with the lowest average was North America (3,140 MW), from idem, p. 26.
- 128 Zaremba, op. cit. note 12.
- 129 A. Frangoul, "Vestas launches 'world's tallest onshore tower for wind turbines'", CNBC, September 29, 2022, <https://www.cnbc.com/2022/09/29/vestas-launches-worlds-tallest-onshore-tower-for-wind-turbines.html>; M. Lewis, "GE is developing a massive 18 MW offshore wind turbine", Electrek, March 13, 2023, <https://electrek.co/2023/03/13/ge-is-developing-a-massive-18-mw-offshore-wind-turbine>.
- 130 Pressures to innovate from GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, p. 54. See also Snieckus, op. cit. note 123.
- 131 Onshore, MingYang's 8.5 MW turbine, from A. Lee, "China raises wind power stakes again as 'world's biggest onshore turbine' busts 8MW", REcharge News, January 4, 2023, <https://www.rechargenews.com/wind/china-raises-wind-power-stakes-again-as-worlds-biggest-onshore-turbine-busts-8mw/2-1-1383010>; it was quickly surpassed by Envision Energy (10 MW), from J.S. Hill, "World's largest onshore wind turbine, and the first to reach 10MW, debuts in China", RenewEconomy, February 14, 2023, <https://reneweconomy.com.au/worlds-largest-onshore-wind-turbine-and-the-first-to-reach-10mw-debuts-in-china/>; two weeks later, SANY's 11 MW prototype was rolled out, from GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, p. 54. Offshore, China's Three Gorges Corporation and Xinjiang Goldwind produced the world's first 16-MW turbine in late 2022, from Xinhua, "World's largest offshore wind turbine off assembly line in China", November 23, 2022, <https://english.news.cn/20221123/89eea57690ea4d4083ee365e0d1af2cf/c.html>; Goldwind announced the production of a 13.6 MW turbine with a record 252-metre rotor diameter, from M. Lewis, "China debuts an offshore wind turbine with the world's largest rotor diameter", Electrek, October 17, 2022, <https://electrek.co/2022/10/17/offshore-wind-turbine-worlds-largest-rotor-diameter/>; also in late 2022, China State Shipbuilding Corp (CSSC) Haizhuang began marketing a turbine with an 18 GW rating, from Snieckus, op. cit. note 123; Windpower Monthly, "The world's largest and most powerful offshore wind turbine unveiled – and more", March 7, 2023, <https://www.windpowermonthly.com/article/1815513/worlds-largest-powerful-offshore-wind-turbine-unveiled->; and MingYang unveiled an 18 MW turbine in early 2023, from Bloomberg, "China Clean Energy Giants Unveil World's Largest Wind Turbines", January 10, 2023, <https://www.bloomberg.com/news/articles/2023-01-11/china-clean-energy-giants-unveil-world-s-largest-wind-turbines>. See also D. Proctor, "New 18-MW Model Takes Over as World's Largest Offshore Wind Turbine", Power Magazine, January 6, 2023, <https://www.powermag.com/new-18-mw-model-takes-over-as-worlds-largest-offshore-wind-turbine>.
- 132 Little opportunity to learn from H. Richards, "Offshore wind turbines are growing larger. How big is too big?" EE News, March 2, 2023, <https://www.eenews.net/articles/offshore-wind-turbines-are-growing-larger-how-big-is-too-big/>; R. Beene and J. Saul, "Wind Turbines Taller Than the Statue of Liberty Are Falling Over", Bloomberg, January 23, 2023, <https://www.bloomberg.com/news/articles/2023-01-23/wind-turbine-collapses-punctuate-green-power-growing-pains>; R. Morison, "Wind turbines are big enough for now, Vestas CEO says", Bloomberg, January 16, 2023, <https://www.bloomberg.com/news/articles/2023-01-16/wind-turbines-are-big-enough-for-now-vestas-ceo-says>. Permitting challenges from A. Lee, "China raises wind power stakes again as 'world's biggest onshore turbine' busts 8MW", REcharge News, January 4, 2023, <https://www.rechargenews.com/wind/china-raises-wind-power-stakes-again-as-worlds-biggest-onshore-turbine-busts-8mw/2-1-1383010>. See also Hill, op. cit. note 131. For the offshore sector, the trend could discourage investment in new installation vessels that might be too small once completed, from Richards, op. cit. this note.
- 133 Morison, op. cit. note 132; Mathis, Beene and Saul, op. cit. note 10; Beene and Saul, op. cit. note 132. Chinese manufacturers also are focusing on reducing manufacturing costs and expecting smaller profits due to grid parity conditions, from Lepic, op. cit. note 101.
- 134 L.M. Lombrana and T. Gualtieri, "Making Wind Turbines Greener Could Also Make Them More Expensive", Bloomberg, November 2, 2021, <https://www.bloomberg.com/news/articles/2021-02-11/making-wind-turbines-greener-could-also-make-them-more-expensive>; Dyrholm in GWEC, "Global Wind Report 2023", March 27, 2023, op. cit. note 1, p. 2. See also Global Alliance for Sustainable Energy, <https://sustainable-energy.eco>, accessed April 12, 2023, and Global Alliance for Sustainable Energy, "Reducing Raw Materials' Environmental and Social Impacts in Electrical Energy Technologies", Circular Design Criteria Working Group Position Paper, undated, <https://energycentral.com/c/enefoundation/global-alliance-sustainable-energy-%E2%80%93-position-paper-release>.
- 135 See, for example, the following: GE, "Environmental, social and governance: Sustainability at core", <https://www.ge.com/sustainability>, accessed April 12, 2023; Vestas, "Our sustainability strategy: Sustainability in everything we do", <https://www.vestas.com/en/sustainability/sustainability-strategy>, accessed April 12, 2023; Siemens Gamesa, "Siemens Gamesa puts decarbonization, recyclability and technological education at heart of ambitious new sustainability strategy", July 21, 2021, <https://www.siemensgamesa.com/newsroom/2021/07/210721-siemens-gamesa-press-release-launches-new-sustainability-strategy>; Nordex Acciona Windpower, "Sustainability report published", April 6, 2023, <https://www.nordex-online.com/en/2023/04/sustainability-report-2022-published>;

- reve, "Goldwind releases its 2021 sustainability report", May 10, 2022, <https://www.evwind.es/2022/05/10/goldwind-releases-its-2021-sustainability-report/86034>.
- 136 American Chemical Society, "Wind turbine blades could someday be recycled into sweet treats", Science Daily, August 23, 2022, <https://www.sciencedaily.com/releases/2022/08/220823095518.htm>.
- 137 For examples of recycling from traditional materials, see the following: M. Gallucci, "Vestas has a new way to keep wind turbine blades out of the dump", Canary Media, February 16, 2023, <https://www.canarymedia.com/articles/wind/vestas-has-a-new-way-to-keep-wind-turbine-blades-out-of-the-dump>; M. Lewis, "This company turns wind turbine blades into concrete", Electrek, January 12, 2023, <https://electrek.co/2023/01/12/this-company-turns-wind-turbine-blades-into-concrete>; Goldwind, "Goldwind recycles turbine blades into 3D printing materials", July 28, 2022, <https://www.goldwind.com/en/news/focus-article/?id=737300515733524480>; A. Lee, "'Golden ratio' | China's Goldwind claims breakthrough using old turbine blades for 3D printing", REcharge, July 28, 2022, <https://www.rechargenews.com/wind/golden-ratio-chinas-goldwind-claims-breakthrough-using-old-turbine-blades-for-3d-printing/2-1-1267998>; A. Frangoul, "GE, Orsted and now Iberdrola: The competition to recycle wind turbine blades heats up", CNBC, June 6, 2022, <https://www.cnbc.com/2022/06/06/iberdrola-sets-up-firm-focused-on-recycling-wind-turbine-blades.html>; Richard and Griggs, op. cit. note 123. For examples of new materials, see also: idem; N. Weekes, "LM Wind Power launches fully recyclable thermoplastic wind turbine blade", Windpower Monthly, March 17, 2022, <https://www.windpowermonthly.com/article/1749931/lm-wind-power-launches-fully-recyclable-thermoplastic-wind-turbine-blade>; A. Paleja, "The world's first turbine with recyclable blades is now operational", Interesting Engineering, August 3, 2022, <https://interestingengineering.com/innovation/the-worlds-first-turbine-with-recyclable-blades-is-now-operational>; Griggs, op. cit. note 123.

# RENEWABLES 2023

## GLOBAL STATUS REPORT



### RENEWABLES IN ENERGY SUPPLY

ISBN 978-3-948393-08-3

**REN21 Secretariat**  
c/o UN Environment Programme  
1 rue Miollis  
Building VII  
75015 Paris  
France

[www.ren21.net](http://www.ren21.net)

2023  
COLLECTION