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RENEWABLES NOW

RENEWABLES 2023
GLOBAL STATUS REPORT

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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

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MARKET TRENDS

REPORT CITATION

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Comments and questions are welcome and can be sent to **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

GLOBAL STATUS REPORT 2023 COLLECTION
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For further details and access to the report, references and endnotes, visit **www.ren21.net/gsr-2023/**

REN21 RENEWABLES NOW

RENEWABLE ENERGY POLICY NETWORK FOR THE 21st CENTURY

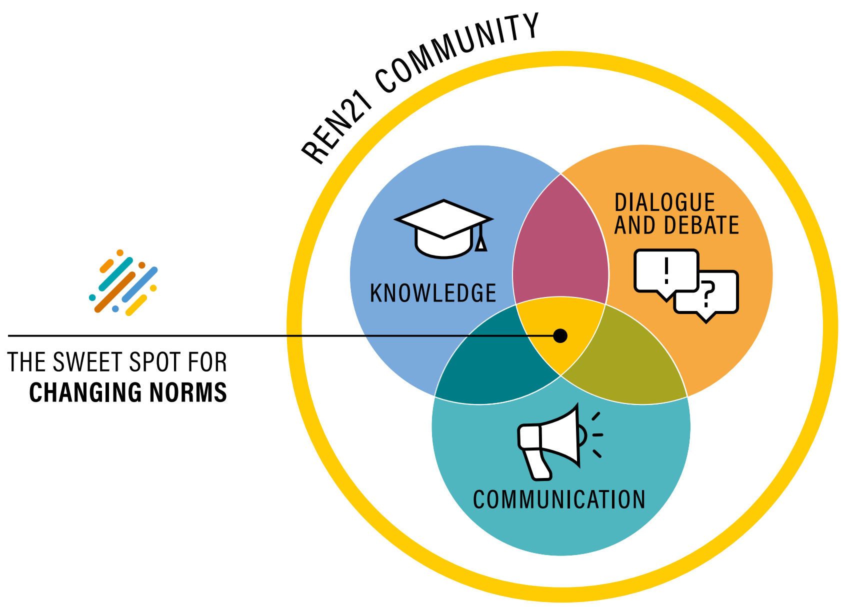
REN21 is the only global community of actors from science, governments, NGOs and industry **working collectively** to drive the rapid uptake of renewables – now!

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:

UN environment programme

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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.

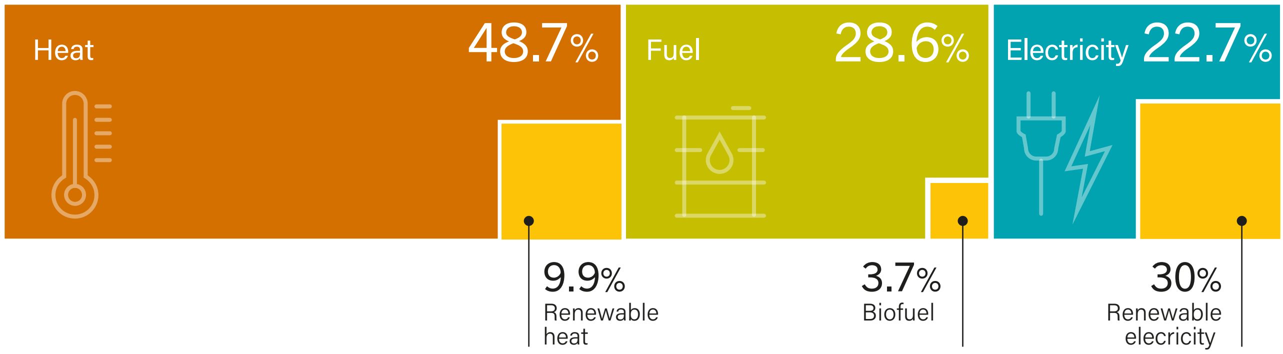
PEER REVIEWERS AND OTHER CONTRIBUTORS

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 Kilkis (OSTIM Technical University); Siir Kilkis (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 (Berooz 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 Myrsalieva (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 Tsipouridis (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 Genration); 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); Noureddine 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

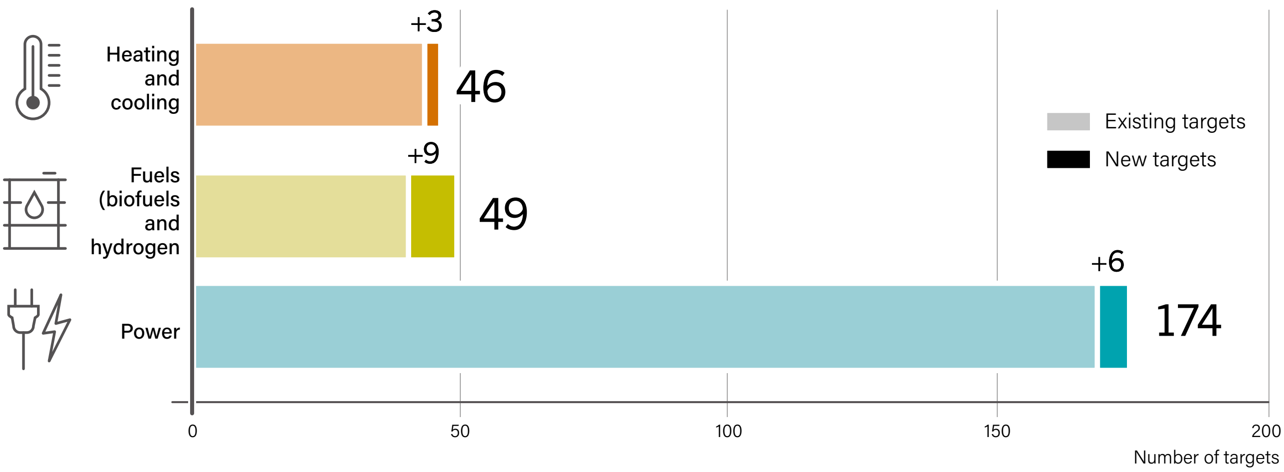
Only 3 countries announced new or revised renewable heating targets in 2022, for a total of 46 countries

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.[1] The world's energy challenges were exacerbated in February 2022 following the Russian Federation's invasion of Ukraine.[2] 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.[3]

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.[4] 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.[5]

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.

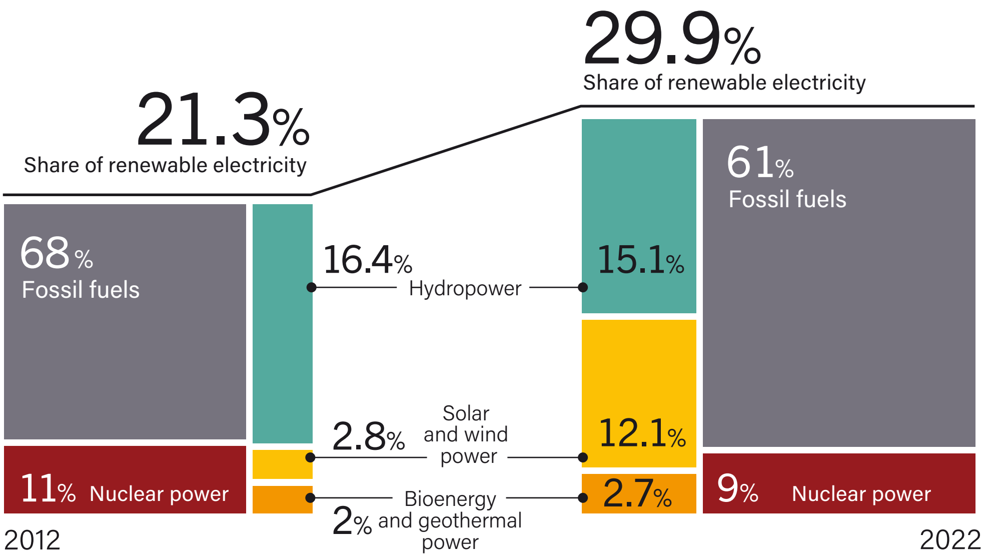
RENEWABLE ELECTRICITY IS DRIVING THE SHIFT IN ENERGY SUPPLY

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[i], which accounted for 48.7% of the total in 2020[6] (→ *see Figure 1.*), followed by fuel – including liquid and gaseous fuels used for transport – which represented 29% of the total.[7] 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.[8] 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.[9] (→ *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.

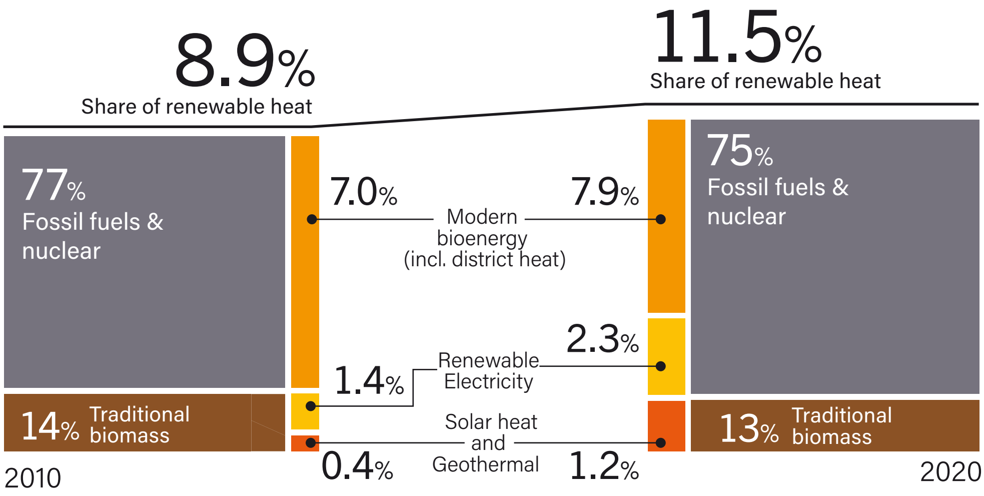
Source: See endnote 6 for this section.

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.[10] (→ *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).[11]

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.[12] In absolute terms, biofuel production increased 60% during the decade.[13] 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.[14] However, more than 95% of current hydrogen production is still based on fossil fuels.[15]

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.[16]

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.[17] Europe followed with 11%, and the United States with 10%.[18] 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.[19]

For **renewable heat**, Europe leads in the modern bioheat market, with a 24% share in 2020, followed by the United States with 13%.[20] China accounted for 73% of the solar water heating market, followed by Türkiye, the United States, Germany and Brazil.[21] 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%).[22] 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 additios of geothermal power were one-third lower than in 2021, with only 0.2 GW added in 2022.[23]

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%.[24] Renewable fuel production has lagged in Asia and the Pacific (11%) and Africa (less than 1%).[25] Australia is an emerging leader in renewable based hydrogen and is set to have the largest number of renewable hydrogen plants worldwide.[26]

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.[27] **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*).[28] Hydropower dominates the region's electricity supply, contributing 45% of total production and 73% of renewable production.[29] In 2022, renewable electricity generation in Latin America and the Carribean grew by 12%.[30]

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.[31] 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.[32]

In **Europe**, the share of renewables regional total electricity generation increased from 25% in 2012 to 36% in 2022.[33] 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).[34] 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%.[35]

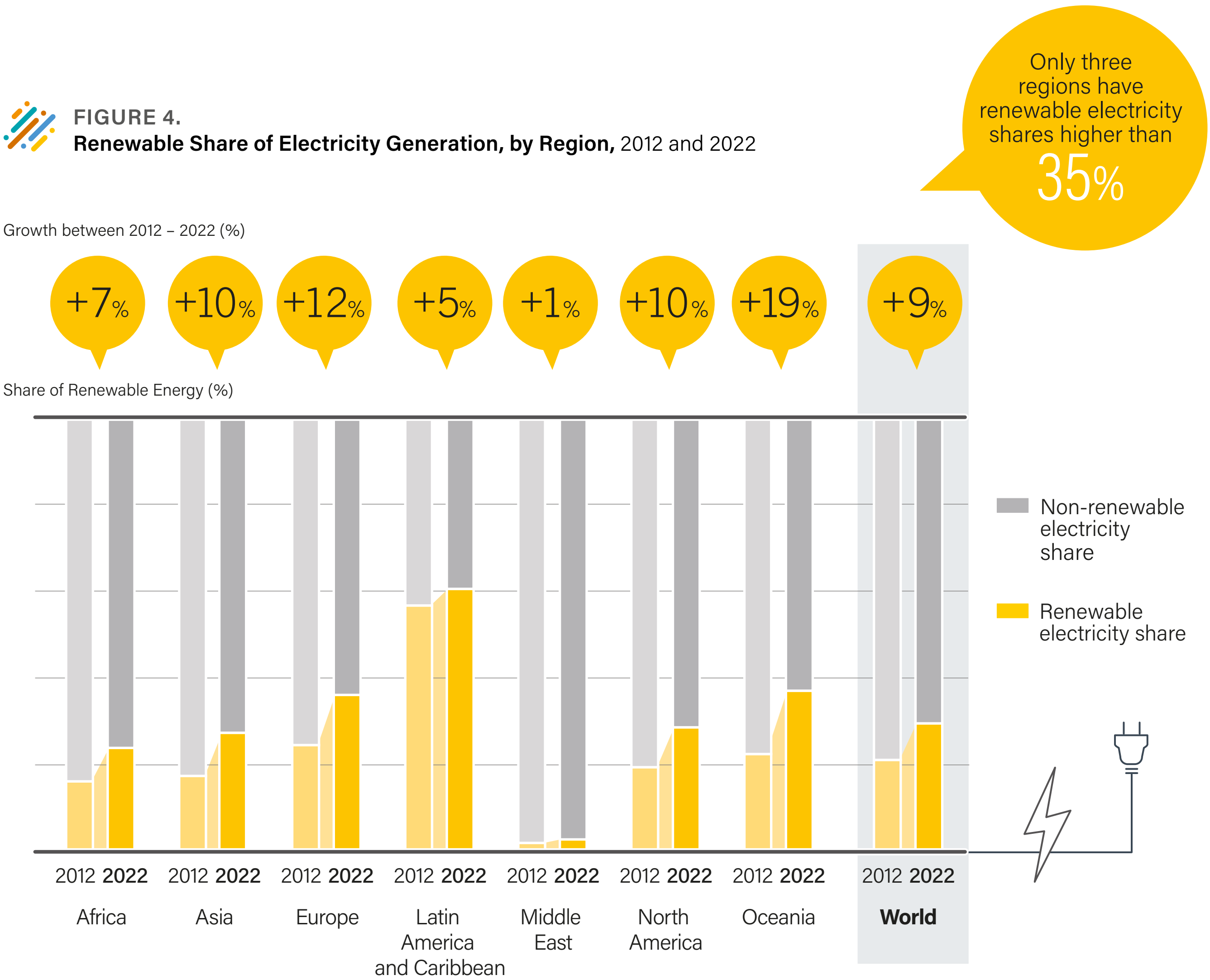
In **North America**, the share of renewables in the electricity mix rose from 19% in 2012 to 29% in 2022.[36] During the decade, wind power's share of generation increased from 3.3% to 9.6%, and solar power's share rose from 0.11% to 4.3%.[37] In 2022, renewable electricity generation in the region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

The share of renewables in **Asia**'s electricity mix increased 10% during 2012-2022, rising from 17% to 27%.[39] 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.[40] In 2022 alone, renewable electricity generation in the region grew 11%.[41]

In **Africa**, the renewable electricity share increased 7%, from 17% in 2012 to 24% in 2022.[42] 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).[43] In 2022, renewable electricity in Africa grew 11% compared to 5% increase in 2021.[44]

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).[45]

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 TECHNOLIGES

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).[46] (→ *See Figure 5.*)

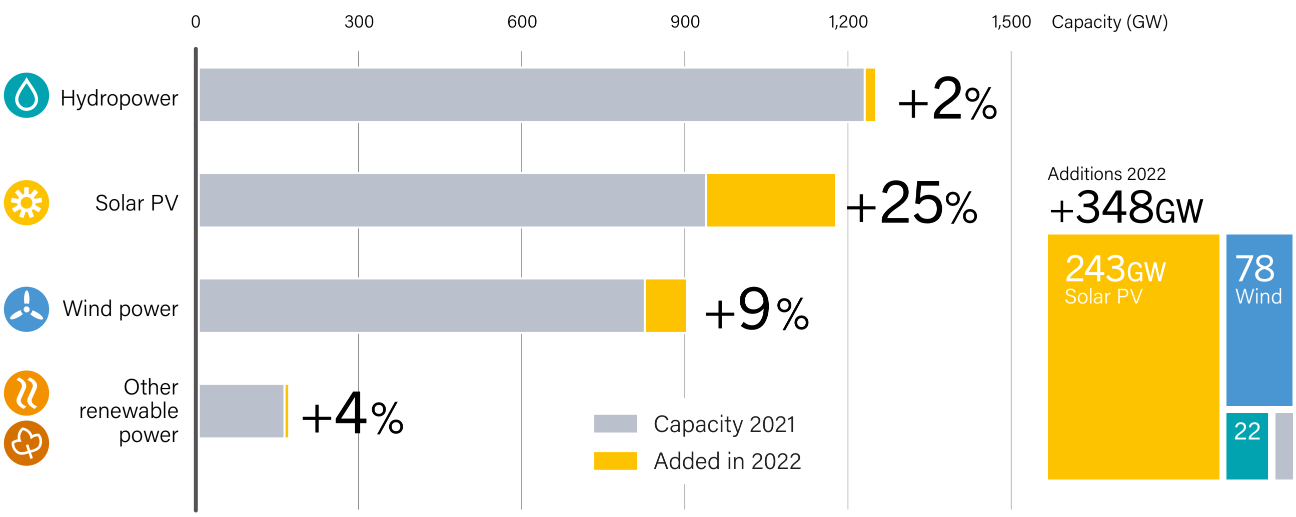
In total, 348 GW of renewable power capacity was added in 2022 (up 13% from the 306 GW added in 2021); however, this annual capacity addition would need to be accelerated by as much as 2.5 times to achieve the capacity growth required to achieve the

Solar PV and Wind accounted for

92%

of renewable power additions.

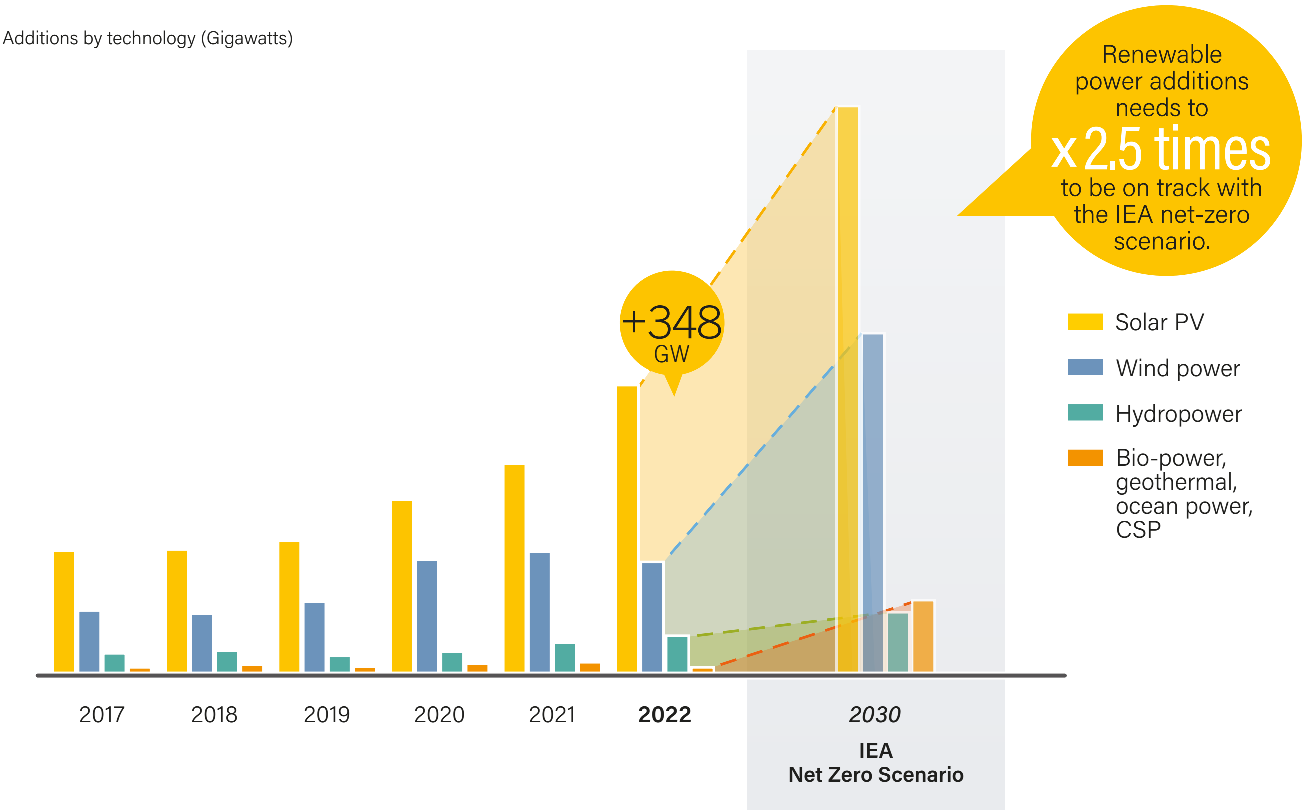
FIGURE 5.
Renewable Power Total Installed Capacity and Annual Additions, by Technology, 2022



Source: See endnote 47 for this section.

International Energy Agency's (IEA) scenario for net zero emissions by 2030.[47] (→ *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.[48] 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).[49] 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.[50] 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.[51]

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



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
POWER					
Total renewable capacity	China	United States	Brazil	India	Germany
Total renewable capacity (no hydro)	China	United States	Germany	India	Japan
Total renewable capacity per capita (no hydro)	Iceland	Denmark	Finland **(+16)** ▲	Belgium **(+8)** ▲	Greece **(+10)** ▲
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 **(+1)** ▲	India **(-1)** ▼
CSP	Spain	United States	China	Morocco	South Africa
Wind	China	United States	Germany	India	Spain
HEAT					
Solar water heating collector capacity	China	Türkiye **(+1)** ▲	United States **(-1)** ▼	Germany	Brazil
Geothermal heat output	China	Türkiye	Iceland	Japan	New Zealand

Net Capacity Additions in 2022

	1	2	3	4	5
TOTAL ADDITIONS PER TECHNOLOGY					
Biopower capacity	China	Japan **(+3)** ▲	Brazil	Indonesia **(+12)** ▲	Türkiye **(-1)** ▼
Geothermal capacity	Kenya **(New)**	Indonesia	United States **(-2)** ▼	Turkiye **(-1)** ▼	Chile **(New)**
Hydropower capacity	China	Lao PDR **(+3)** ▲	Canada **(-1)** ▼	France **(New)**	Ethiopia **(New)**
Solar PV capacity	China	United States	India	Brazil **(+1)** ▲	Netherlands **(+8)** ▲
Concentrated Solar Thermal Power (CSP) capacity	China **(New)**	United Arab Emirates **(New)**	–	–	–
Wind capacity	China	United States	Brazil	United Kingdom **(+1)** ▲	Germany **(+2)** ▲
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%).[52] Wind energy manufacturing capacity grew by a more modest 2%.[53] 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.[54]

The manufacturing of solar PV panels remained geographically concentrated in China, which dominated with more than 80% shares across all production stages in 2022.[55] The next largest countries with respect to manufacturing capacity are Vietnam and India, accounting for 5% and 3%, respectively, of the global capacity.[56] In 2022, 90% of the growth occured 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.[57]

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

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.[60] 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.[61]

In 2022, global manufacturing of renewable energy and enabling technologies grew by nearly

40%.

POLICY

OVERALL CONTEXT

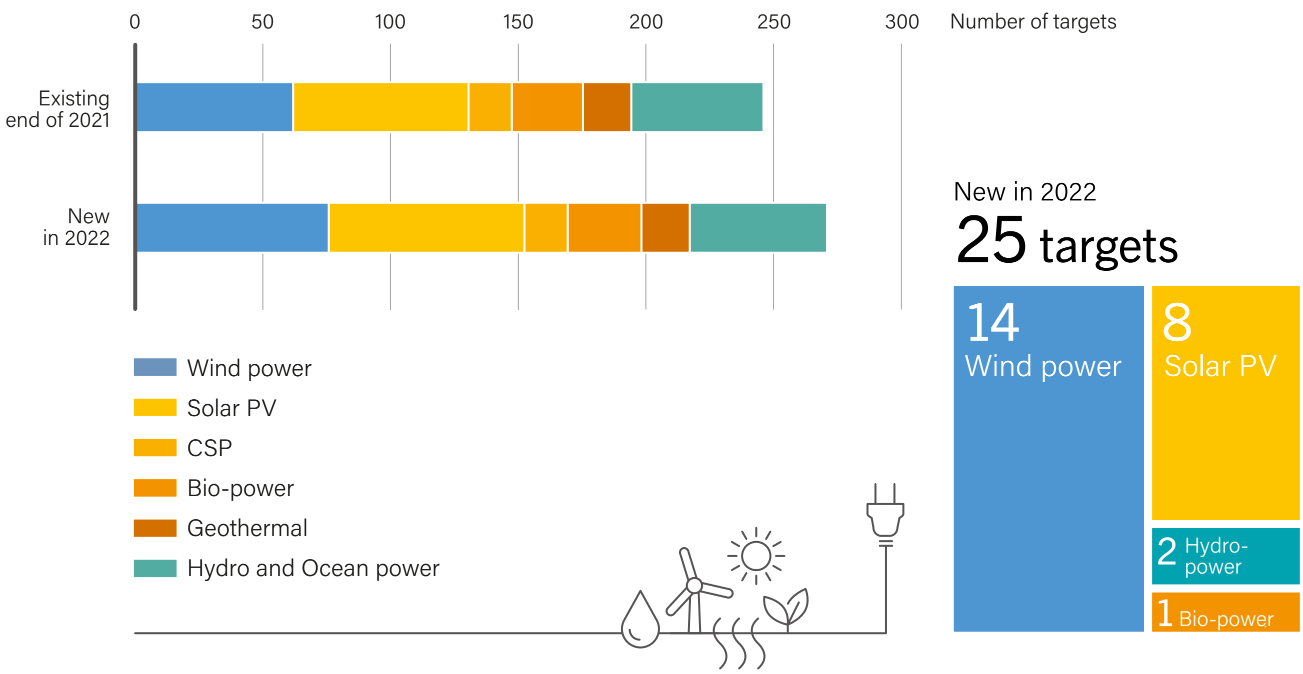
As policy makers around the world grapple with energy security concerns, they have prioritised measures that can ensure a steady and reliable energy supply while speeding decarbonisation of the sector.[1] This has led to the uptake of well-defined and specific policy measures.[2] Major announcements 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.[3] In response to the ongoing energy crisis, governments also increased their spending on the energy transition.[4] 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.[5] 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.[6] (→ *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.[7]

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.[8] 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.[9] In total, more than 250 technology-specific power capacity targets were in place in 126 national and sub-national jurisdictions by year's end.[10]

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.

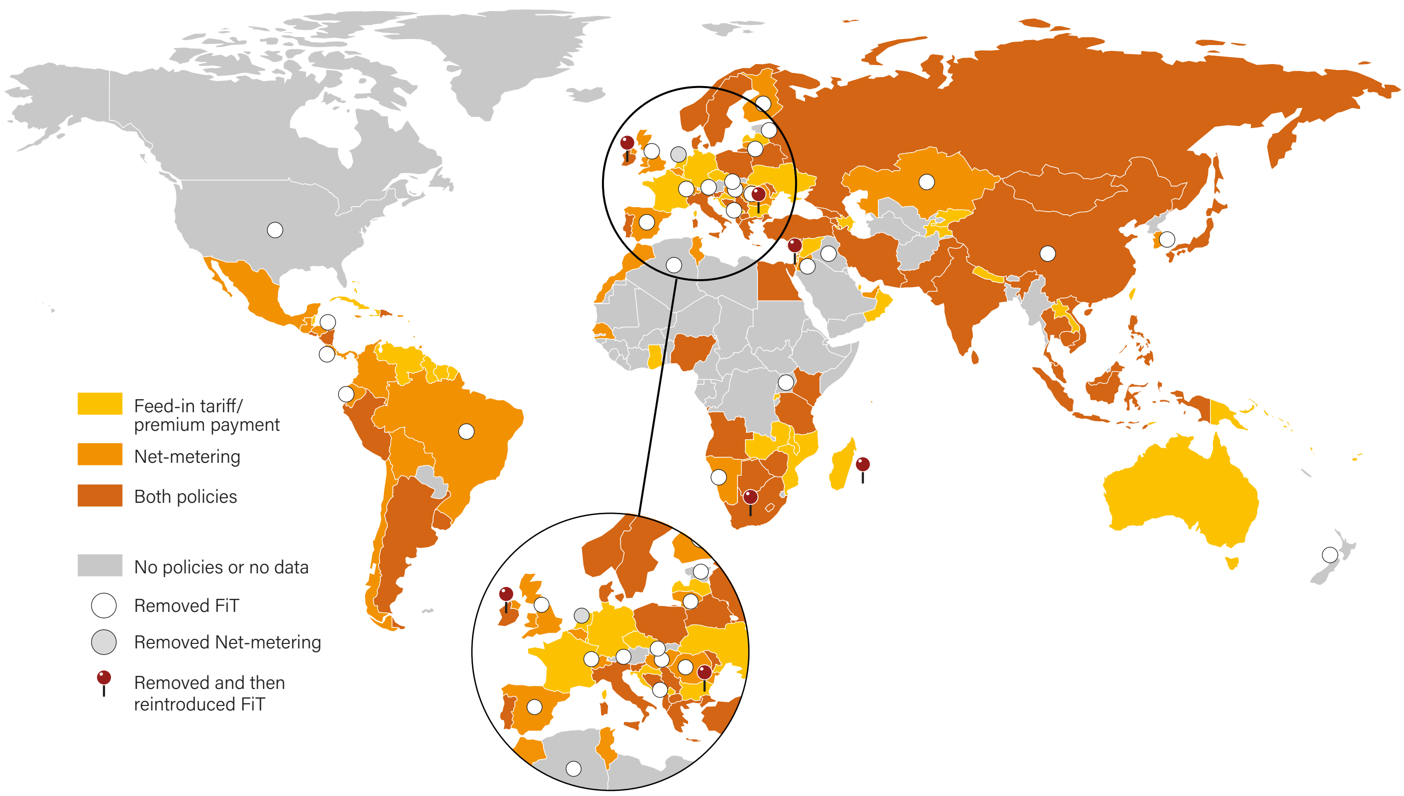
The number of countries with support **policies** for renewables in the power sector remained at 156 in 2022, the same as in 2021.[11] Although some countries adopted new policies, others removed policies (mainly feed-in tariff policies).[12] Most countries use a mix of policy instruments to support 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.[13]

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.[14] (→ *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.[15] By the end of 2022, 83 countries had in place feed-in tariff or premium payment policies.[16] 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.[17]

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.[18] 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.[19] Mauritius included in its 2022-2023 budget provisions for a FIT for medium-scale systems.[20] South Africa announced the reintroduction of FITs for solar PV to tackle load shedding.[21] Thailand introduced a 25-year FIT for solar PV and solar-plus-storage, and Japan adopted provisional FITs for fiscal year 2023.[22]

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.[23] The Netherlands removed its net metering policy in 2022 after the parliament voted to end the measure.[24] By year's end, a total of 92 countries had net metering policies in place.[25]

Cyprus announced that it would expand funding for solar net metering by EUR 40 million (USD 43 million).[26] 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.[27] Egypt released updated net metering rules in Decree No. 6 of 2022, with increases to the maximum net metering capacity allowed.[28] 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.[29]

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.[30] Poland is shifting from net metering to net billing[i].[31] 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.[32] 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.[33]

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.[34] 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.[35] The Philippines announced a Green Energy Auction Programme for 2023 of a combined 2 GW for hydropower, solar, biomass and wind power capacity.[36]

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.[37] South Africa concluded its sixth auction round by awarding 860 MW of solar power capacity.[38] 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.[39]

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.[40] Across much of Europe, the United States and several other countries, permitting processes continue to be challenging and in lead to undersubscribed auctions.[41] To attract interest, Germany raised the price cap for wind and solar PV tenders.[42]

Financial and fiscal policies – such as tax exemptions, rebates, grants and loans – are popular instruments to incentivise the uptake of renewables.[43]

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.[44] 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.[45] The credits are guaranteed for 10 years, helping to provide confidence to the market.[46]

Other countries announced financial and fiscal incentives. Through RePowerEU, the EU plans to ease access to tax credits for green investment.[47] Canada announced tax credits totalling USD 83 billion for clean electricity, clean technology manufacturing chains and clean hydrogen.[48] 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.[49] Bulgaria is allocating EUR 102 million (USD 112 million) for green energy and storage projects in the tourism sector.[50] 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.[51]

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.[52] At the sub-national level, 36 US states and the District of Columbia had RPS as of November 2022 to support renewable energy generation.[53] 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.[54]

Mandates for **rooftop solar PV** require certain buildings or properties to install solar panels on their roofs.[55] 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).[56] 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^2) of surface by 2026, on all existing public and commercial buildings by 2027 and on all residential buildings by 2029.[57]

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.[58] 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^2 in area.[59] In Germany, 9 out of the 16 federal states have rooftop solar PV mandates, all of which took effect in January 2022.[60] 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.[61]

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.[62] Among advancements during the year, California enacted legislation authorising regulators to define a new community programme for the state.[63] The US National Community Solar Partnership issued a roadmap for reaching 5 million community solar households by 2025.[64] 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.[65]

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

Vietnam's Draft Power Development VIII includes targets for 16 GW of onshore and nearshore wind and 7 GW of offshore wind.[69] 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.[70]

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.[71] Ireland introduced a requirement that offshore wind power projects be built in (yet unidentified) Designated Marine Areas, effectively putting offshore development on hold.[72]

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[i] with such strategies to 45.[73] (→ *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.[74]

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

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

The US Inflation Reduction Act includes a tax credit for renewable hydrogen of USD 3 per kilogram.[81] 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.[82]

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.[83] The revised text focuses on accelerating permitting for renewable energy projects and ensuring the availability of a skilled workforce.[84]

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.[85] 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.[86] 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.[87]

Policies around **district heating** gained momentum in 2022, especially in the face of high energy prices during the year.[88] 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.[89] Denmark approved a new law that allows district heating companies to negotiate pricing with geothermal operators to put a cap on consumer costs.[90] 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.[91]

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.[92] 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.[93]

The RePowerEU policy targets the installation of 20 million heat pumps by 2026 and nearly 60 million by 2030.[94] The EU also announced an action plan to boost regional heat pump manufacturing and deployment.[95] In France, grant support for installing ground-source heat pumps was raised to EUR 5,000 (USD 5,500) per unit in early 2023.[96] Germany launched rebates of up to 40% for homeowners to install heat pumps.[97] 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.[98]

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.[99] 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.[100] Such policies have resulted in rising heat pump sales and provided clear signals to the expanding heat pump industry.[101]

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[i].[1] Investment increased 17.2% from 2021, due largely to the global rise in solar photovoltaic (PV) installations.[2] These estimates do not include investment in renewable heating and cooling technologies, for which data are not collected systematically. Global investment in heat pumps[ii] reached USD 63.4 billion, up 9.6% from 2021.[3] (→ *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.[4]

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.[5] 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.[6] (→ *See Policy section.*)

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

USD **495** billion

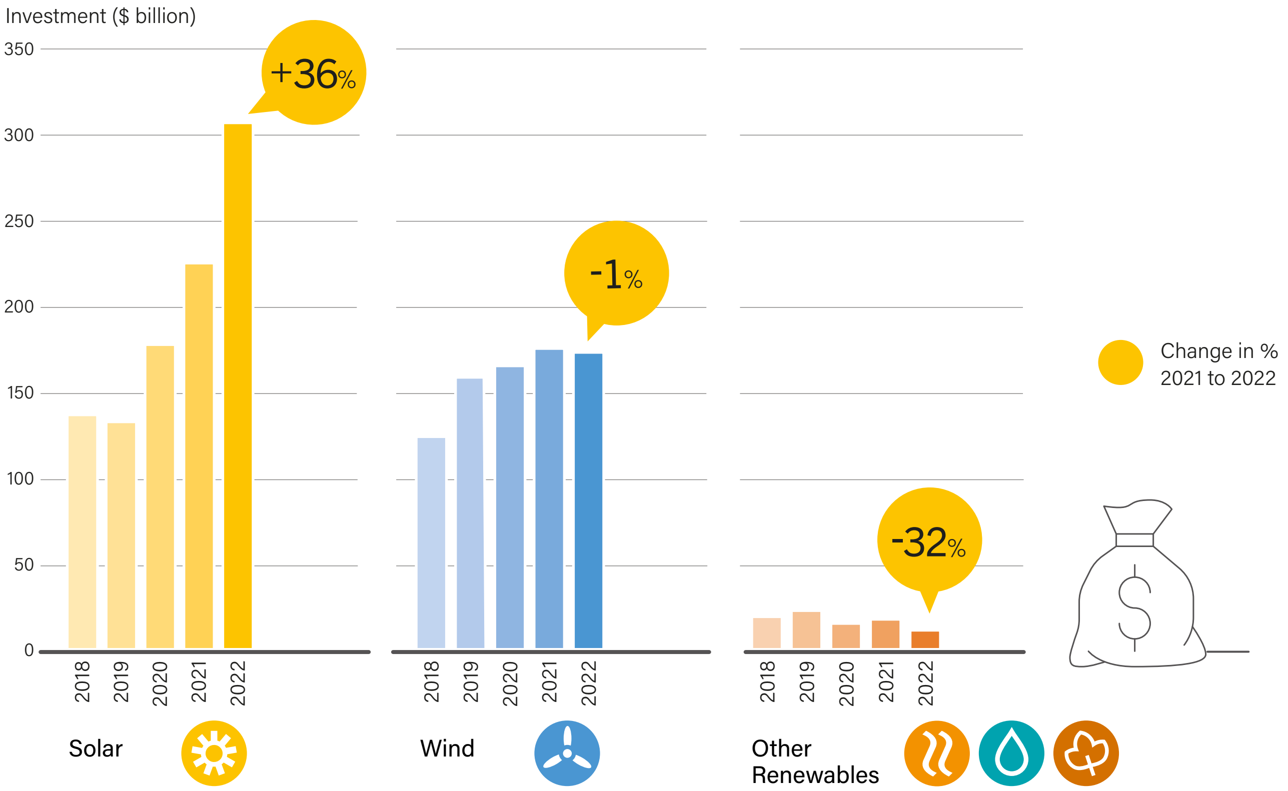
in 2022.

Inflation (of around 8%) played a role in the investment growth in renewables in 2022, contributing to higher costs for components, construction and financing.[7] However, inflation represented only a fraction of the overall investment increase, meaning that investment expanded well beyond the effects of inflation.[8] 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.[9] Without these cost reductions, much more investment would be needed to bring the same level of capacity online.[10]

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%.[11] (→ *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.[12] 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.[13]

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.[14] 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.[15]

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.[16] 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.[17]

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.[18] (→ *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%).[19] All other world regions accounted for 4% or less of the total.[20]

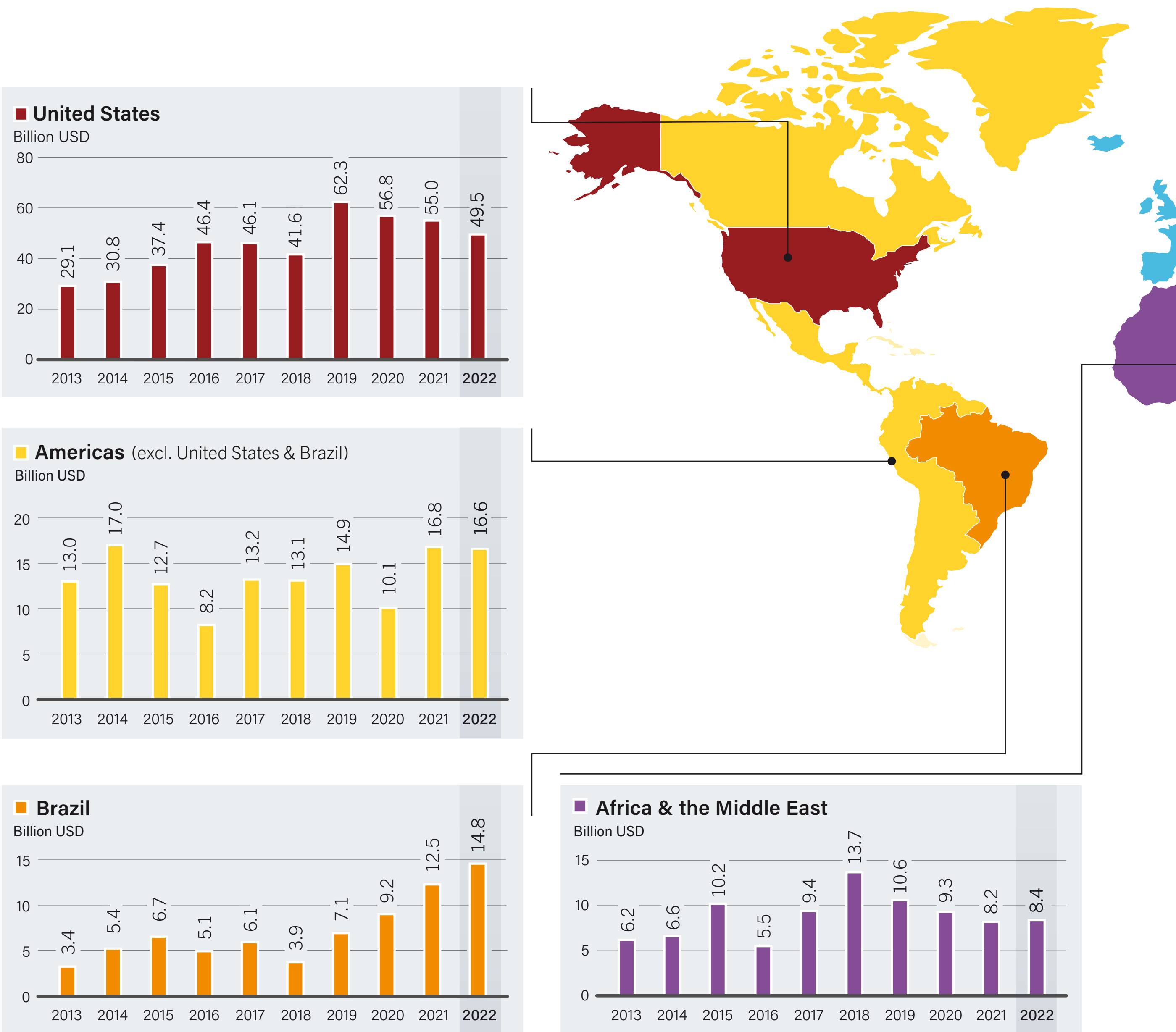
China's overall investment in renewables increased sharply in 2022, rising 56.2% to reach USD 274.4 billion.[21] This was due largely to continued growth in the country's solar PV capacity, which grew 78.9% to USD 164.5 billion.[22] Wind power investment also increased in China, rising 33.2% to reach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

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.[25] 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.[26] 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.[27]

In **Europe**, investment in renewable energy projects fell 26% to USD 55.9 billion in 2022.[28] 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.[29] 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.[30] Bulgaria, Estonia and Romania also showed notable growth, although starting from a much smaller base.[31]

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



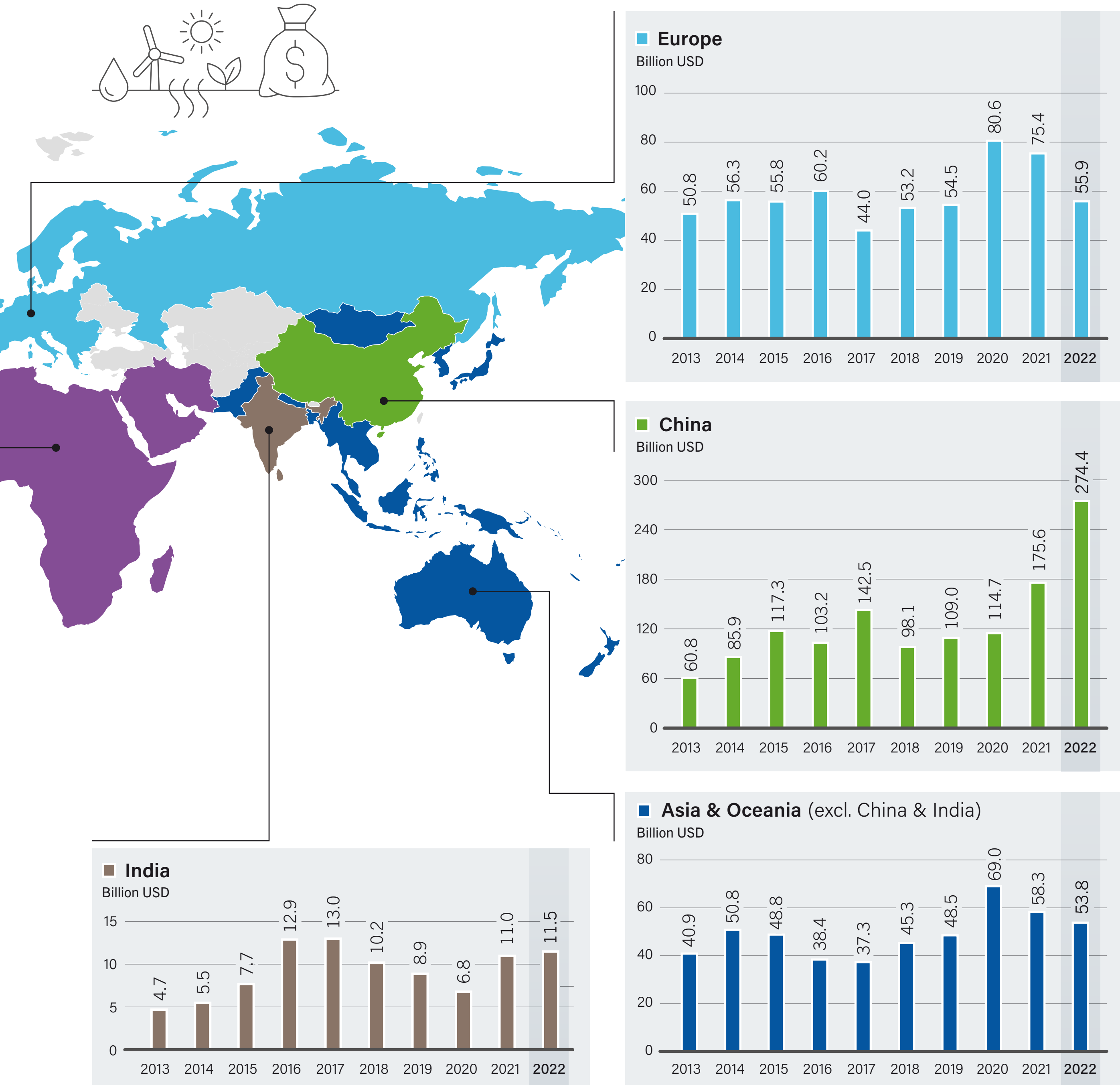
Note: Figure does not include investment in hydropower projects larger than 50 MW.
Reference: Bloomberg NEF, Energy Transition Investment Trends 2023
Source: See endnote 70 for this chapter.

down 32.8% to USD 8.8 billion, and in the United Kingdom it plummeted 81.4% to USD 2.2 billion.[32] 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.[33] In the regional ranking, Spain again took the lead in renewable energy investment, followed by Germany and Poland.[34]

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.[35] 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).[36] 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.[37] 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.[38]

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.[39] Investment in biofuels increased markedly during the year, up 239.6% to USD 0.18 billion.[40] 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.[41]

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.[42] 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).[43] 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.[44]

In **India**, total new investment in renewables increased 4.4% to USD 11.5 billion in 2022.[45] Investment in solar PV rose 19% to USD 8.6 billion.[46] Biofuel investment grew marginally, and investment in all other renewable technologies, including wind power, fell during the year.[47] 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.[48]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.[49]

Brazil's total investment in renewables was up 18.3% to USD 14.8 billion.[50] 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.[51] 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.[52]

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.[53] This demonstrates the rise in unregulated electricity market shares coupled with growing corporate demand for clean energy.[54]

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.[55]

Outside Brazil and the United States, renewable energy investment in the **Americas** totalled USD 16.6 billion, down slightly from 2021.[56] 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.[57] Biofuel investment dropped 100% to only USD 1.1 billion.[58] Investment in renewables was impacted by inflation, the discontinuation of COVID-19 stimulus packages, weak local currencies and slow economic growth.[59]

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.[60] 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.[61] To enable greater grid integration of variable renewables, both countries have taken steps to support utility-scale battery capacity[i], which is only beginning to be deployed in the region at scale.[62]

Investment in renewables in the **Middle East and Africa** was up 3.0% to reach USD 8.4 billion in 2022.[63] 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).[64] 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.[65] Partners in this Just Energy Transition Investment Plan for the country include France, Germany, the United Kingdom, the United States and the EU.[66]

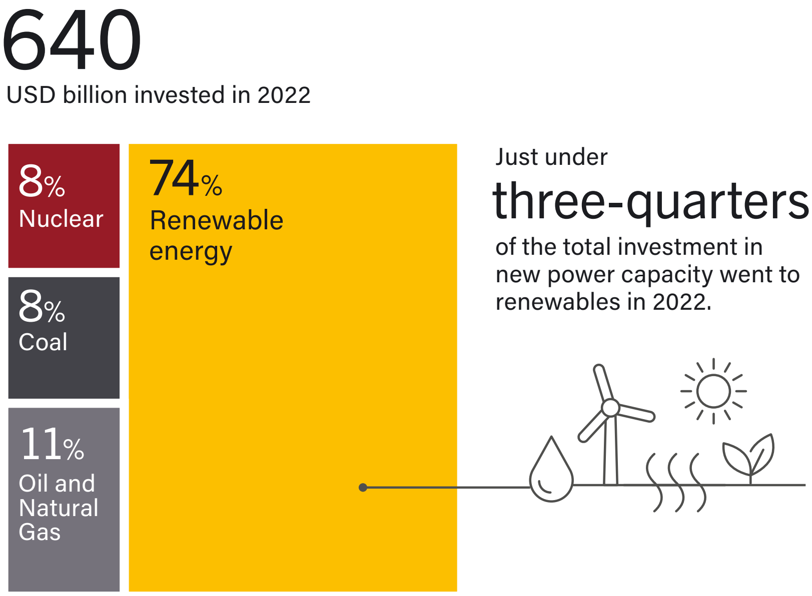
Many developing and emerging economies face unique challenges in financing renewable energy projects, compared to the developed world. Investment in these countries may be complicated by political instability, macroeconomic uncertainty (related to inflation and exchange rates), policy and regulatory 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.[67] (→ *See Sidebar 1*) Country related risks and underdeveloped local financial systems also can directly affect the cost of capital.[68] 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.[69]

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.[70] Investment in new renewable power capacity accounted for 74% of the total investment committed to new power generating capacity (including fossil fuels and nuclear).[71] (→ *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



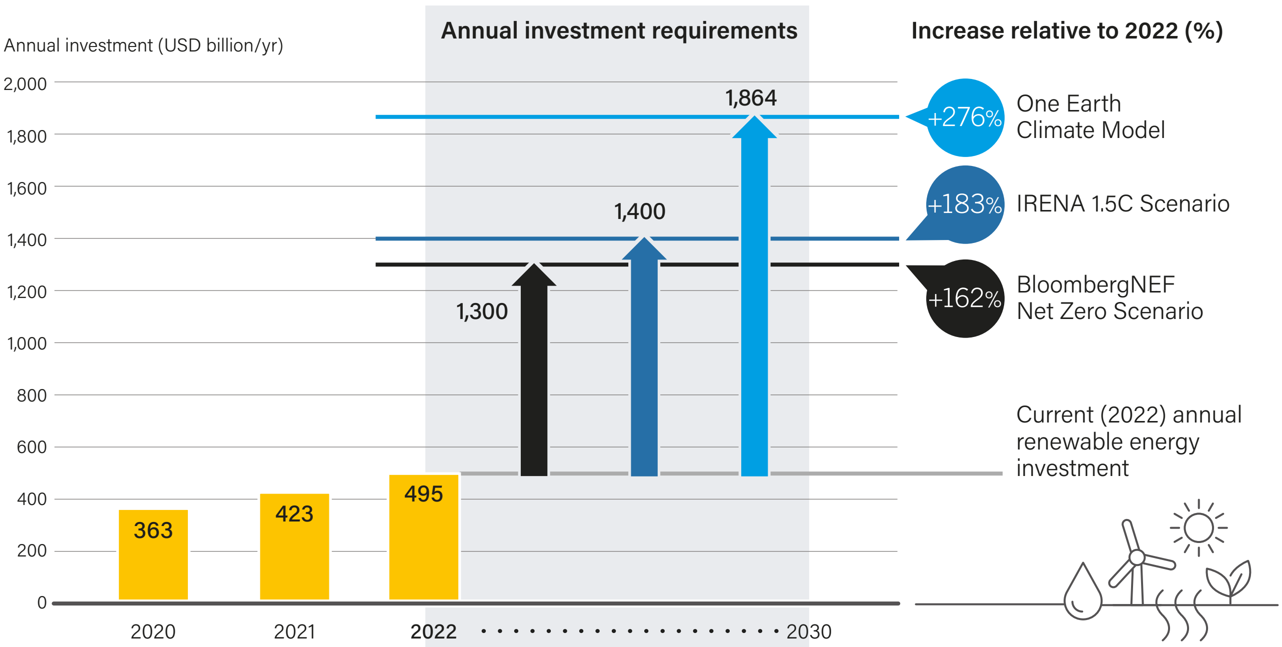
Source: See endnote 70 for this section.

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.[72] 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.[73] 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.[74] (→ *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.

i 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.

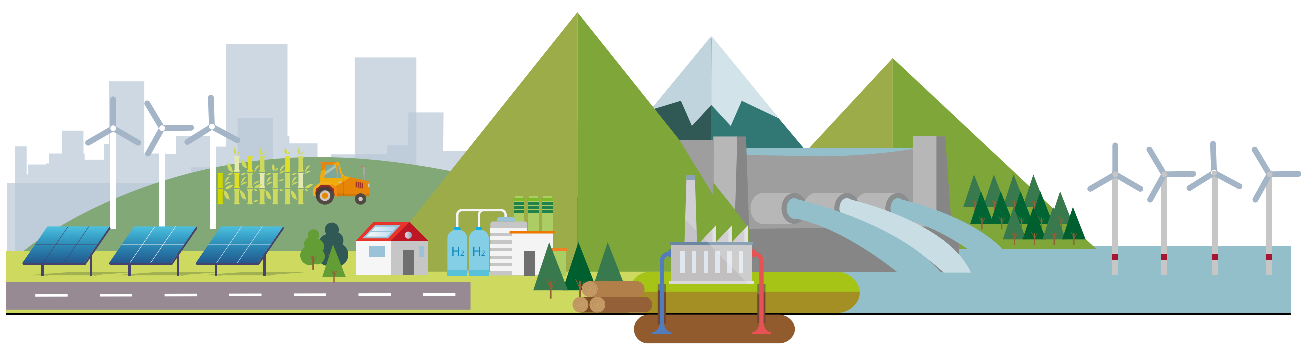
Almost **10%** of the total installed renewable power capacity was **added in 2022.**

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.

H_2

As of end-of 2022, announced **hydrogen projects** would lead to an installed electrolyser capacity of 134-240 GW 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.[1] 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.[2] 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.[3]

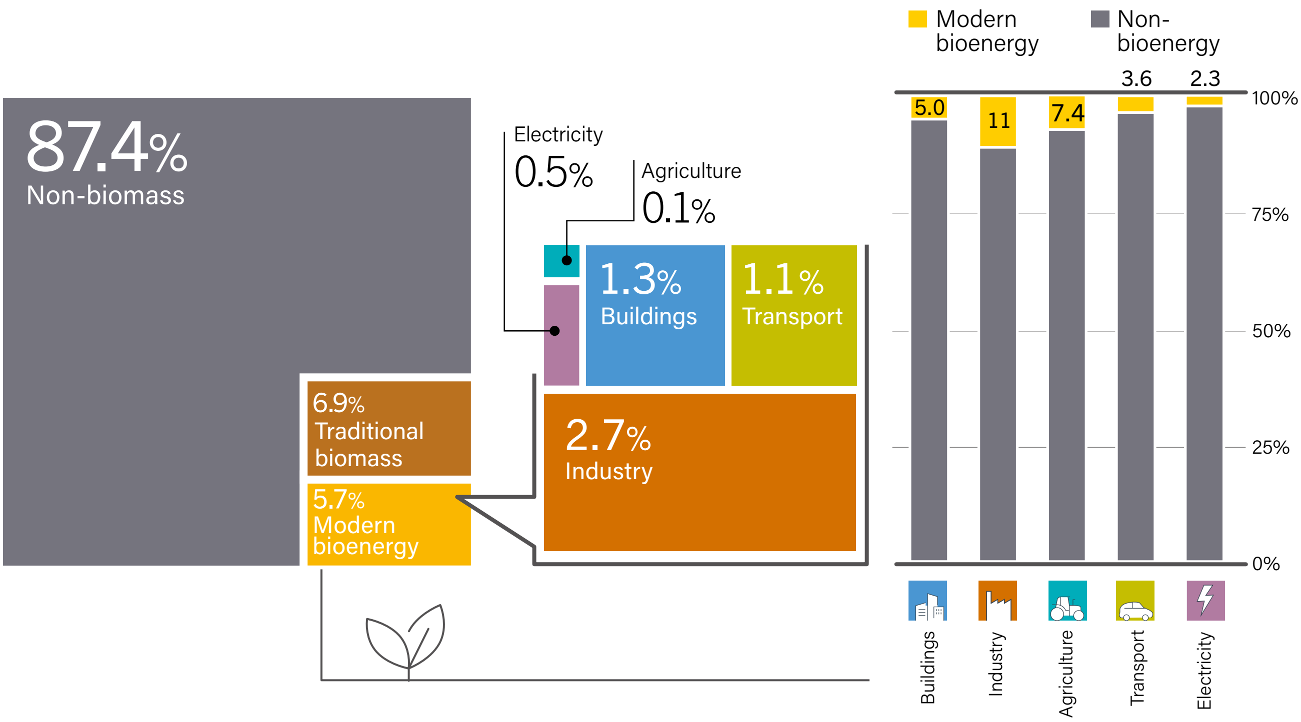
The use of biomass for energy can be broadly classified into traditional and modern bioenergy. Traditional bioenergy typically involves the direct combustion of biomass such as wood, charcoal, cow dung and crop waste in inefficient appliances such as open-fired cook stoves. Such use occurs mainly in developing countries and produces household air pollution that is harmful to human health.[4] 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.[5]

Bioenergy is the largest renewable energy source globally, as it provides heat, electricity and fuels for transport.[6] 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.[7] The use of modern bioenergy for industry, buildings, transport, agriculture and power was 20.6 EJ, representing 5.7% of total energy consumption.[8] (→ *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.[9] In transport, consumption of liquid and gaseous biofuels was 3.8 EJ, providing 3.6% of all renewable energy in the transport sector.[10] The electricity sector consumed 1.9 EJ of biomass, or 2.3% of energy use in that sector.[11]

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

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.[14] Under scenarios for net zero greenhouse gas emissions, the use of traditional biomass would need to be phased out by 2030.[15] Renewable alternatives include modern bioenergy technologies such as biogas, ethanol and processed biomass such as pellets and briquettes.[16]

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.[17] 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%.[18] Heat production from solid biomass nearly tripled globally during 2010-2020.[19]

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.[20] (→ *See Figure 13.*) In **industry**, biomass provided 9.9 EJ of renewable heat, or 11% of the overall heat demand.[21] The use of bioheat in industry increased 36% between 2010 and 2020.[22] 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.[23] In 2022, Heineken opened the largest biomass plant in Cambodia to provide thermal energy to its brewery in Phnom Penh.[24]

Primary energy supply of bioenergy increased by

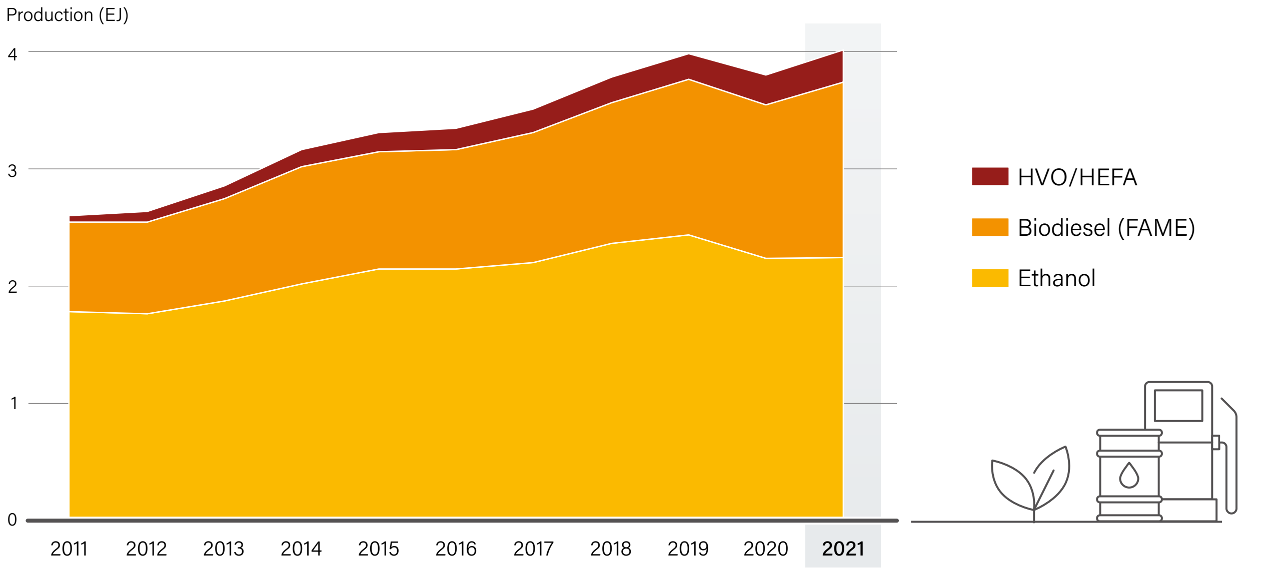
17%

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.[25] District heating accounted for 8% of overall heat demand in 2021.[26] However, more than 90% of the district heating was from fossil fuels, mainly coal in China and natural gas in the Russian Federation.[27] In Europe, waste feedstock was used for most district heating, with Denmark, Sweden, Estonia, Lithuania and Latvia leading the way.[28]

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%.[29] 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

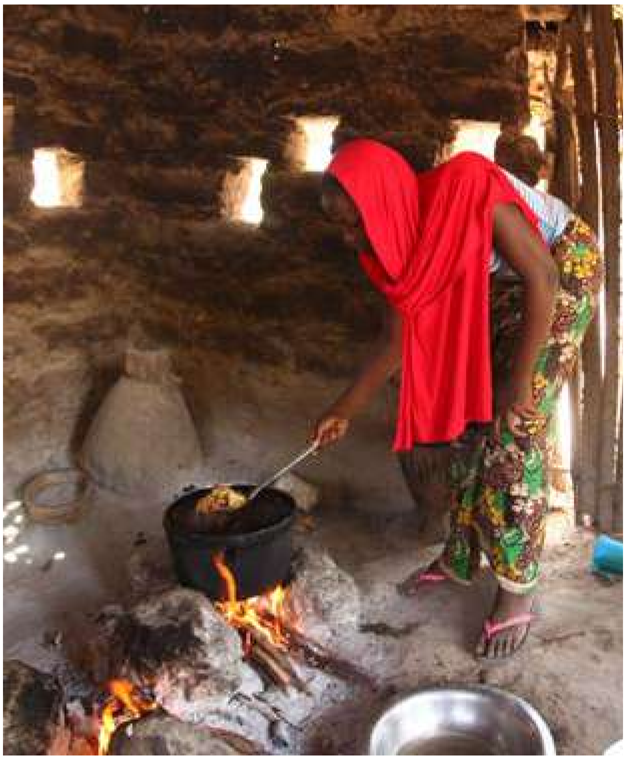


Source: See endnote 50 for this section.

in residential and commercial buildings.[30] 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.[31] In 2022, Egypt announced plans for the country's first waste-to-energy plant.[32]

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

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%).[40] Modern and renewable solutions include bottled ethanol, distributed solar, pellet gasifiers and electric pressure cookers.[41] The share of people with access to clean cooking solutions increased 9 percentage points during 2010-2020.[42] 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.[43] At an estimated USD 26 million, this was well below the USD 8 billion per year required for universal access to clean cooking.[44]



TRANSPORT BIOFUELS

Liquid biofuels offer a solution to replacing fossil oil in the transport sector.[45] In 2020, biofuels accounted for 3.6% of total energy use in the sector.[46] 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.[47]

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).[48] Higher blends also are possible with existing ED95 and B100, which are typically used in heavy-duty transport and with a modified diesel engine.[49]

In 2021, global **production** of liquid biofuels totalled 162 billion litres (4.06 EJ).[50] (→ *See Figure 14.*) Bioethanol production totalled an estimated 106 billion litres (2.24 EJ), accounting for two-thirds of global biofuel production.[51] 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).[52] Despite intense focus and significant opportunities, biojet (SAF) production remains at an early stage of market development, with 150 million litres produced in 2022.[53]

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.[54] Biodiesel production increased 4.3%, followed by bioethanol production at a modest rate of 2.2%.[55] Renewable diesel production grew 44%, and biojet production doubled in 2021.[56]

Ethanol is the largest biofuel produced globally and accounted for 66% of total biofuel production in 2021.[57] The United States is world's largest ethanol producer, followed by Brazil; together, they produced more than 80% of the global total in 2021.[58] 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.[59] 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.[60]

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).[61] 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.[62]

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.[63] A planned nationwide blending mandate of 10% by 2020 was not met, with the blend rate reaching only 1.8%

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

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.[67] Even so, there is renewed interest, with new projects being announced in Brazil, India and Romania.[68]

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.[69] 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.[70] France, German and Spain contribute 62% of the region's FAME biodiesel production.[71]

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.[72] 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.[73] Thailand postponed its proposed B10 mandate and is instead focusing on B7 due to surging feedstock prices.[74]

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.[75] 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.[76] 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.[77] **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.[78] In Sweden, 281 plants produced 2.3 TWh of biogas in 2021, out of which 67% was upgraded to biomethane.[79] Seventy percent of it was used for transport.[80] Total global biomethane production in 2020 was around 5 billion cubic metres, accounting for 0.1% of global natural gas consumption.[81] 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.[82]

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.[83] International agreements in the aviation sector target reducing greenhouse gas emissions 50% by 2050.[84] 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.[85] 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).[86]

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.[87] The Inflation Reduction Act aims to produce 3 billion gallons of SAF by 2030 and offers tax credits for SAF biofuels.[88] The EU also has introduced SAF targets via the REFuelEU initiative.[89]

Maritime transport accounts for 2-3% of global greenhouse gas emissions and for 80% of the international trade of goods.[90] 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.[91] 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.[92] Critical barriers to growth include pricing, sustainability and supply chain infrastructure.[93]

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). [94] In 2022, 672 TWh of electricity was generated from a wide variety of feedstocks.[95] Production of electricity from biomass grew slightly at 0.8%, while the share in overall electricity generation remained the same at 2.4%.[96]

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.[97] Urban municipal and industrial waste generated 113 TWh (16%) of electricity, while biogas generated 90 TWh (13%).[98]

Installed biopower capacity reached an estimated 149 GW in 2022, or just over 4% of total renewable power capacity.[99] Biopower capacity increased 5% in 2022, one of its slowest rates of year-on-year growth in the last decade.[100] (→ *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).[101]

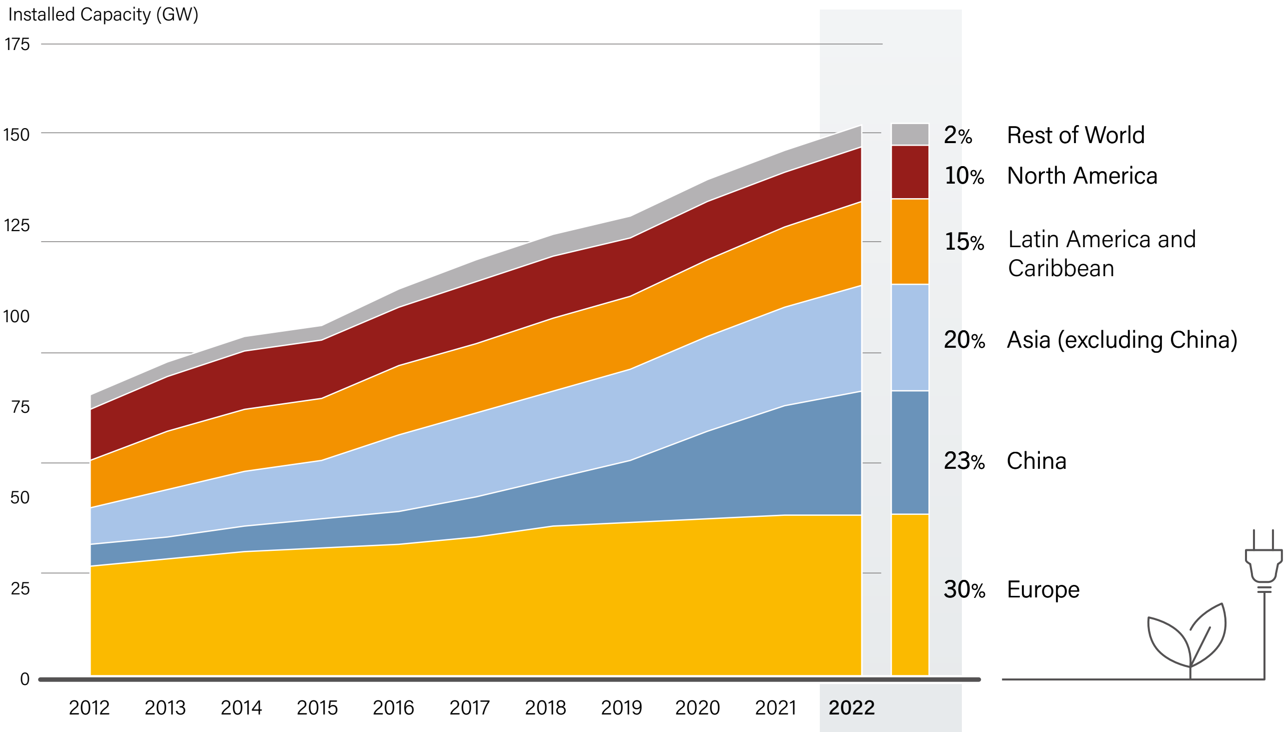
China alone accounts for more than one-quarter (26%) of the global electricity production from biomass, with generation of 172 TWh in 2022 – mainly from forest and agricultural biomass as well as municipal solid waste.[102] In Brazil, the bioenergy share (mainly from sugarcane bagasse) in electricity generation reached an estimated 8.6% in 2022.[103]

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.[104] 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.[105] Although India used only 83,066 tonnes in 2022, financial incentives for processing biomass could generate new supply to meet this demand.[106] Biomass electricity generation fell 10% in the United Kingdom, reflecting outages at some key installations.[107]

In Europe, biopower generation from solid biofuels (excluding charcoal) grew 12% in 2021 to reach 93 TWh.[108] 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.[109] In 2021, Finland, Sweden and Germany were the region's top producers, accounting for 37% of production.[110]

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



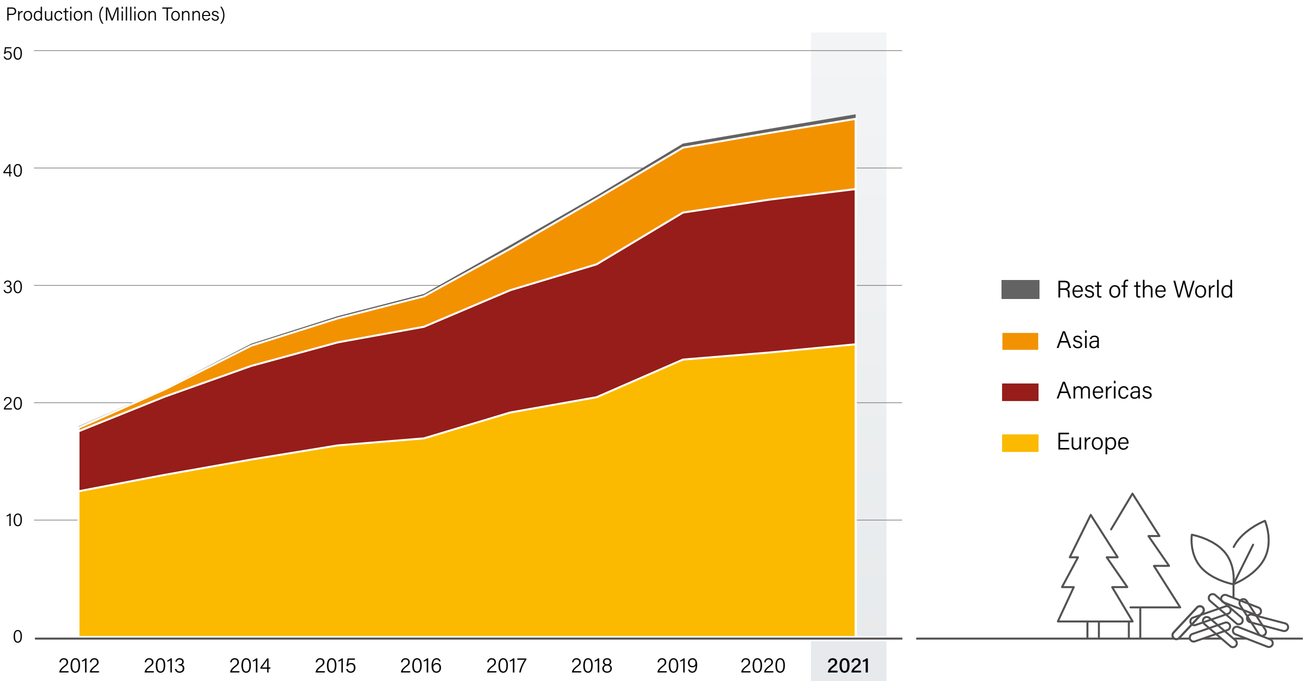
Source: See endnote 100 for this section.

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

for renewables.[111] 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.[112]

One of the most prominent and fastest growing biomass commodities is wood pellets. In 2022, global production totalled 44 million tonnes.[113] (→ *See Figure 16.*) The largest producer was the United States, followed by Vietnam, which recently took second place.[114] 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.[115] Major consumers include the EU (both commercial power generation and domestic heating) and Japan (mainly power).[116]

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. One 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[i] 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).[1] 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.[2]

GEOTHERMAL POWER

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

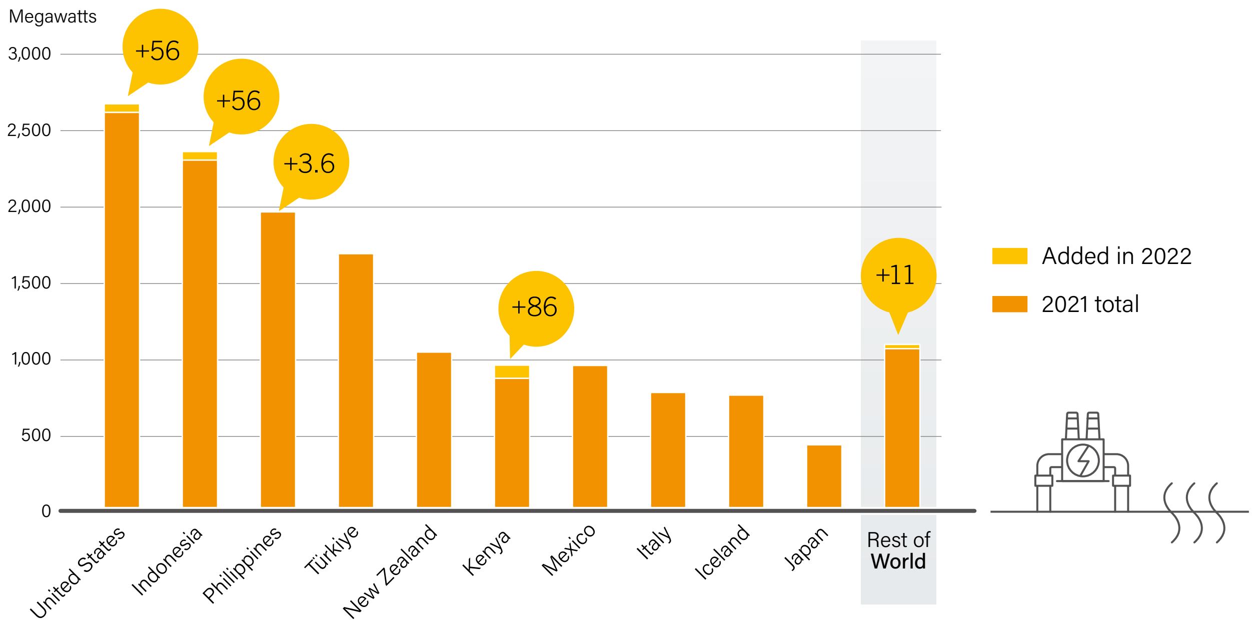
The top 10 countries for geothermal power capacity at the end of 2022 were the United States, Indonesia, the Philippines, Türkiye, New Zealand, Kenya, Mexico, Italy, Iceland and Japan.[6] However, capacity values are subject to high uncertainty due to a lack of standardised reporting criteria.[7]

Kenya had the largest geothermal power capacity addition in 2022 as it completed the 86 MW Unit 6 at the Olkaria I complex.[8] The addition raised the country's geothermal capacity to 0.95 GW, representing 42% of Kenya's total generating capacity.[9] 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.[10] Total planned upgrades are expected to increase capacity by another 123 MW.[11]

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.[12] During the five-year period of 2016-2021, net capacity increased 3.2% while generation grew less than 1%.[13] Three projects were completed in 2022, including the addition of 13 MW (net) at the Ormat Technologies (United States) Tungsten Mountain facility in Nevada.[14] In California, Ormat also completed the 30 MW (17 MW net) Casa Diablo-IV.[15] Geothermal power in the United States continues to supply around 0.4% of US net electricity generation, as much as 17 TWh[i] in 2022.[16] 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[ii] (EGS).[17]

Indonesia completed three projects in 2022, adding 55.5 MW.[18]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.[19] On the North Sulawesi site of the 120 MW Lahendong complex (developed in stages from 2001 through 2016), a 0.5 MW binary-cycle[iii] unit was installed.[20]

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.[21] In 2021, geothermal power generation was 15.9 TWh, or 5.5% of the country's total grid supply.[22] 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.[23] The government hopes to reverse that pattern and see renewable capacity outpace other sources this decade.[24]

In late 2022, **Nicaragua** saw the commissioning of a 10.4 MW (net) binary-cycle unit at the existing San Jacinto Geothermal Project.[25] 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).[26]

The Philippines ranks third globally for total installed geothermal power capacity at 1.9 GW (1.8 GW of net dependable capacity).[27] 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.[28] 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.[29]

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.[30] 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.[31]

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.[32] 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.[33]

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.[34] 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).[35] Annual additions then contracted to 99 MW in 2020 and 63 MW in 2021.[36]

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.[37] In early 2023, the Turkish government indicated pending revisions to the FIT that would reflect current conditions.[38]

GEOTHERMAL HEAT

Worldwide, the capacity for geothermal direct use[i] – direct extraction of geothermal energy for thermal applications – totalled an estimated 38 gigawatts-thermal (GW_{th}) in 2022.[39] Based on reported values for 2019 and the preceding five-year growth rate, the estimated annual capacity increase in 2022 was 2.7 GW_{th}.[40] 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).[41]

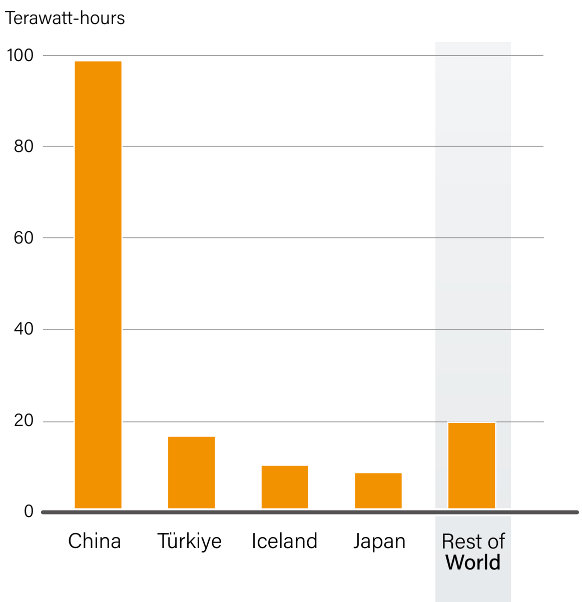
> The top 4 countries represent
> **90%**
> of the global geothermal heat market.

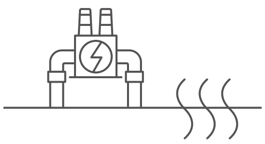
The top countries for geothermal direct use in 2022 were (in descending order) China, Türkiye, Iceland and Japan.[42] (→ *See Figure 18.*)

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.[43] Direct use in other countries includes (in descending order) New Zealand, Hungary, the Russian Federation, Italy, the United States and Brazil.[44]

i 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.[45] 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.[46] 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.[47]

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.[48] 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.[49]

Iceland ranks third globally in the use of geothermal heat.[50] As of 2021, annual geothermal heat consumption was around 35 PJ, from an installed capacity of around 2.5 GW_{th}.[51] Direct geothermal supply meets 90% of space heating demand in Iceland.[52] Available geothermal resources for direct use far exceed current utilisation.[53] 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.[54]

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.[55] 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.[56] Political, financial and social barriers also limit project development, with public acceptance becoming a more pressing concern.[57] As of late 2022, 70 projects were in various stages of development, with 19 advancing towards commencing heat production.[58] 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.[59]

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.[60] 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.[61] The local distribution network also will be upgraded for greater efficiency and to accommodate the lower geothermal supply temperatures.[62]

In **Germany**, no new geothermal plants came online in 2022.[63] 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.[64] 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.[65] 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.[66] Work was under way during the year to expand geothermal heat supply and distribution networks in the Munich area.[67]

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.[68] 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.[69]

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.[70] In addition, two German projects met critical setbacks when drilling failed to find enough permeability and flow for commercial utilisation.[71]

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.[1] 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.[2]

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.[3]

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.[4] In 2022, China classified heat pumps as a renewable energy technology at the national level for the first time.[5]

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.[6]

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.[7] Worldwide, the heat pump market grew an estimated 11% in 2022, the second consecutive year of double-digit growth.[8]

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.[9] Increasingly, **ground-source heat pumps** are being deployed in China to replace coal-fired furnaces.[10]

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.*)[11] For the first time, US annual heat pump sales eclipsed annual sales of gas boilers, although sales of both devices have been rising.[12] State and local policies have driven heat pump sales, even before federal legislation came into force.[13]

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

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.[18] (→ *See Snapshot: Poland.*) Markets doubled in Belgium and the Czech Republic, although starting from a much smaller base.[19] **Air-to-water heat pumps** are most common in Europe, comprising around half of all units sold.[20]

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.[21] 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.[22] Mandates restricting fossil fuel use in new buildings are increasingly common in the United States as well, although they have faced backlash.[23]

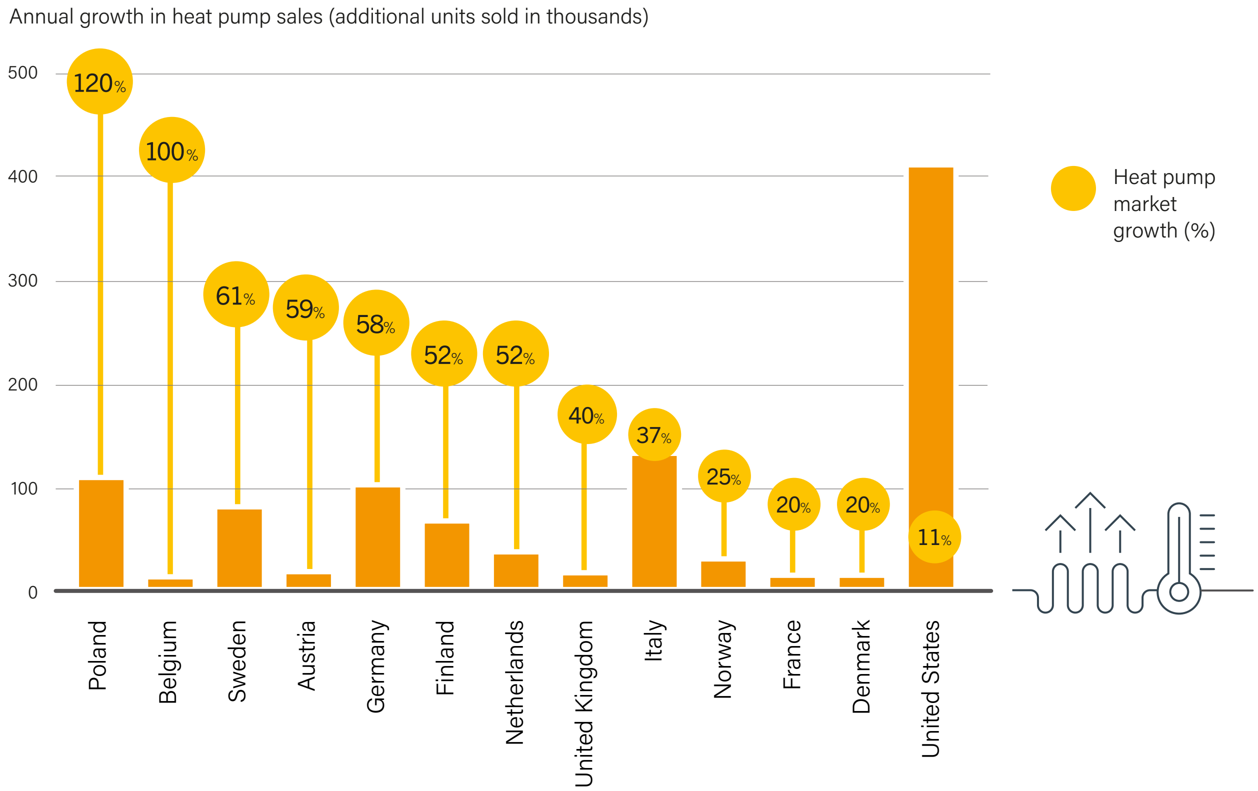
HEAT PUMP APPLICATIONS AND TRENDS

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.[24]

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.[25] 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.[26] In Europe and the United States, industries have turned increasingly to heat pumps to reduce dependence on fossil fuels.[27] Manufacturers have announced massive models of up to 120 MW in capacity to generate process steam for the chemical industry.[28]

Heat pumps also supply thermal energy for district heating networks.[29] 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.[30] 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.[31] Two projects under discussion in Serbia would use heat pumps based on wastewater to heat district energy networks.[32]

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



Source: See endnote 11 for this section.

SNAPSHOT

POLAND

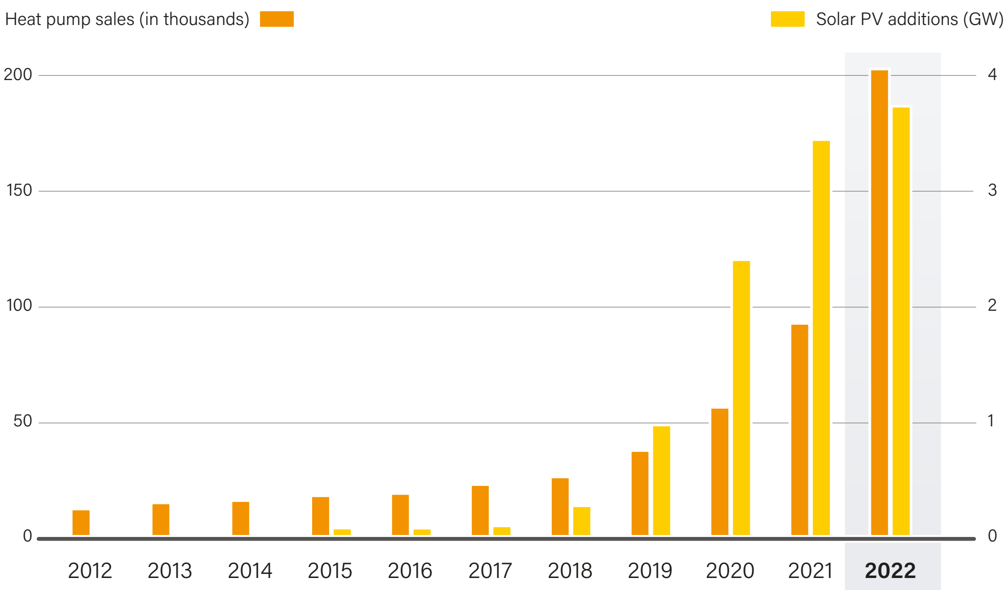
Heat Pumps Grew Rapidly in Poland in 2022

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.[33] 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.[34] 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.[35] Stiebel Eltron announced an investment of EUR 600 million (USD 640 million) to triple its production by 2025.[36]

Additional investment announcements came from BDR Thermea, Bosch, Ecoforest, Groupe Atlantic, Hoval, NIBE, Midea Group and Panasonic.[37] Many heat pump component manufacturers also pledged new investments.[38] 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.[39] In early 2023, LG Electronics announced that it would open its first heat pump manufacturing facility in the United States.[40]

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.[41] Despite this, many countries have seen reductions in the upfront costs of heat pumps[i].[42] Policies to reduce such costs, especially for low-income households, are important for wider adoption of the technology.[43]

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.[44] This is often exacerbated by energy taxation regimes that place heavy burdens on electricity.[45] Denmark, Germany, the Netherlands and the United Kingdom have begun reforming their tax regimes to favour electric heating, especially with heat pumps.[46] Other countries have reformed tariffs to further incentivise heat pumps.[47]

Despite ongoing cost barriers, many households that switched to heat pumps from existing fossil fuel boilers saw savings on their energy bills.[48] 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.[49]

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.[50] 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_2). However, some alternatives may have environmental hazards and complicated or expensive operating and installation conditions that hamper their use.[51]

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.[52] 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.[53]

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[i] via electrolysis, a process that splits water molecules into hydrogen and oxygen. The hydrogen can be stored[ii], 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.[1] 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.[2] Nevertheless, governments and industries are increasingly recognising the potential of renewable hydrogen and committing large resources to its development.[3]

RENEWABLE HYDROGEN PRODUCTION FACILITIES

Currently, the global demand for hydrogen is met almost entirely (around 95%) with hydrogen produced from fossil fuels.[4] 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.[5] 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.[6] Electrolyser manufacturing capacity doubled between 2017 and 2022 to nearly 8 GW, as successful pilot and demonstration projects advanced to commercial-scale projects.[7] 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.[8]

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.[9] 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.[10] **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.[11]

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.

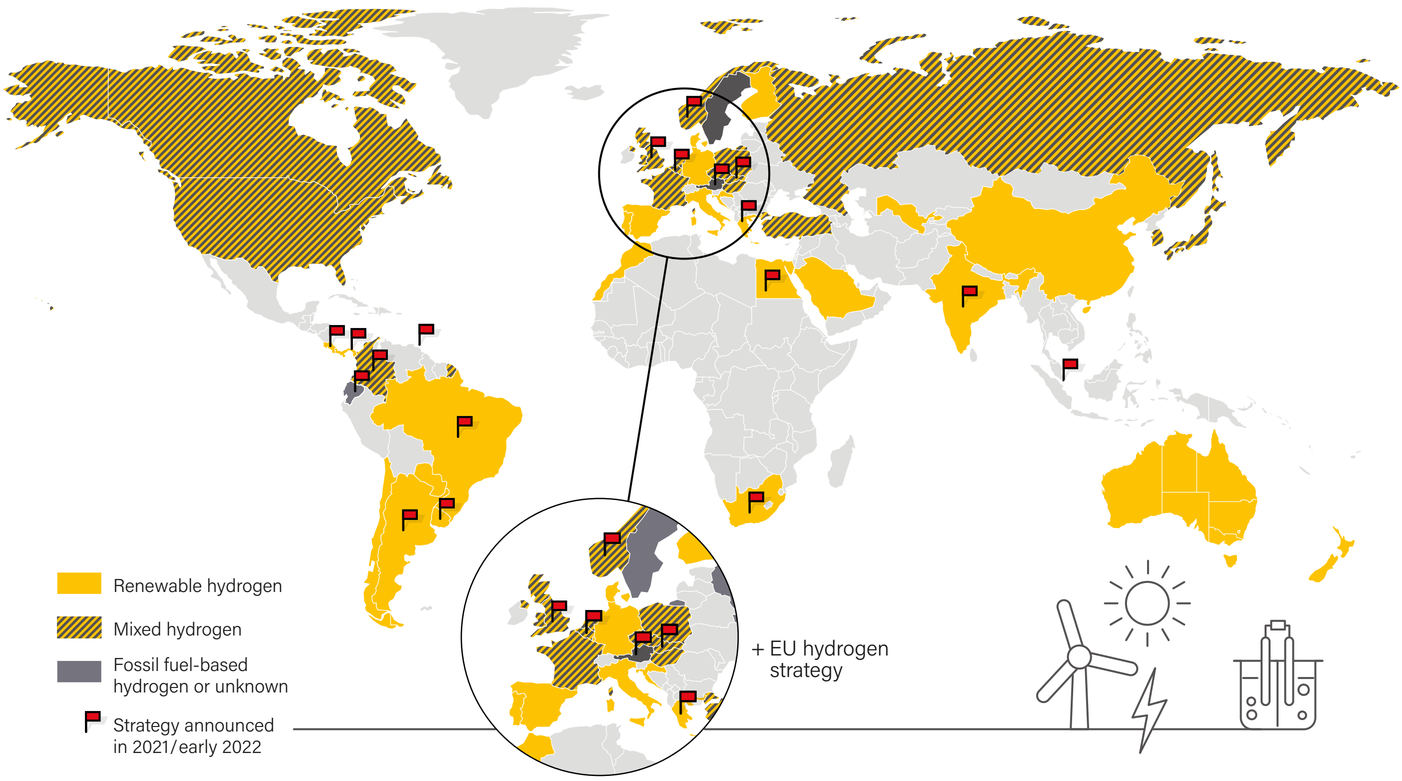
In 2022, higher costs for key elements of renewable hydrogen projects resulted in part from global supply chain issues (related to geopolitical instability in Europe) and from rising global demand for solar PV and electrolysers.[12] At this early development stage of the clean hydrogen industry globally, 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.[13]

Hydrogen strategies are being developed and implemented worldwide, with leading players in Asia, North America, Australia and the EU.[14] (→ *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.[15] 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.[16] As of early 2023, Japan faced challenges in scaling up hydrogen production and use due to high costs and lack of infrastructure.[17]

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.[18] 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.[19]

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.[20] 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.[21]

In 2020, the **European Commission** adopted its overarching "hydrogen strategy for a climate-neutral Europe".[22] 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.[23] 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.[24] In 2023, the EU (with 28%) and Japan (24%) were the global leaders in patent filings related to hydrogen.[25]

Germany's National Hydrogen Strategy intends to expand the role of hydrogen to decrease national dependence on coal.[26] 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.[27] 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.[28]

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.[29] 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.[30]

Spain released a strategy in 2020 that provides a vision for developing a favourable environment for the supply and demand of renewable hydrogen.[31] Key milestones of the strategy are commissioning 300-600 MW of electrolysers by 2024 and 4 GW by 2030, and reducing 4.6 million tonnes of CO_2 emissions, through mobilising USD 9.6 billion of investments.[32] 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 electrolysers, 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.[33]

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.[34] The United States is the world's second biggest producer and consumer of hydrogen after China, accounting for 13% of global demand.[35] 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.[36]

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).[37] 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.[38]

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.[39] 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.[40] The system includes three 20 MW electrolysers supplied by Thyssenrupp Nucera, with a second phase expected to expand the project's capacity beyond 100 MW.[41]

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.[42] 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.[43] The project will produce hydrogen, e-methanol and e-petrol powered by 3.4 MW wind turbines.[44] Expected annual production is 350 tonnes of crude methanol, 130,000 litres of petrol and 16 tonnes of carbon-neutral liquefied gas.[45]

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.[46] 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.[47]

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.

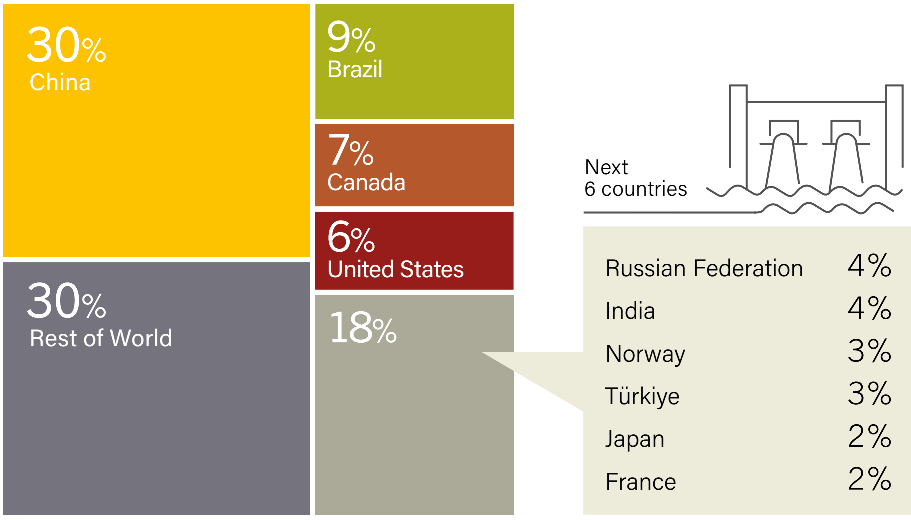
Global hydropower markets added at least 22.2 GW in 2022, for a total installed capacity of 1,220 GW[i,1] Generation increased 5% over 2021 to reach 4,429 TWh.[2] However, as in 2021, the capacity added in 2022 was well below the estimated 30 GW of hydropower additions that are needed annually to keep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

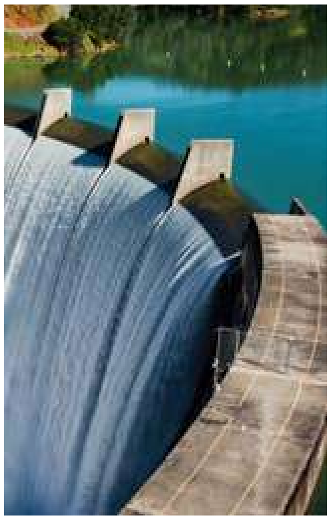
Fluctuating water levels, related in part to climate change, have raised concerns about hydropower infrastructure and the development of future facilities and storage. Africa, Asia, Europe and North America all experienced severe droughts in 2022, reducing water supplies and the capacity use of plants.[5] 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.[6] Many drought-stricken areas have turned to coal to supplement power needs.[7] 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.[8] (→ *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).[9] (→ *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.[10] 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.[11]

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





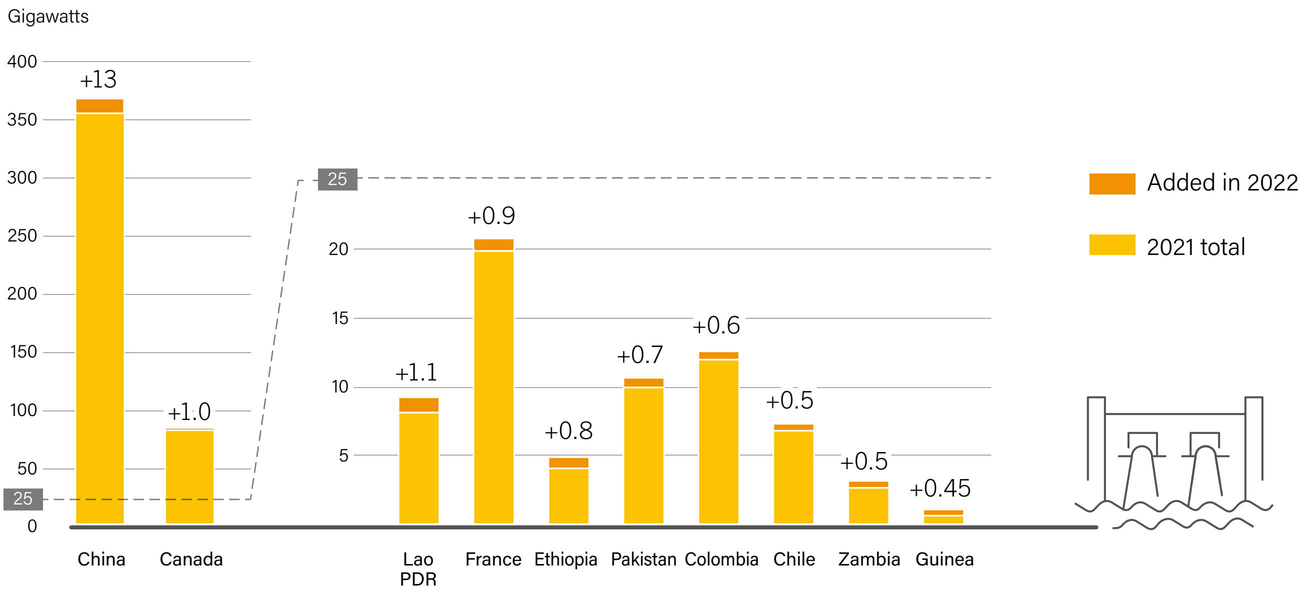
Source: See endnote 9 for this section.

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.[12] 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.[13] 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.[14] Conversely, the Yangtze River registered record low water levels, posing a threat to Sichuan Provence, which receives 80% of its energy from hydropower.[15]

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.[16] 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.[17] Overall, at least 38 GW of Belt and Road Initiative hydropower projects are either in operation or under construction, with another 11 GW planned.[18] 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.[19]

Brazil ranked second globally in hydropower installed capacity and generation, although it only added just over 300 MW in 2022.[20] Favourable rain conditions boosted production 17% in the country.[21] In total, Brazil generated 92% of its overall electricity from renewables during the year, and hydropower contributed 78% of the renewable energy production.[22]

Canada remained third in both total hydropower installed capacity as well as hydroelectric generation.[23] 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 Quebéc.[24] Hydro-Quebéc, 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.[25]

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.[26] The decades-long megadrought in the US west continued to affect generation in the first half of 2022.[27] 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[i].[28] 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.[29] Overall, generation across California, Oregon and Washington state grew 14.2% in 2022 to 129,918 TWh, representing 49.6% of the US total.[30]

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

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[i]. 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_2 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[ii]. 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 proper 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_2 equivalent per kWh produced or a power density of greater than 10 watts per square metre (W/m^2); for facilities in operation before 2020, the criteria are less than 100 grams of CO_2 equivalent per kWh or greater than 5 W/m^2.

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.[34] Severe drought led some hydropower reserves in Italy and Spain to drop by half.[35] To partially fill an energy generation gap of 185 TWh, many countries turned to coal production, which rose 7% in 2022.[36] 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.[37] In Austria, Croatia, Latvia, and Sweden, hydropower accounted for more than 35% of the total electricity mix in 2022.[38]

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.[39] **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.[40] **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.[41] 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.[42]

Türkiye added 80 MW in 2022, outpacing additions in 2021 for a total capacity of 32 GW[i].[43] Over the last two decades, Türkiye has invested heavily in hydropower, adding around 650 systems.[44] The recently completed 588 MW Yusufeli dam, the world's fifth largest, began filling its reservoir in 2022.[45] The Tigris-Euphrates river system, where increasingly complex water needs involve five countries that share the basin, rebounded after a dry 2021.[46] 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.[47]

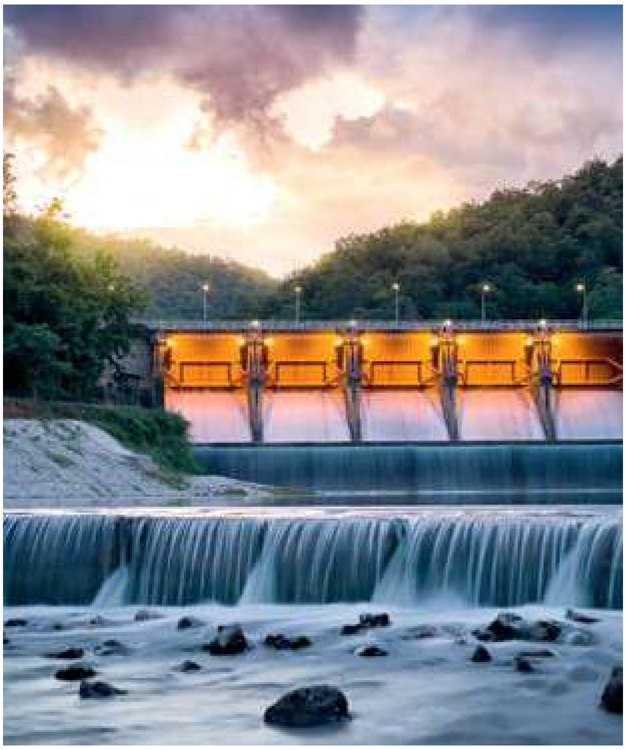
In **Africa**, hydropower capacity increased 2.6 GW to reach 37.7 GW in 2022, generating at least 150 TWh.[48] The region is the most untapped globally for hydropower development, with a potential capacity of 474 GW as of 2021, especially in West Africa and parts of Southern and Central Africa.[49] In 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.[50]

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.[51] 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.[52] In August 2022, the dam started producing electricity from the second of 13 turbines of 375 MW each.[53]

Hydropower is set to supply the bulk of energy in **Tanzania**.[54] 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.[55] 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.[56] In **Nigeria**, all four 175 MW turbines of the Zungeru Hydropower Station were commissioned in 2022 and began operation.[57] 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.[58]

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.[59] In 2022, the region had a total installed capacity of 20.9 GW and generated 69 TWh.[60]

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.[61] Around 600 GW of hydropower plants are 30 years or older, and 400 GW are 40 years or older.[62] 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.[63] In Latin America and the Caribbean, an estimated 70 GW of capacity will need short- or medium-term modernisation, at around USD 32 billion.[64]



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

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.[5]

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.[6] Most projects targeting industrial-scale production are based on horizontal-axis turbines mounted on the sea floor or on a floating platform.[7] These devices have demonstrated considerable reliability, and total generation surpassed 80 GWh as of the end of 2022.[8]

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.[9] Around 25 MW of wave power has been deployed since 2010.[10]

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.[11] 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.[12]

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.[13] 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.[14]

i 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.[15] 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.[16]

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.[17]

In the **Republic of Korea**, the 80 kW Uldolmok Tidal Power Pilot Plant was deployed at an open-sea test site.[18] 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.[19]

In **France**, Sabella redeployed its 1 MW bottom-fixed tidal turbine in the Fromveur passage in Brittany.[20] 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.[21] 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[i] (CfDs) as well as new investment from the Scottish National Investment Bank and individuals via the Abundance Investment platform.[22]

Longstanding leader MeyGen also saw success in the new CfD programme, agreeing to add 28 MW of capacity by 2027.[23] 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.[24] 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.[25]

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.[26]

In **China**, Hann Ocean deployed its 15 kW wave rotor device at Shengsi island.[27] 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.[28] 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.[29] The prototype was undergoing testing, which was expected to conclude by March 2023, with the eventual device targeting a capacity of 800 kW.[30]

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

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.[34]

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.[35] 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.[36]

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.[37]

Saga University in **Malaysia** and other research institutions are conducting ongoing research on a hybrid system of OTEC and desalination.[38] 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.[39]

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.[40] Dedicated revenue support is essential to achieve predictable returns and to attract private investors until the industry reaches a higher level of maturity.[41]

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.[42] 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.[43] 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.[44]

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).[45] Tidal power projects from Orbital Marine Power, Simec Atlantis Energy and Magallanes Renovables were awarded contracts.[46] 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.[47] 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.[48]

Deploying ocean power at scale also will require streamlined consenting processes.[49] 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.[50] 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.[51]

The EU committed

USD

42.7 million

for demonstrating tidal arrays.

KEY FACTS

SOLAR PHOTOVOLTAICS (PV)

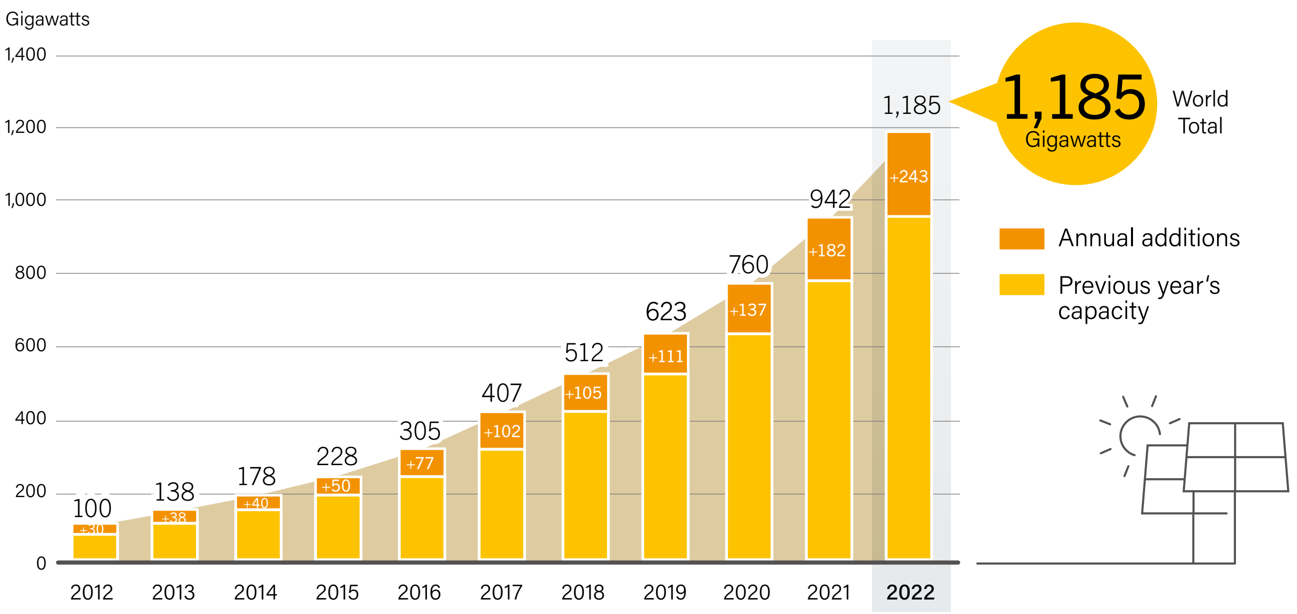
- Solar PV maintained its record-breaking streak, with new capacity increasing 37% in 2022, while global solar production reached an average of 6.2%, up from 5% in 2021.
- For the tenth consecutive year, Asia dominated regionally in new solar PV installations, contributing 64% of the global added capacity 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.[1] (→ *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.[2] This record-breaking increase was possible despite ongoing disruption across the solar supply chain due to both shortages and rising costs of raw materials.[3]

Solar PV contributed an estimated 6.2% of global electricity generation in 2022, up from 5% in 2021.[4] 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.[5] Around 22 countries had enough installed solar PV capacity to meet 5% of their electricity demand, up from 18 countries in 2020.[6] 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%).[7]

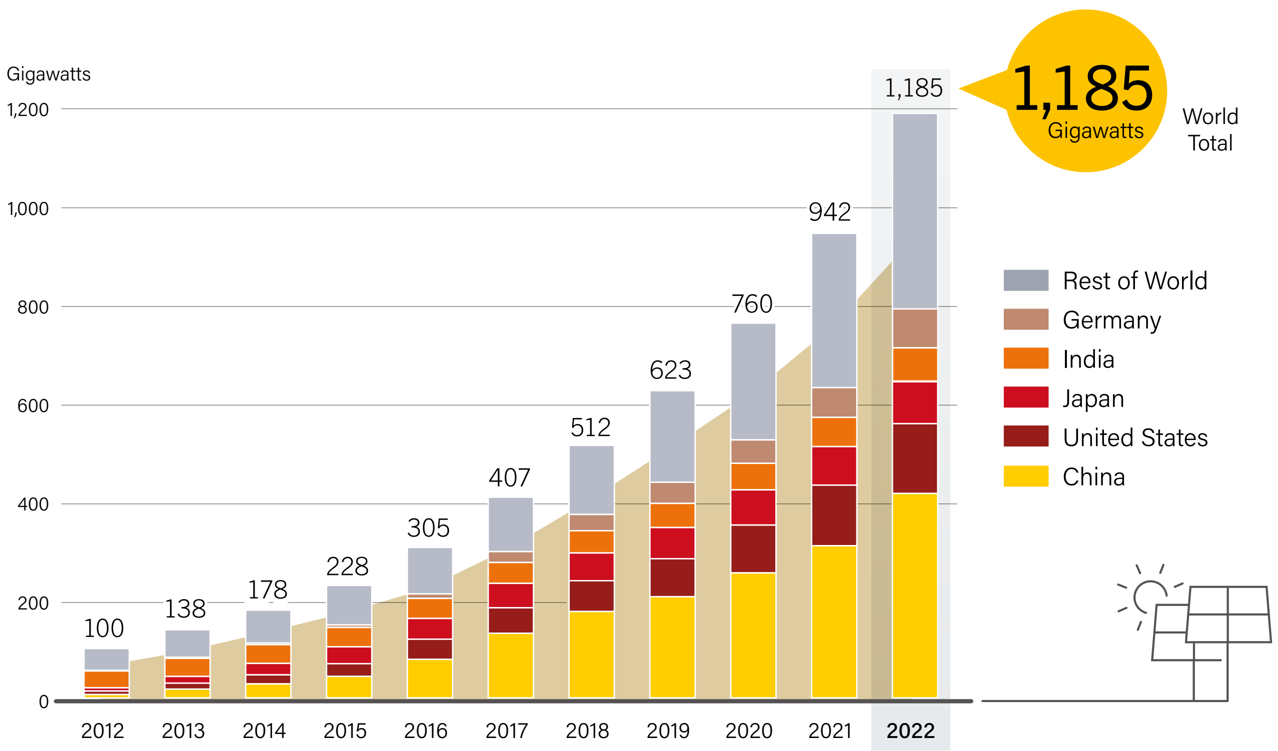
For the tenth consecutive year, Asia dominated regionally in new solar PV installations, followed by the Americas, which again surpassed Europe.[8] The top five countries[i] by capacity added (in descending order) were China, the United States, India, Brazil, and Spain, together comprising around 66%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



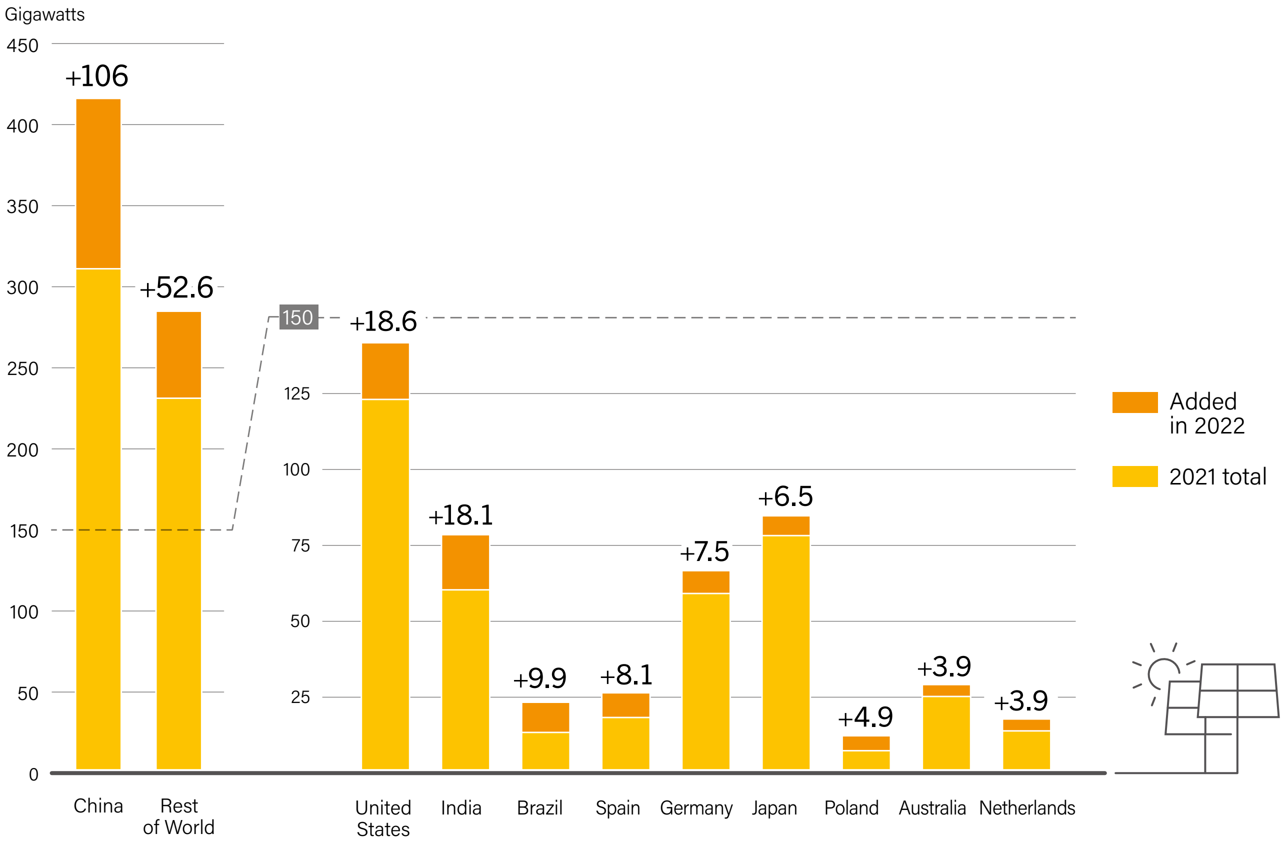
Source: See endnote 9 for this section.

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.[10] (→ *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.[11] (→ *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.[12] Similar to 2021, installations of rooftop PV in 2022 occurred mainly in China, the United States, Spain, Australia and Germany.[13]

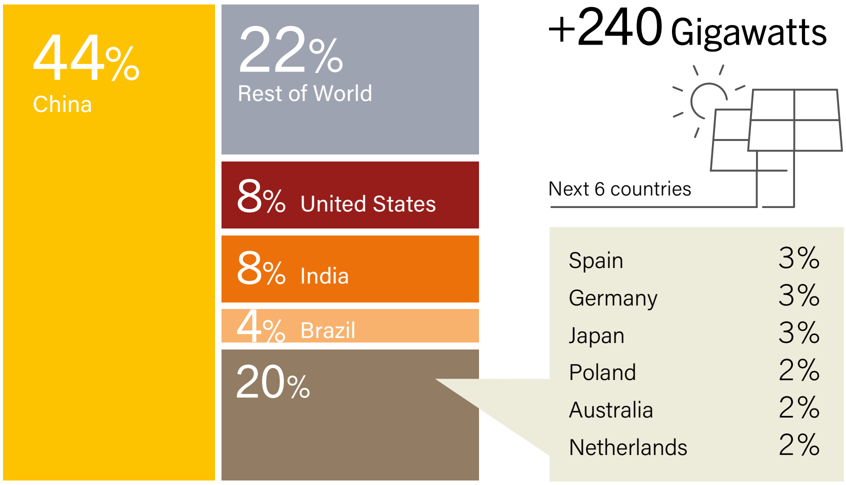
Global rooftop solar PV additions rose around
54 %
in 2022 to reach 115.2 GW.

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.[14] 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.[15] Belgium lowered the VAT for PV installations and heat pumps deployed on buildings constructed in the last ten years.[16] Italy loosened permits for utility-scale PV and simplified the permitting process for commercial rooftop systems up to 200 kW.[17] 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.[18]

China's solar PV market experienced unprecedented growth in 2022, adding an estimated 106 GW, or around 93% more than in 2021.[19] Around 58% of the new capacity was distributed solar PV (61.4 GW), while 44.6 GW was centralised solar PV.[20] 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[i] and 248.7 GW (60%) from centralised plants.[21] China's market for centralised solar PV plants grew around 18%, while distributed solar PV grew 47%.[22] 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.[23]

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

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).[26] The solar PV additions included around 15.7 GW of utility-scale solar (87%) and 2.4 GW of rooftop PV installations.[27] This brought India's cumulative installed solar PV capacity to around 79 GW.[28]

However, this was still well below India's target of 100 GW of solar by 2022.[29] 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).[30]

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.[31] A new mandate for solar PV announced in Tokyo requires all new homes and buildings to install rooftop PV starting in 2025[ii],[32] 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.[33] (→ *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.[34]

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.[35] 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.[36] The top state for new solar PV additions was California (4.7 GW), followed by Texas (3.3 GW) and Florida (1.7 GW).[37] 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.[38]

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.[39] 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.[40] 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.[41]

The US Inflation Reduction Act, signed in August 2022, is expected to have a positive long-term impact on the solar PV market.[42] 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.[43]

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.[44] This included a record 7.6 GW of new distributed capacity and 2.5 GW of centralised PV systems.[45] Market growth in Brazil was driven mainly by high electricity bills and by new regulations for distributed generation.[46] 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.[47] 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.[48]

China's added solar PV capacity was around

93%

more than in 2021.

Europe added 40.5 GW of solar PV in 2022 to reach 206 GW of installed capacity, marking another year of outstanding growth.[49] New installations in the EU-27 reached 38.9 GW, 63% more than the 25.9 GW added in 2021.[50] 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.[51] 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.[52] Portugal added a notable 2.5 GW in 2022, reflecting 250% year-on-year growth, and Italy added 2.6 GW, with 174% growth.[53]

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.[54] The German market was driven mainly by government auctions and more than 3 GW of tenders.[55] Power purchase agreements (PPAs) also played a role, with unsubsidised installations accounting for around 872 MW of capacity added.[56] In 2022, solar PV contributed a record 11.8% of Germany's electricity production, up from 9.8% in 2021.[57]

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).[58]

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.[59] Installations included 4.3 GW of utility-scale and 2.7 GW of self-consumption distributed PV systems.[60] 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.[61] 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.[62] Spain now faces a potential overcapacity challenge, necessitating investments in grid expansion and energy storage.[63]

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).[64] Residential prosumers[i] represented around 80% of the new capacity, motivated by an attractive net metering scheme and by rising electricity prices.[65] 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.[66]

The Netherlands, the other new entrant to the top 10 installers, added 4 GW of solar PV in 2022.[67] 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.[68] 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).[69]

Australia remained the largest solar PV market in Oceania adding around 3.9 GW in 2022 for a total capacity of nearly 30 GW.[70] 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.[71]

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.[72] By year's end, an estimated 3.4 million homes across the country had rooftop solar systems installed.[73] Household battery additions also grew significantly (44%) in 2022, with an estimated 50,000 battery systems added.[74] 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.[75]

The **Middle East and Africa** added around 7.2 GW of solar PV in 2022.[76] Africa installed around 950 MW – up 14% from the 833 MW installed in 2021 – bringing the total capacity to at least 10 GW.[77] 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).[78]

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**[i] 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.[79] The top five countries with the highest estimated floating PV potential are the United States, China, Brazil, India and Canada.[80] 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.[81]

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.[82] 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.[83] Similarly, Italy compiled a detailed list of standards for agricultural PV projects, facilitating the expansion of this market in the country.[84]

Building-integrated PV (BIPV) systems and **vehicle-integrated PV**[ii] 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.[85] 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.[86]

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.[87] 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.[88]

The cost of **polysilicon**[iii], which represents around 35% of the total cost of a PV module, continued to increase in 2022.[89] 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.[90] The rise in price is attributed to increased demand, macroeconomic fluctuations and supply chain issues.[91] 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.[92]

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.[93] 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.[94] Germany, in particular, is strategising to restore the country's fully fledged solar PV manufacturing supply chain.[95]

In the United States, the government's 2021 ban on imports of materials manufactured in Xinjiang came into effect in June 2022.[96] 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.[97] In July 2022, the US government announced a USD 56 million investment to expedite domestic solar manufacturing.[98]

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

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.[1] (→ *See Figure 28.*) This growth followed the first year ever of contraction of global CSP capacity in 2021.[2] Overall, the global CSP market has slowed following an initial surge of development in Spain and the United States in the early 2010s.[3] 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.[4]

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**.[5] Once completed, the plant will be the world's largest CSP facility at 700 MW (including the 100 MW central tower).[6] 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.[7]

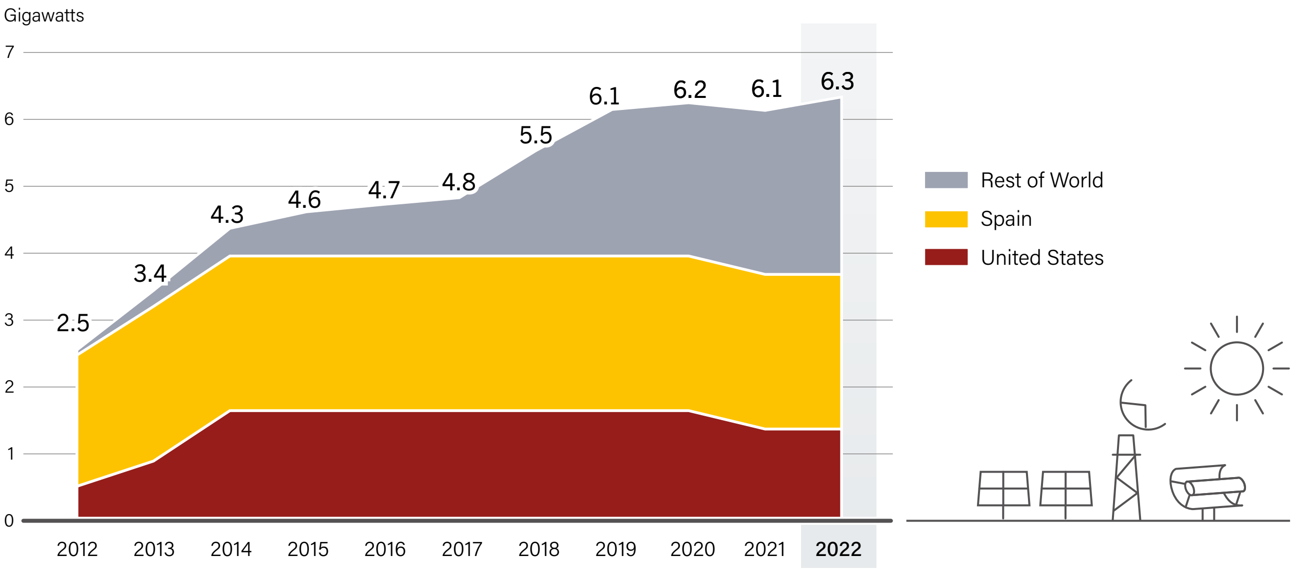
Most of the world's CSP capacity under construction is in **China**. As of the end of 2022, at least 30 CSP projects were in various stages of construction and commissioning in the country, with 14 projects (totalling 1.4 GW of capacity) scheduled to come online during 2023.[8] If these projects are 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.[9] In early 2023, the first of these Chinese projects started commercial operations, a 50 MW tower CSP facility.[10]

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.[11] A state council action plan also proposes developing CSP, promoting its co-location with wind power and solar PV.[12] 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.[13] Western regions in China with a high level of solar irradiation are encouraged to use CSP as a power source for peak shaving.[14]

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.[15]

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.[16] The country has not added new CSP capacity since 2015.[17] 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.[18]

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.[19] 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.[20] 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.[21]

Italy had 8 MW of CSP capacity under construction in 2022 and aims to add 880 MW by 2030.[22] 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.[23] 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**.[24] 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.[25]

CSP INDUSTRY

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

The **cost**[i] **of electricity generated by CSP** plants fell 68% between 2010 and 2021.[27] This decline was driven largely by decreases in total installed costs and by improved capacity factors.[28] The growing addition of thermal energy storage also has grown plant capacity factors, improving plant dispatchability while decreasing levelised electricity costs.[29] In addition, hybridisation with solar PV has been responsible for driving down CSP costs, especially in China.[30]

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

Upfront costs rebounded in 2021, although the increase should be considered with caution, as only one project was brought online.[31] (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.[32] 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.[33]

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.[34] In early 2023, construction began on the final stage of a USD 100 million CSP demonstration project in the United States.[35] The US Department of Energy has a goal to reduce the cost of heliostats one-third by 2030 from its 2021 level.[36] 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).[37]

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_{th}[i], after an increase in 2021 that followed seven years of decline.[1] 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.[2] However, sales declined in other large markets including India (-21%), China (-12.3%), Spain (-12%) and Portugal (-11%), following strong growth in 2021.[3]

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.[4] 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.[5]

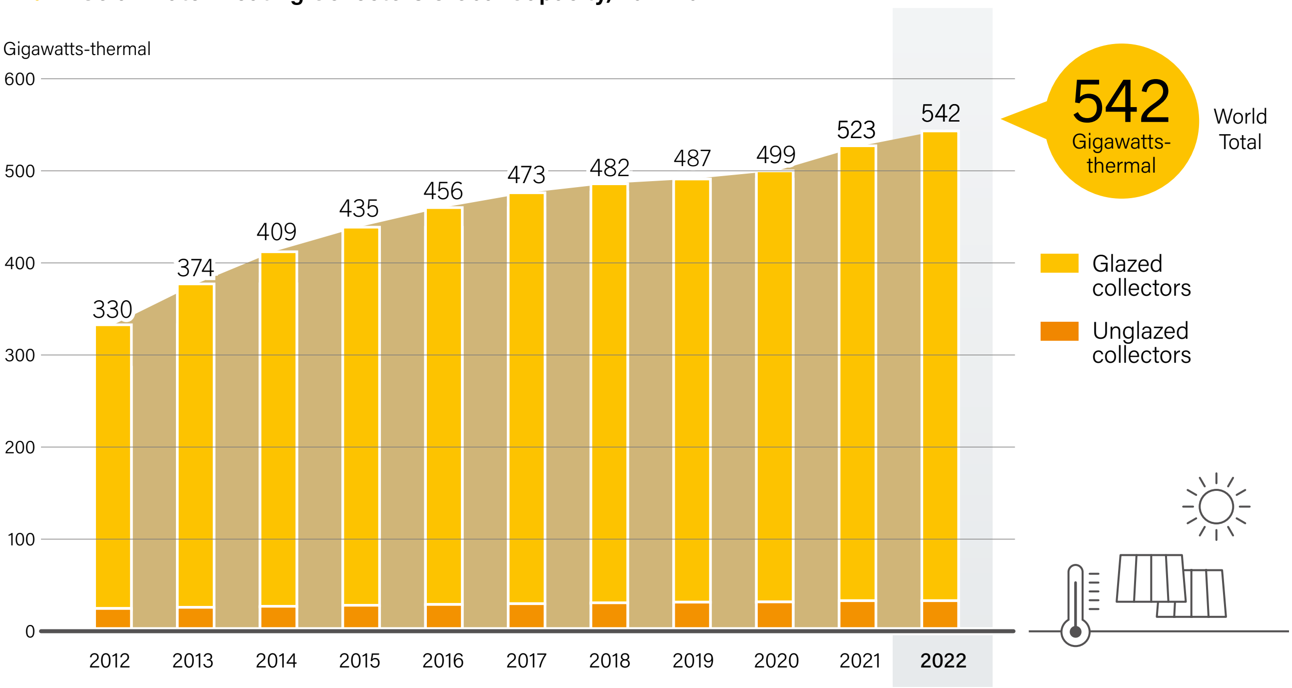
Small-scale solar thermal systems and combi-systems (for water and space heating) continued to account for around 60% of annual installations, but in recent years they have lost market share across much of Europe and China.[6] Demand for large-scale projects, in contrast, is increasing, with several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

By year's end, millions of residential, commercial and industrial clients in around 150 countries were benefiting from solar thermal heating systems.[9] Cumulative global capacity in operation reached an estimated 542 GW_{th} in 2022, up 3.3% from 523 GW_{th} in 2021.[10] (→ *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.[11]

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.[12] The top 20 countries for new additions remained largely the same as in 2021, led by China, Türkiye, Brazil, India and the United States.[13] (→ *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.[14]

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

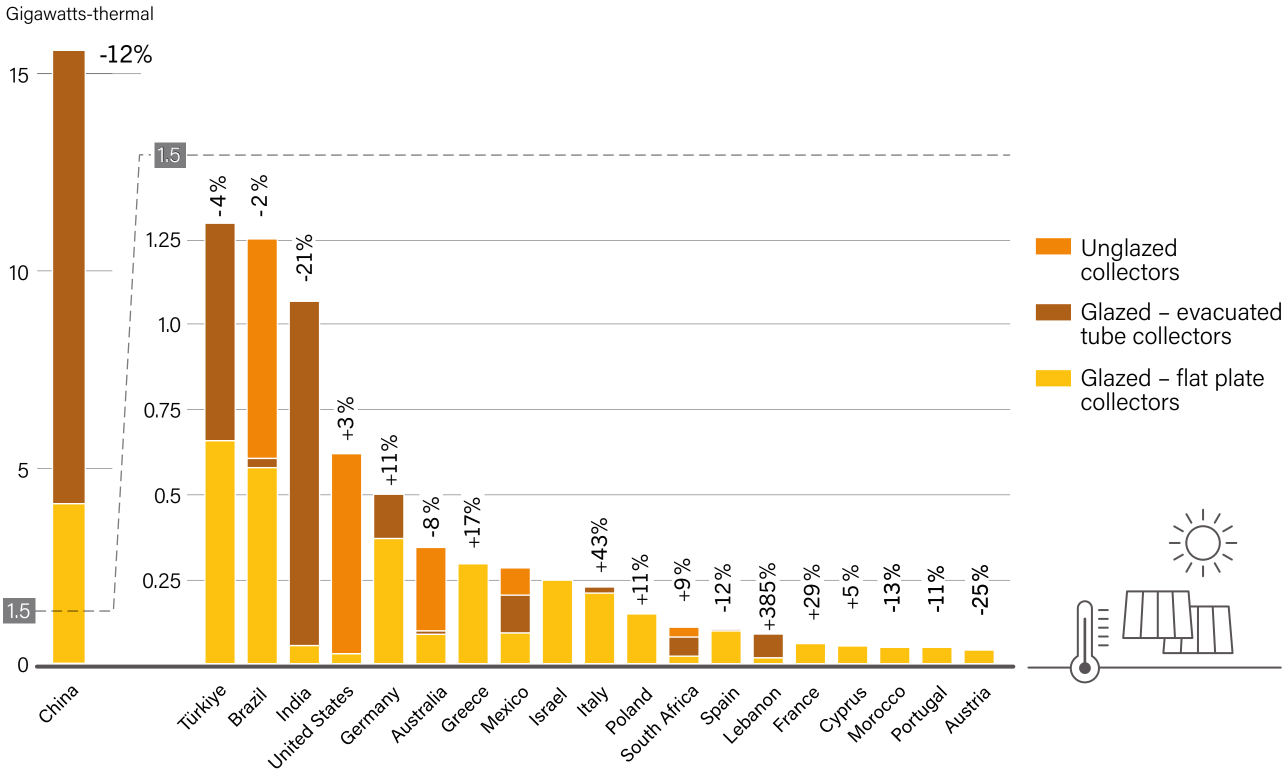
FIGURE 29.
Solar Water Heating Collectors Global Capacity, 2012-2022



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.[15] Even so, the country continued to account for the largest share of global annual sales, at nearly 69%.[16] China added an estimated 15.2 GW_{th} (21.7 million square metres, m^2) in 2022, down 12.3% from 2021, for a total of 396.2 GW_{th} (566 million m^2).[17] By 2022, China's energy savings from the use of solar thermal technologies exceeded an estimated 1 billion tonnes of standard coal.[18]

Sales of vacuum tube collectors in China fell 11%, to 11.2 GW_{th}, accounting for nearly three-fourths of total sales, while flat plate sales declined 19%, to 4 GW_{th}.[19] Most new installations were in the engineering market[i] (83%), with the rest in the retail market.[20] 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.[21] China's industry moved further towards modularisation and increased intelligence of systems, while price competition became increasingly fierce.[22]

Despite industry expectations of double-digit growth, **Brazil's** market contracted 2.1% relative to 2021, when sales grew 28% to a record high.[23] 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.[24] Brazil added a total of 1.26 GW_{th} (nearly 1.8 million m^2), with systems for swimming pools (unglazed collectors) accounting for nearly 52% of the newly installed collector area, or 0.6 GW_{th} (920,463 m^2).[25] 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.[26] Brazil's total operating capacity grew 8.5% in 2022, to 9.1 GW_{th}.[27]

Following strong growth in 2021, **India's** market declined 21% in 2022.[28] The country added an estimated 1.06 GW_{th} (1.52 million m^2) for a total of 13.9 GW_{th} (19.8 million m^2), close to meeting the Solar Mission target for 2022.[29] Sales of vacuum tube collectors dropped 19%, while flat plate collector sales fell 50%, to their lowest share (5%) in eight years.[30] 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.[31] 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.[32]

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.[33] 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.[34] Türkiye also is home to the world's largest solar thermal cooling system, inaugurated in 2022.[35] In total, Türkiye added an estimated 1.3 GW_{th} in 2022, down more than 4% from 2020, for a cumulative operating capacity of 19.1 GW_{th}.[36] 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.[37]

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

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.[41]

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.

i 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).[42] Most solar thermal systems in Europe are on rooftops and are used for residential water heating.[43] The top five European countries for new additions in 2022 were Germany, Greece, Italy, Poland and Spain.[44]

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_{th} (709,000 m^2).[45] This was Germany's third year of market stability or growth following several years of contraction.[46] 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.[47] By the end of 2022, Germany reached an estimated 15.5 GW_{th} (22.1 million m^2) of capacity in operation.[48]

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

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

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

As in 2021, **Spain** was the only top-five European market where additions fell during the year.[60] The 12% decline in 2022 followed a 24% decline over the period 2017-2021, with an estimated 102 MW_{th} (145,500 m^2) added in 2022.[61] 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.[62] This is despite significant government incentives, such as grants for industry and for up to 60% of some residential installations.[63]

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.[64] Additional plants, or extensions of existing ones, were commissioned in Austria, Denmark and Italy (where two new plants came online).[65] By year's end, 325 large-scale[iii] solar thermal district heating systems with a total capacity of nearly 1.8 GW_{th} (2.56 million m^2) were documented as operating around the world, many of them with seasonal storage capacity.[66]

China reported[iv] commissioning a total of 119.7 MW_{th} (171,068 m^2) in an estimated 25 solar district heating systems.[67] By the end of 2022, the country had around 67 solar district heating systems totalling 400 MW_{th}.[68] Work continued on the 79.8 MW_{th} (114,000 m^2) 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.[69]

Germany had a record year, with eight plants (totalling 30.8 MW_{th} or 44,000 m^2) starting operations in 2022, compared with nine plants (33 MW_{th}) in all of Europe during 2021.[70] 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.[71]

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^2).

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

Only one solar district heating system began operating in **Denmark** during 2022, a 1.9 MW_{th} (2,664 m^2) project in the city of Hørsholm, following one new plant in 2021.[75] 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_{th} (1.6 million m^2) operating at the end of 2022.[76] 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.[77] 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.[78] However, public funding expanded in 2022 to include solar thermal.[79]

Total solar collector sales in **Austria** fell 15% in 2022, despite a significant extension to a large system for district heating in Graz.[80] 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.[81] In early 2023, 27 feasibility studies were under way for nearly 1 million m^2 of solar collector area.[82]

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.[83] 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.[84] The European Commission, Germany's KfW bank and the EBRD, together with a local contribution, will fund a 40.6 MW_{th} collector field with absorption heat pumps and a 408,000 m^3 seasonal storage facility in Kosovo's capital, Pristina.[85]

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.[86] 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.[87]

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[i] requiring low (below 150°C) or medium (150-400°C) temperature heat.[88] 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[ii].[89]

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

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

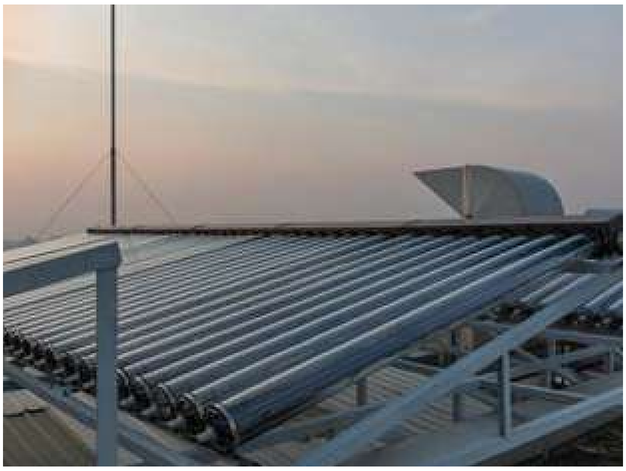
The list of countries with the highest numbers of newly commissioned SHIP projects[iv] changed again in 2022, with the Netherlands taking the lead over China and Mexico with 38 systems, followed by China (17), France (14), Mexico (13) and Germany (9).[98] The leading markets for new capacity installed[v]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

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^2 of gross collector area.[100] Outside of China, the number of annual installations nearly doubled from 55 systems in 2020 (totalling 22 MW_{th}) to 97 in 2022 (23 MW_{th}).[101] The Netherlands and France (1.8 MW_{th}) led in Europe due to a large number of subsidised agricultural systems.[102] After several years with little activity, the United States brought online four new systems, including its first solar steam boiler.[103]

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

Such **heat purchase agreements** are increasingly common and are moving SHIP into new markets.[110] 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[vii].[111]

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.[112] SHIP remains a challenging sector because awareness of the options remains low, clients typically want short payback periods, and projects require significant lead time[viii].[113] GlassPoint (United States), which built the world's largest SHIP plant in Oman (33 MW_{th}) in 2019, was liquidated in 2020 but restarted operations in 2022, committing to develop a 1.5 GW_{th} solar steam plant[ix] for a mining company in Saudi Arabia.[114]



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, dying) 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[i] 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.[1] (→ *See Figure 31.*) In total, an estimated 89 GW[ii] was mechanically installed around the world during 2022.[2]

The year 2022 was the third largest ever for new installations.[3] 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.[4] 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.[5]

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.[6] 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.[7] 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.[8]

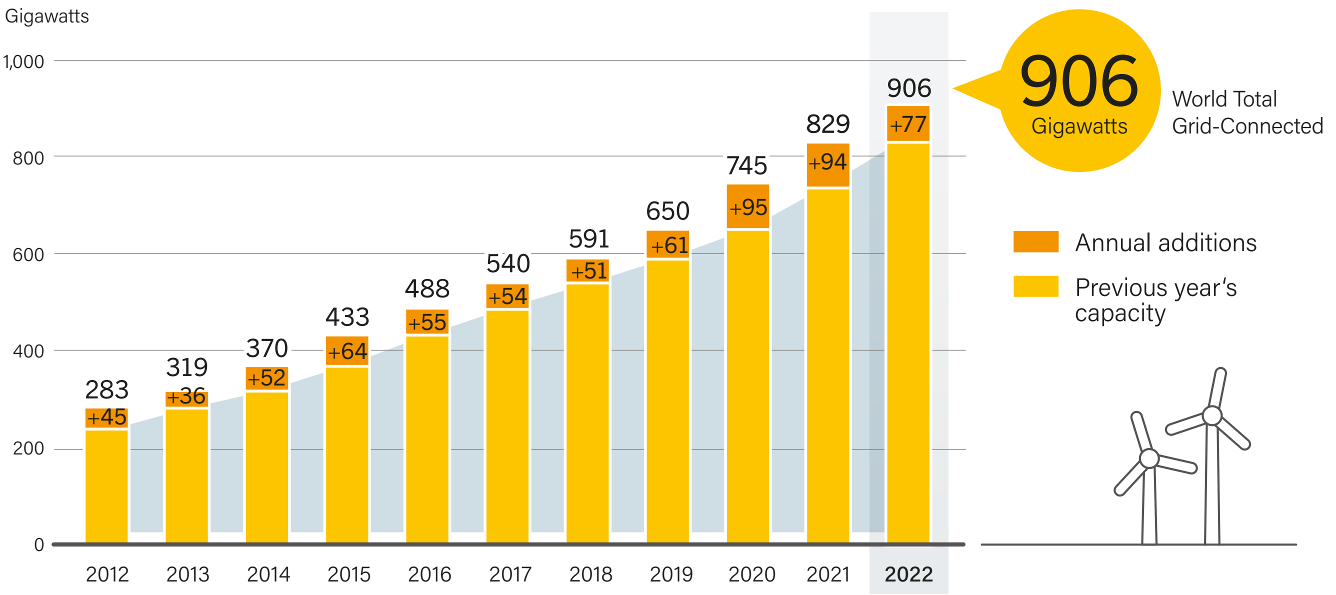
Despite the competitiveness of wind energy and ambitious national targets, new obstacles in 2022 compounded existing challenges, affecting installations and investments, the health of the wind industry and its ability to scale production to meet future demand.[9] Pressured by policies that for years 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.[10] 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.[11] The COVID-19 pandemic disrupted supply chains, created logistics challenges, pushed up costs for shipping and materials, and delayed projects[iii] – challenges that continued into 2022.[12]

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[i] wind energy.[13] Unfavourable policies and shifting regulatory landscapes in many countries increased market uncertainty, while developers delayed projects due to rising costs and interest rates, thereby reducing new turbine orders.[14] Western manufacturers also faced increased competition from Chinese turbine makers, which have pro-actively pursued sales overseas.[15]

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

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.[16] 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.[17]

i 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.[18] 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.[19]

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.[20] On a positive note, non-price criteria are increasingly being included in policy design, at least for offshore wind auctions in Europe.[21] In addition, strong community engagement and local investment have helped reduce local resistance to projects and speed the permitting process in many countries.[22]

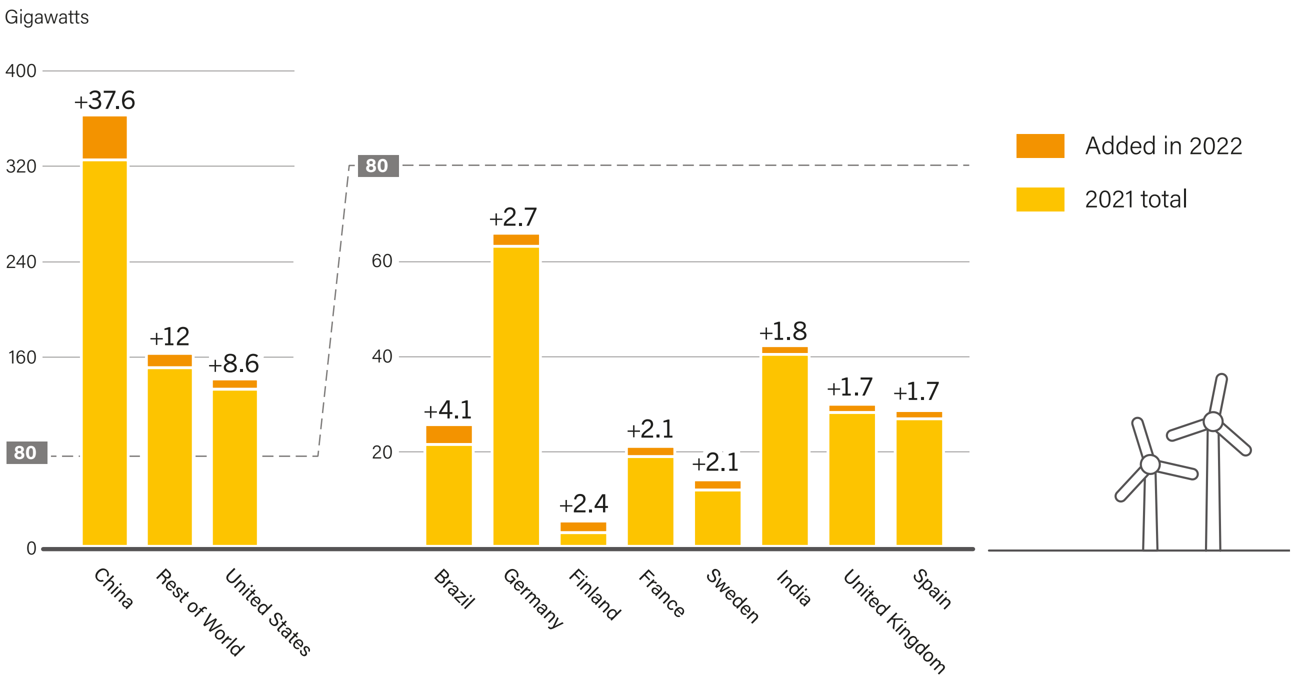
TOP MARKETS

New wind farms reached full commercial operation in at least 45 countries in 2022, down from 52 countries in 2021.[23] 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).[24] 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%).[25] 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.[26] Other countries in the top 10[i] for total capacity additions were France, Sweden, India, the United Kingdom and Spain.[27] (→ *See Figure 32.*) The list of the 10[ii] leading countries for cumulative capacity remained the same as in 2021.[28]

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.[29] Installers connected 37.6 GW[i] 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.[30] 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.[31] Project commissioning late in the year also was slowed significantly by pandemic-related restrictions.[32]

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.[33] 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.[34] In late December, the government announced a target to reach 430 GW of wind power capacity by the end of 2023.[35]

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.[36] The country accounts for some 60% of global turbine and component manufacturing capacity.[37] 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[ii].[38] 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).[39]

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[iii] (gross additions, all onshore), the country's lowest annual additions since 2018.[40] 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[iv].[41] By year's end, the United States had 144.2 GW (including 42 MW offshore) of wind power capacity in operation.[42] Wind energy accounted for 10.2% of US utility-scale electricity generation in 2022, up from 9.2% in 2021.[43]

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.[44] Announcements for wind PPAs rose 15% relative to 2021, although they were below those for the period 2018-2020.[45] 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.[46]

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.[47] Brazil accounted for almost 80% of installations in Latin America and the Caribbean during 2022.[48] The country's strong growth was driven by public auctions and particularly by private PPAs, with the shift towards corporate PPAs continuing.[49] Wind energy has achieved the country's lowest free market price for electricity.[50] At the end of 2022, Brazil had more than 25.6 GW of operating wind power capacity.[51] Wind energy was the country's second largest source of electricity after hydropower, accounting for 13.6% of the mix in 2022.[52]

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%.[53] All of Europe added a record 17.9 GW (net 17.4 GW[i]) 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).[54] 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).[55]

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.[56] Individual countries worked to simplify planning procedures during the year, and in December the EU formally agreed on emergency measures to address permitting challenges.[57]

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

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.[61] These six countries accounted for nearly 60% of Europe's annual wind power installations and were all among the global top 10.[62] Except for Sweden and the United Kingdom, annual additions increased significantly in all of these countries in 2022.[63]

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 MW 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).[64] 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.[65] Wind energy generation increased 9%[ii] in 2022, to 125.3 TWh.[66]

To accelerate deployment, Germany committed to installing 10 GW of onshore wind power annually starting in 2025 and set new targets for offshore capacity.[67] 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[iii] on profits from generation.[68] 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.[69]

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.[70] 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.[71] Finland met around 14% of its electricity demand with wind energy in 2022.[72]

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.[73] 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).[74] Wind energy met an estimated 8% of France's electricity demand during the year.[75]

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).[76] The country ranked fourth in Europe and seventh globally for new capacity.[77] Sweden does not use auctions to support deployment of wind power capacity, but the domestic industry is supported by a strong PPA market.[78] 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.[79]

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).[80] Onshore additions rose slightly (0.5 GW), while offshore installations fell nearly 50% (below 1.2 GW), following a record year in 2021.[81] After several years of low onshore installation rates, the UK government signalled plans to relax restrictions on land-based construction set in 2015.[82] At year's end, total capacity approached 28.5 GW (14.6 GW onshore, 13.9 GW offshore).[83] 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.[84]

Spain added nearly 1.7 GW (all onshore), more than twice the additions of 2021, bringing total capacity to 29.8 GW.[85] 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.[86] Wind energy generation increased slightly over 2021 to an estimated 61 TWh.[87]

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[i] in wind energy's output and share of total electricity demand.[88] 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).[89] 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%).[90] 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).[91] These five countries together accounted for nearly 66% of the regional total.[92]

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

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.[96] 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.[97] 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.[98] 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.[99]

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).[100] (→ *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.[101] In late 2022, China's largest unsubsidised offshore wind power project (0.9 GW) entered full operations off the coast of Guangdong Province.[102] 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.[103]

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.[104] 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.[105] In mid-2022, the United Kingdom held the world's first commercial leasing round to support large-scale floating wind power[i], 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.[106]

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.[107] Germany also added capacity (0.3 GW) during 2022.[108]

At year's end, Europe's total offshore capacity reached 30.3 GW across 13 countries.[109] 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.[110] 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.[111]

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.[112] More than 13 GW was awarded through state and federal lease sales, including the first offshore wind lease sale[ii] in the Pacific Ocean (California).[113] 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.[114] In all, 10 US states had combined procurement targets of more than 74 GW.[115]

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.[116] 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.[117] 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.[118]

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.[119] 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).[120] Asia (mostly China) was home to nearly 53% of global offshore capacity, taking over the lead long held by Europe.[121]

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.[122] 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.[123] Chinese firms led in the volume of new wind-related patent applications.[124]

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

Western turbine manufacturers continued to invest in new models even though they were not making enough profit to cover the costs.[128] 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.[129] Chinese firms also have been driven by price pressures to innovate and are competing to outsize one another in turbines.[130] 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.[131]

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.[132] 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.[133]

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

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.[134] 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.[135] 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.[136] 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.[137]

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.

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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

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ENDNOTES – GEOTHERMAL POWER AND HEAT

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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.

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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 produçao...", 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.

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39 Brazil from information and sources in this section; Australia from Ferrari, op. cit. note 5; United States from Heavner, op. cit. note 13.

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44 Based on data and sources throughout this section.

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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.

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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 m² = 0.7 GW_{th}.

67 Weiss and Spörk-Dür, op. cit. note 1. The figure of 25 is based on an average reported size of 4.86 MW_{th} (6,945 m²) 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_{th}, 500 m²) were in operation (totalling 2,148 MW_{th}; 3.1 million m²), including district heating systems and those for individual buildings. The total installed capacity of these systems equaled 2,148 MW_{th}, corresponding to 3.1 million m² 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/o66GAR8KQMK7I7DB_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_{th}, 185,000 m²). Around 130 MW_{th} (185,000 m²) of vacuum tube collectors were added in 2022 and nearly 367 MW_{th} (524,000 m²) 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 m²), Aschersleben (3,717 m²), Schönwald (2,860 m²), Horb am Neckar (2,416 m²), Markt Erlbach (2,400 m²), and Dettenhausen and Sigmaringen (both 2,312 m²), 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 m², and of the 50 plants in preparation is based on gross collector area of 286,400 m², 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_{th} (8,013 m²) 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_{th} (1,611,065 m²); accounting for decommissioning, a total of 1,125 MW_{th} (1,607,015 m²) was in operation; in addition, another three projects totalling 8.3 MW_{th} (11,910 m²) 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 m², bringing the total to 6,134 m², 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 m² 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_{th}/35,000 m² of collector area) was completed, and a plant in the range of 45-136 MW_{th} 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. Byström, 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^2 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^2 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_{th} 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^2) 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^2, 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_{th} (4,000 m^2) 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; 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.

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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.

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50 Feitosa, op. cit. note 49.

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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.

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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.

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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.

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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.

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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, totaling 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.

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"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.

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