REN21

RENEWABLES 2024
GLOBAL STATUS REPORT

ENERGY SUPPLY

2024

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FOREWORD

In 2023, ongoing economic and geopolitical developments continued to cause major changes to the world's energy system. Markets were tighter and policy makers shifted their focus to ensuring security of supply. High inflation and cost of capital are inhibiting investment, particularly in developing countries with high debt burdens, making development highly unequal across regions.

The good news is that many governments are adopting and promoting renewables as an affordable and secure source of energy to stabilise supply and mitigate inflation. Significant momentum has already been building in the power sector, where renewable electricity is driving the shift in energy supply. Renewables now account for over 30% of total final energy consumption in the power sector.

But we need to accelerate this trend with necessary targets and policies. Special attention must be paid to increasing renewable uptake in heat and fuels as rates still hover at 10% and 3.5% respectively. The UNFCCC COP28 agreement to triple renewable energy capacity and double energy efficiency improvements provides a real opportunity. With the Nationally Determined Contributions (NDCs) towards reducing greenhouse gas emissions under the Paris Agreement, there is a window of opportunity to make clear commitments and raise ambition on renewable energy, but this opportunity must be seized now.

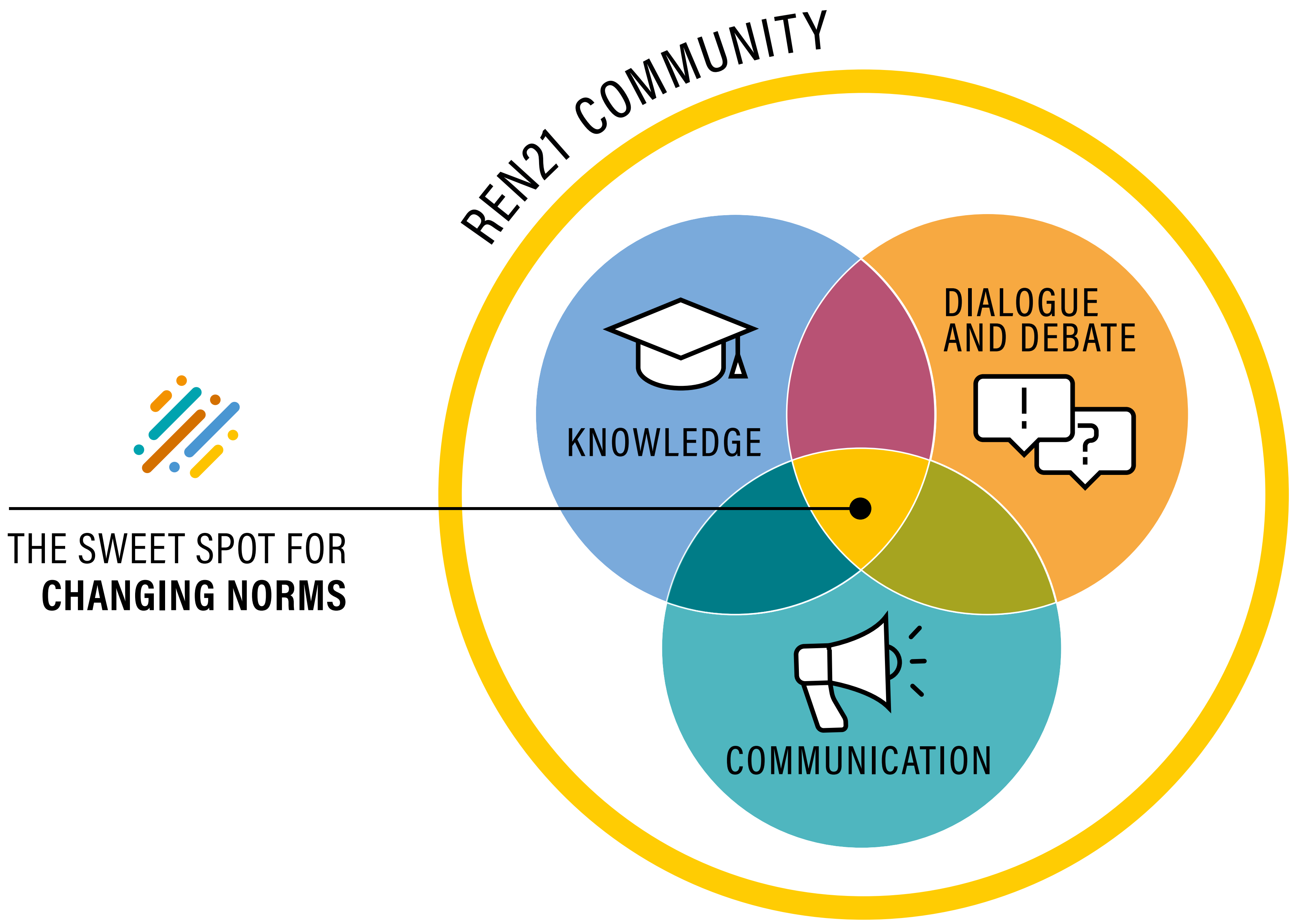
The *Renewables 2024 Global Status Report – Energy Supply Module* delves into the intricacies of renewable energy progress, examining the distribution of energy among carriers and outlining critical obstacles. It is the third of five modules released this year and represents the collaborative efforts of hundreds of contributors who provide unbiased data and knowledge.

I hope that, in this module, you will find the essential elements and tools to support your work in enabling a swift transition to renewable energy. Thank you to the REN21 team, authors, special advisor and contributors who have given their knowledge, time and effort to produce this report. Their insights and commitment are core in producing these crowd-sourced and peer-reviewed reports. I am confident that this publication will serve as a valuable resource for policy makers, industry leaders and stakeholders to inform decision making in support of a sustainable energy future.

Sincerely,

Rana Adib
Executive Director, REN21

RENEWABLE ENERGY POLICY NETWORK
FOR THE 21st CENTURY



REN21 is unique. It is the only global, **multi-stakeholder network** dedicated to renewables.

We create an **enabling environment to support renewable uptake**. Together, we build knowledge, shape dialogue and debate, and communicate this information to strategically drive the deep transformations needed to make renewables the norm.

Shifting to renewables is more than a fuel switch; it requires engaging with market players and society at large. **REN21 works in close co-operation with its community**, providing a platform for all stakeholders to engage and collaborate.

Through these collective efforts, REN21 builds bridges and amplifies positive and sustainable energy solutions. Our goal: enable decision makers to **make the shift to renewable energy happen – now.**

20 YEARS OF REN21

This year marks two decades since the inception of REN21 – an opportunity to celebrate 20 years of instrumental contributions to the advancement, shaping and understanding of renewable energy worldwide.

Established in 2004, REN21 emerged from the collective vision of global pioneers who convened to call for accelerated commitments towards renewable energy adoption. For two decades, REN21 has been pivotal in elevating renewables to the forefront of global agendas for leaders and decision makers across all stakeholder groups, enabling knowledge exchange, dialogue and debate about the global transition to renewables.

The 20th-anniversary celebration of REN21 is also the occasion to acknowledge REN21's flagship knowledge product, the *Renewables Global Status Report*. Since the GSR's first release in 2005, REN21 has published 18 editions of the report, crafted annually with the most up-to-date insights, facts and stories from thousands of contributors spanning diverse regions and sectors. The GSR has been central to fulfilling REN21's mission, becoming a reference for many and positioning REN21 as the global trusted voice on renewables.

20 YEARS OF CROWD-SOURCED, CROWD-OWNED KNOWLEDGE AND DATA

REN21's data and knowledge collection method is unique, drawing upon the organisation's global multi-stakeholder community of experts. Contributors from across the globe are invited to submit data, insights and stories on annual developments in renewable energy technologies, market trends, policies and local perspectives, resulting in a comprehensive and diverse dataset.

REN21 performs rigorous data validation and fact-checking throughout the report's development, ensuring accuracy and reliability. Validation of the data is a collaborative and transparent process conducted through open peer reviews.

Collectively, hundreds of experts contribute to making the GSR one of the most authoritative and comprehensive publications in the field of renewables. Alongside its wealth of key facts and figures, the GSR is openly accessible, fostering a shared language that shapes the sectoral, regional and global debate on the energy transition.

Supported by:

Federal Ministry for Economic Affairs and Climate Action

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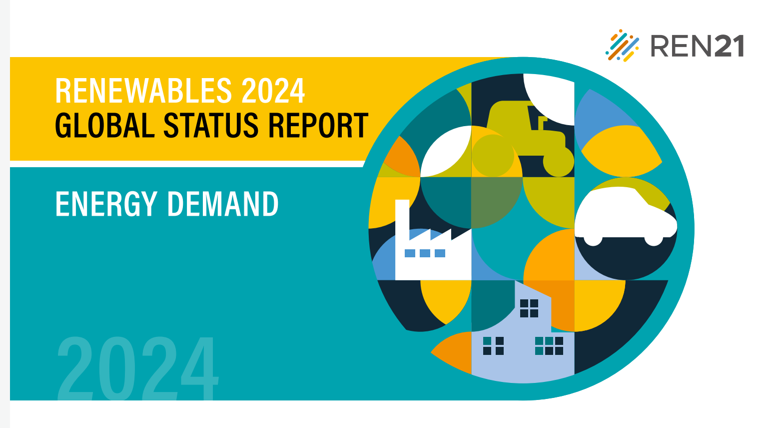
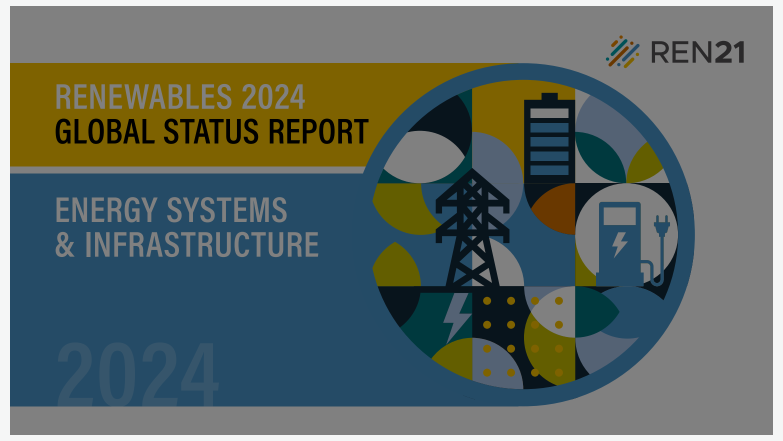
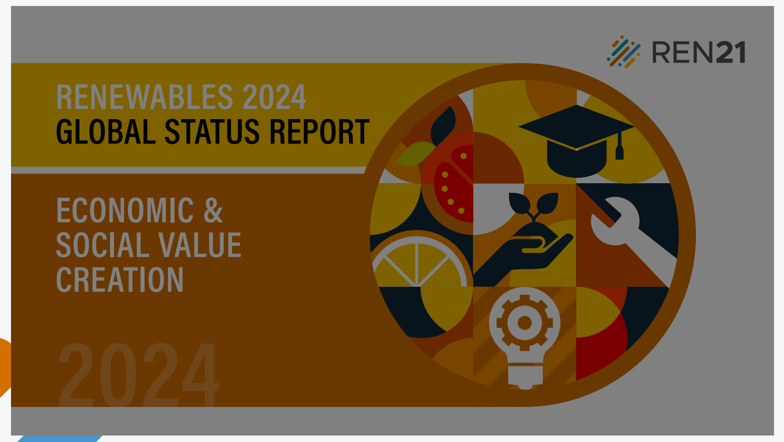
A large share of the research for this report was conducted on a voluntary basis.

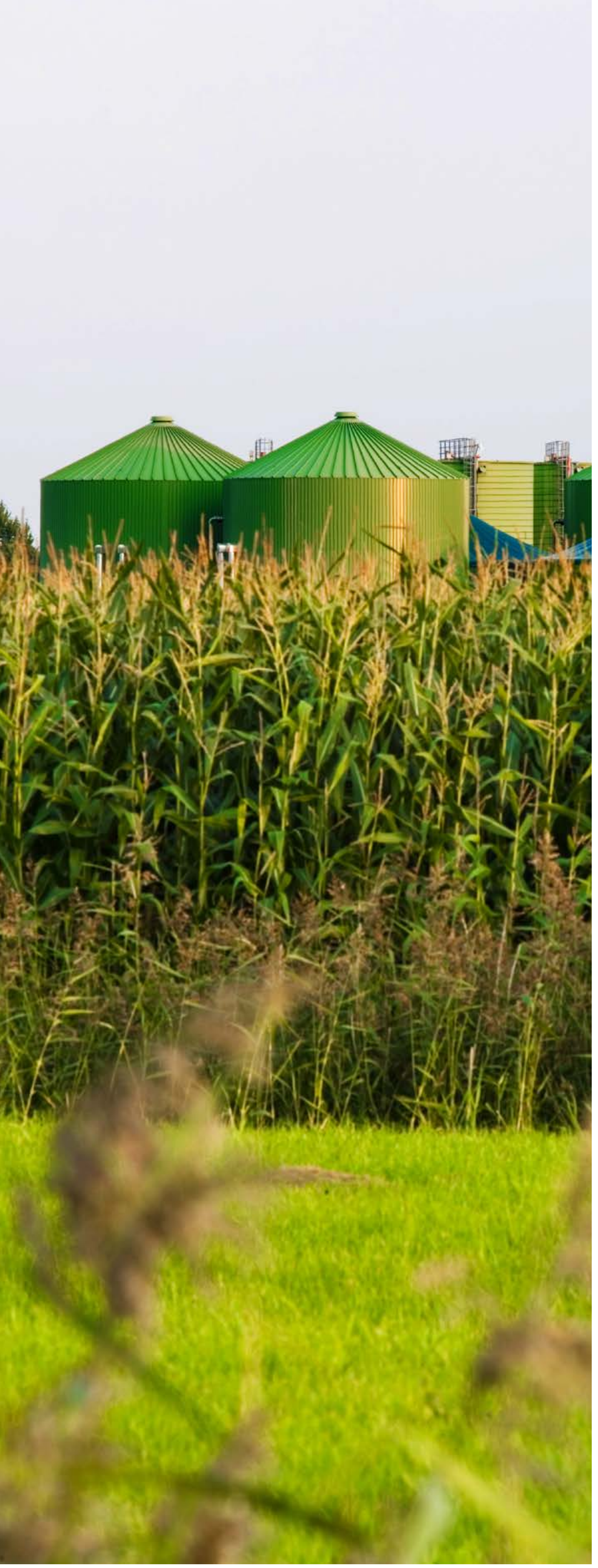
RENEWABLES GLOBAL STATUS REPORT
2024 COLLECTION

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. Structured as a collection of five publications, this year's 19th edition of the GSR reflects key trends in global energy. In addition to presenting the latest developments in renewable energy supply, the GSR also provides a global overview of the renewables landscape and dives into different energy demand sectors with dedicated modules on buildings, industry, transport and agriculture. The collection further includes a publication on renewable energy systems and infrastructure as well as a publication on renewables for economic and social value creation, acknowledging the key benefits of renewables for economies and societies. Collectively, these five publications offer readers a systemic global overview of the current uptake of renewables.









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ENERGY SUPPLY

TABLE OF CONTENTS

For further details and access to the report, references and endnotes, visit **www.ren21.net/gsr-2024**

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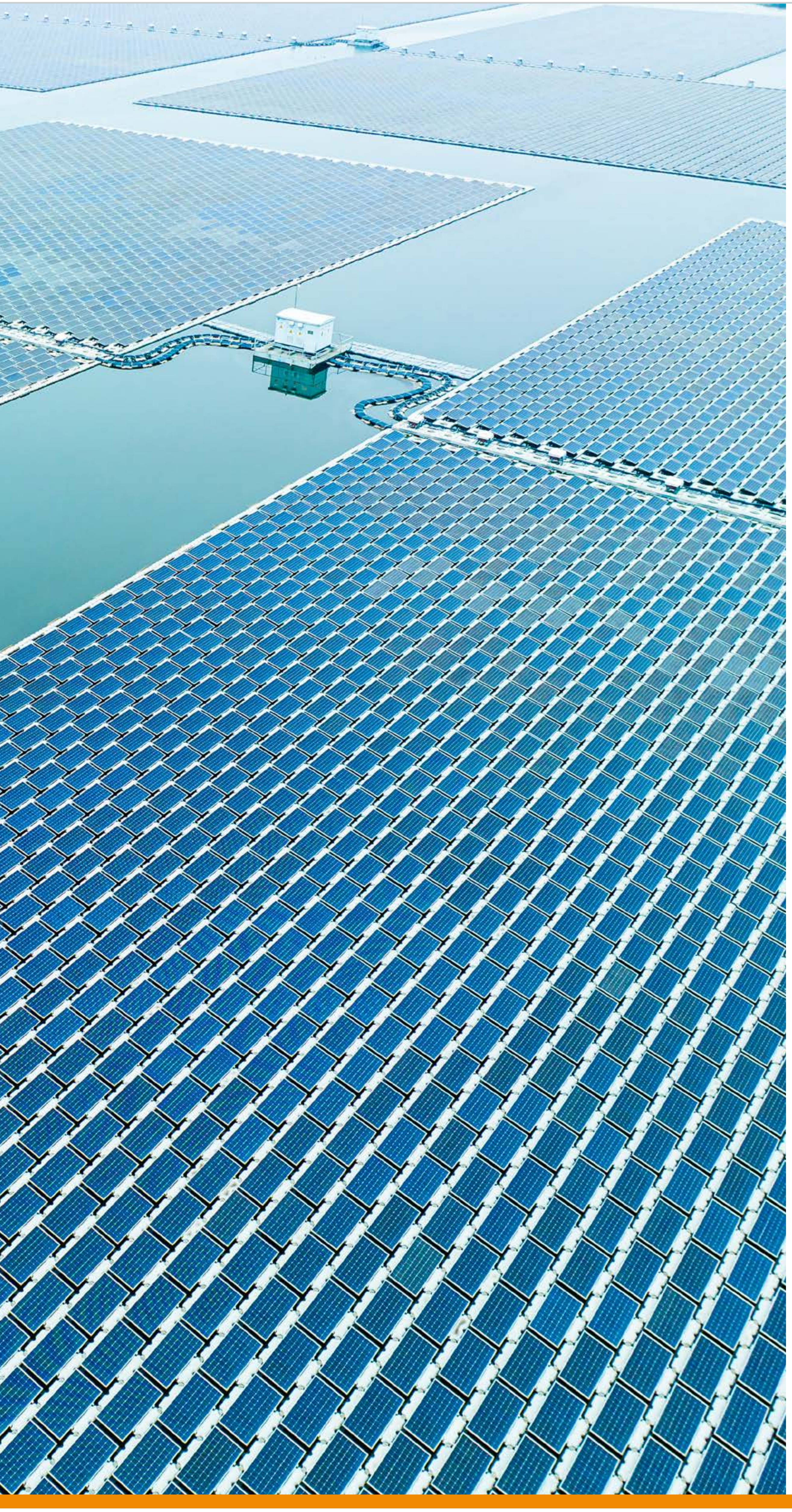
Comments and questions are welcome and can be sent to **gsr@ren21.net**.



FIGURES

TABLES

SIDEBARS

SNAPSHOTS

GLOBAL STATUS REPORT 2024 COLLECTION

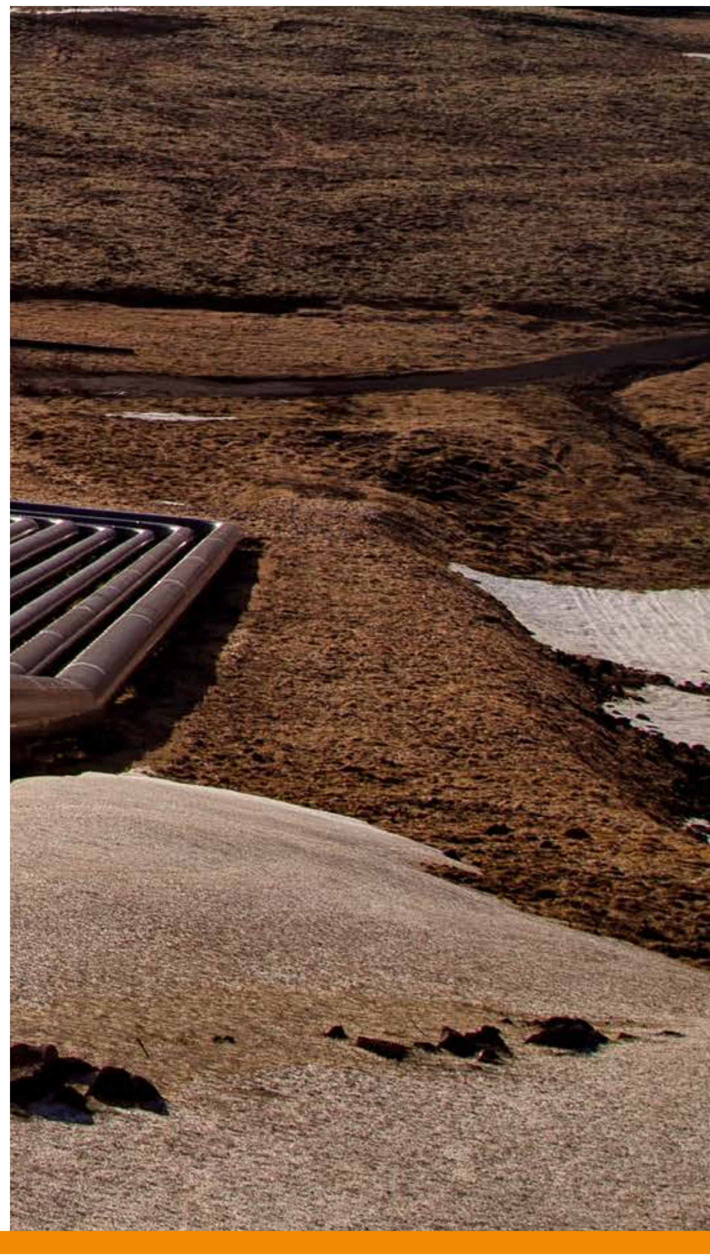
ENERGY SUPPLY

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 2024 *Supply* Data Pack at

→ http://www.ren21.net/gsr2024-data-pack/supply



GLOBAL TRENDS

Developments in renewable energy supply are uneven across energy carriers, regions and technologies.

536 GW renewable power capacity added in 2023

USD billion 623 investment in renewable power and fuels in 2023

182 countries with renewable energy targets across all sectors and technologies in 2023

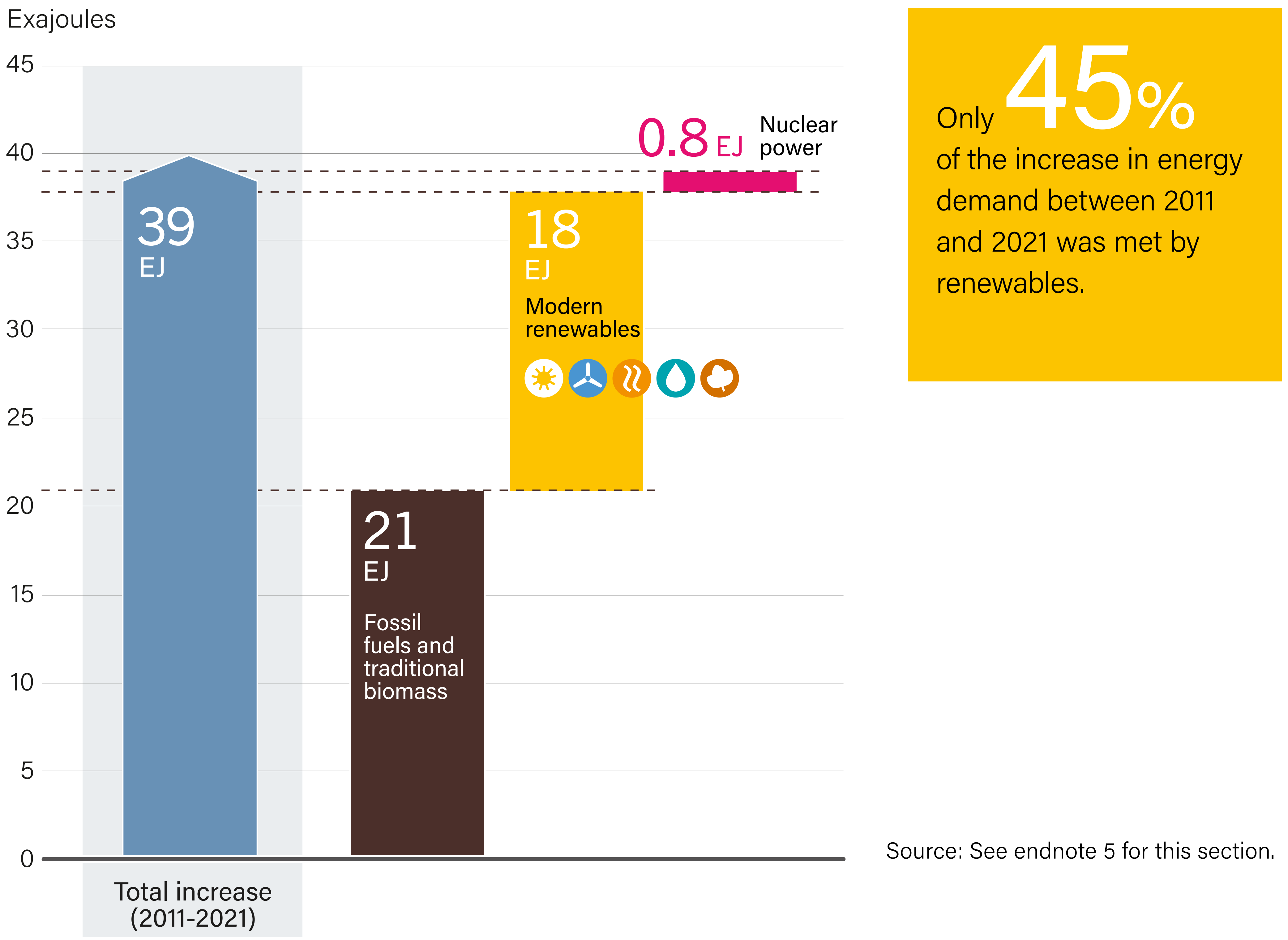
KEY FACTS

- Global investment in and deployment of renewables reached an all-time high in 2023, despite high interest rates and higher costs of raw materials.
- Globally, renewable energy supplied 30% of electricity, 10% of heat and 3.5% of fuel in 2023.
- Global renewable capacity additions need to reach almost 1 terawatt (TW) per year to achieve the global target of 11 TW by 2030.
- Investment in renewable energy and enabling technology manufacturing grew 70% in 2023, mainly in solar PV and batteries.
- In 2023, 24 countries updated their targets for the share of renewables in the electricity supply.

MODULE OVERVIEW

Ongoing economic and geopolitical developments spurred extensive transformations in the global energy supply landscape in 2023, with tighter markets and an increased focus on energy security. The post-pandemic economic rebound sparked high energy demand, which strained supply chains and caused price volatility, while the Russian Federation's invasion of Ukraine compounded these challenges and further destabilised markets.[1] High inflation and cost of capital continued to hamper investment, particularly in developing countries with high debt burdens.[2]

FIGURE 1.
Increase in Energy Demand by Source, 2011-2021



Source: See endnote 5 for this section.

Many governments have promoted renewables as an affordable and secure source of energy to stabilise supply and mitigate inflation. Policy packages such as the US Inflation Reduction Act and the European Union's (EU) REPowerEU are aimed at boosting domestic manufacturing and deployment.

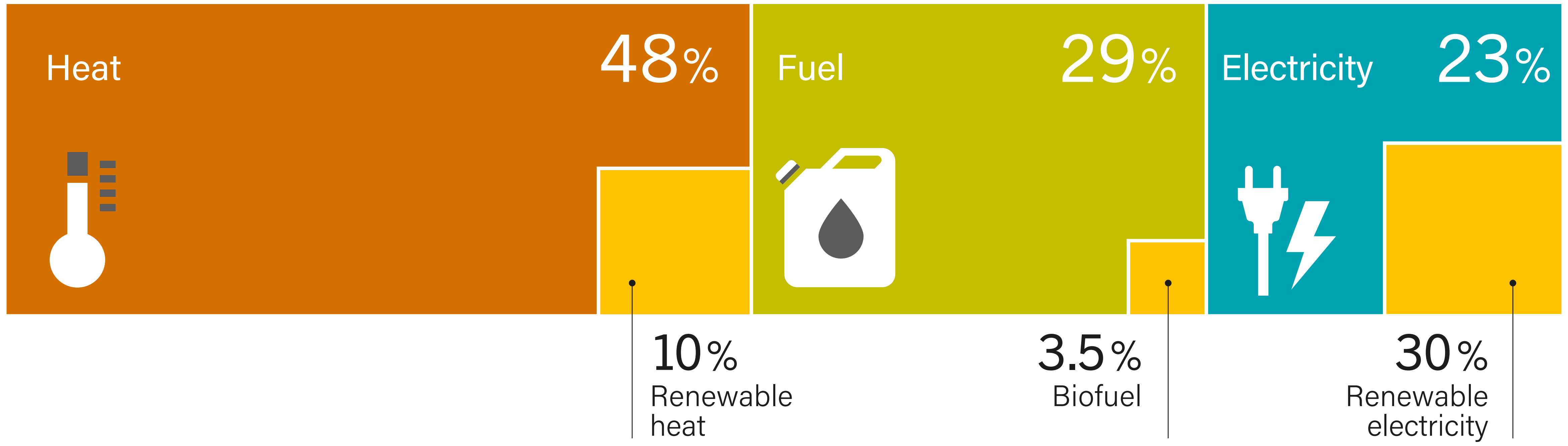
Direct subsidies to fossil fuels totalled around USD 600 billion in 2023, still above 2021 levels but below the all-time high of more than USD 1 trillion during the global energy crisis in 2022.[3] Many countries have moved to phase out fossil-fuelled heating systems and internal combustion engines, and there is increasing momentum to ban fossil fuels altogether and to redirect subsidies towards renewables.[4]

RENEWABLE ELECTRICITY IS DRIVING THE SHIFT IN ENERGY SUPPLY

Between 2011 and 2021, total energy demand increased by 39 exajoules (EJ); fossil fuels and traditional biomass covered 53% of the increase while modern renewables covered only 45%.[5] (→ *See Figure 1.*)

In 2021, nearly half of the world's total final energy consumption was in the form of direct heat, followed by fuels (including liquid and gaseous fuels for transport), with a 29% share.[6] (→ *See Figure 2.*)

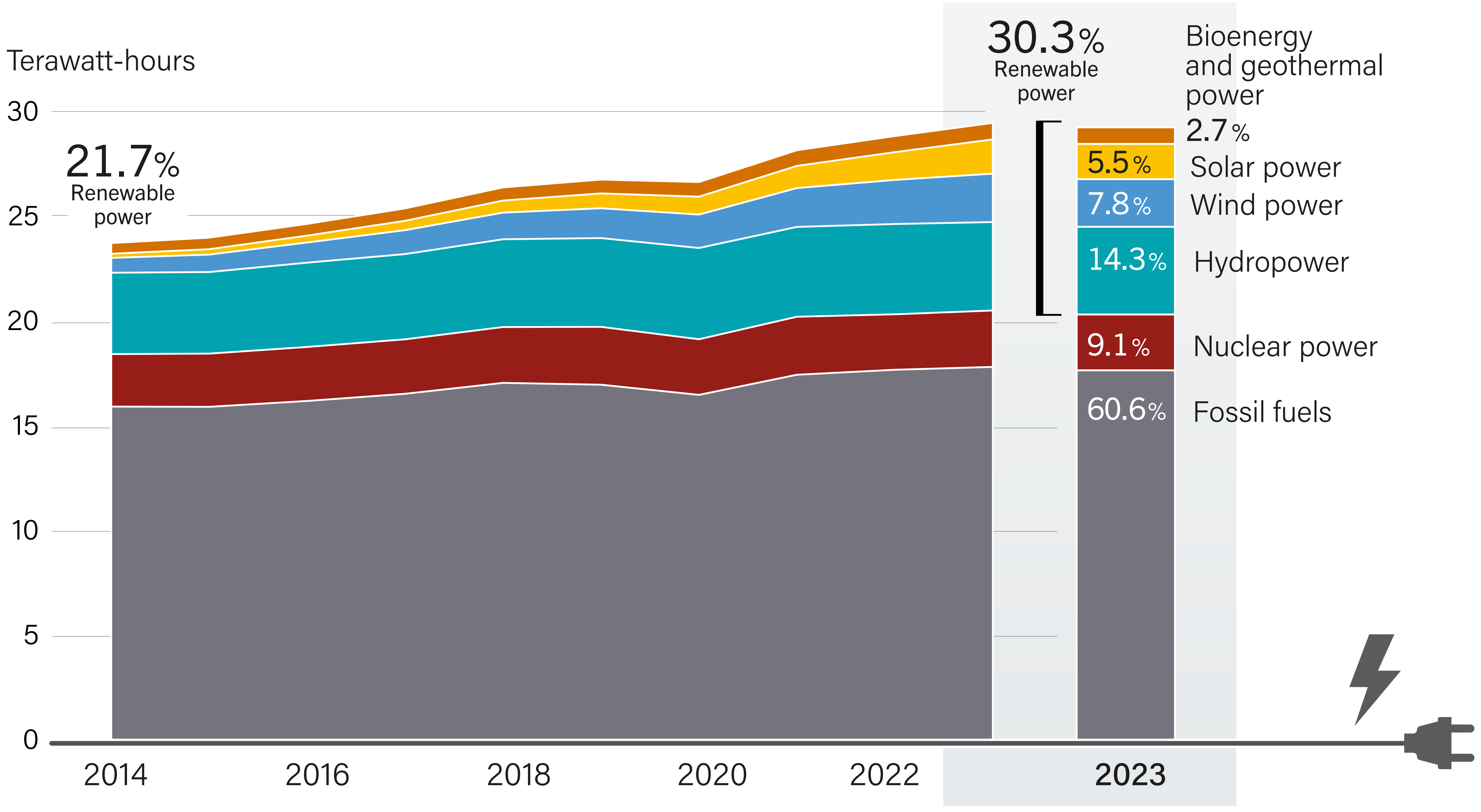
FIGURE 2.
Total Final Energy Consumption and Share of Modern Renewables, by Energy Carrier, 2021



Source: Based on IEA. See endnote 6 for this section.

The proportion of electricity (also used for heat and transport) in the global energy supply has been rising consistently – reaching 23% in 2021, up from 19% in 2011 – with increasing dependence on electricity to meet demand across all sectors.[7] The renewable share in electricity generation increased marginally from 29.4% in 2022 to 30.3% in 2023, although this mostly covered the increase in electricity demand rather than replacing fossil fuels.[8] (→ *See Figure 3.*)

FIGURE 3.
Electricity Generation by Energy Source, 2014-2023



Source: Ember. See endnote 8 for this section.

Installed **renewable power** capacity continued to grow, particularly wind and solar power, driven by policy support and investment that reached a record high of USD 622.5 billion in 2023 (up 8.1% from 2022).[9] The majority (86%) of power capacity additions during the year were renewable, with record additions in solar photovoltaics (PV) (407 gigawatts, GW) and wind power (117 GW), which together accounted for 98% of renewable capacity additions.[10] Capacity growth in 2023 was driven largely by China (solar PV and wind power), as well as by the United States and the EU (solar PV), and India and Brazil (solar PV and wind power).[11]

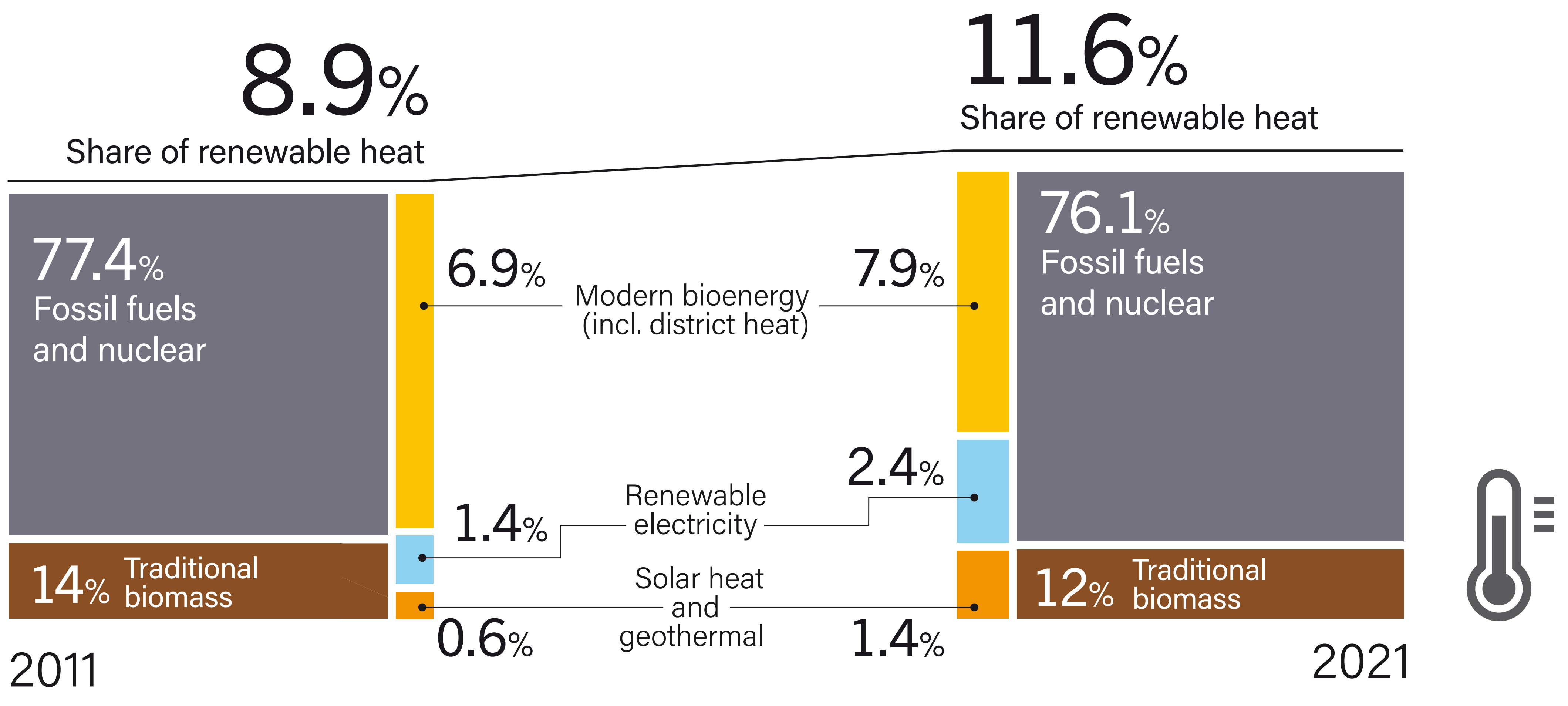
Progress in **renewable heat** has been comparatively slower, with the share of modern renewables (excluding traditional biomass[i]) in the heat supply increasing moderately from 8.9% in 2011 to 11.6% in 2021.[12] (→ *See Figure 4.*) Modern bioenergy remained the dominant source of renewable heat, supplying 7.9%, while solar thermal and geothermal direct heat contributed 1.4%; the remaining 2.4% was supplied by renewable electricity.[13]

Biofuels accounted for almost all **renewable fuels**. Renewable hydrogen has been seen as a potential game-changer for decarbonising energy-intensive sectors, and in 2023 the number of electrolysis plants grew rapidly to total around 1.1 GW of capacity, up from 700 megawatts (MW) in 2022.[14] However, more than 99% of current hydrogen production is still based on fossil fuels.[15]

Renewable electrcity generation has grown an average of **5.4%** per year over the last decade.

i Traditional biomass is solid biomass (including fuel wood, charcoal, agricultural and forest residues, and animal dung) that is used in rural areas of developing countries with traditional technologies such as open fires and ovens for cooking and residential heating. Often the traditional use of biomass leads to high pollution levels, forest degradation and deforestation.

FIGURE 4.
Share of Renewable Heat Production by Energy Source, 2011 and 2021



Source: IEA. See endnote 12 for this section.

REGIONAL DISPARITIES IN THE ENERGY TRANSITION

Regional developments in renewables remained highly unequal in 2023, with technological advances and investments occurring mainly in China, the EU and the United States.[16] These regions saw significant investments in solar PV and wind power as well as energy storage, backed by substantial policy support and financial incentives. China maintained the global lead in renewable energy **investments**, accounting for 44% of the total in 2023, followed by Europe (20.9%) and the United States (15%).[17] Africa and the Middle East together represented only 3.6% of investment in renewables.[18]

In the **renewable heat** sector, modern bioenergy produced 1.3 EJ of derived heat in 2021, a 9% increase from 2020; solid biomass (wood chips, pellets, etc.) comprised more than half of the total, followed by waste-to-energy (43%) and biogas (only 4%).[19] The solar heat market contracted 7.2% globally, to reach a newly installed capacity of an estimated 21 gigawatts-thermal (GW_{th}).[20] China accounted for around 65% of global sales of solar water collectors (for heating), followed by India, Brazil, Türkiye and the United States.[21] China was the world's fastest growing market for geothermal heat, with key markets also in Türkiye, Iceland and Japan; together, these four countries accounted for nearly 90% of global geothermal direct use in 2023.[22] A total of 0.1 GW of geothermal power capacity was added in 2023.[23]

For **renewable fuels**, the United States supplied 40% of the world's biofuels in 2022 (latest available data), followed by Brazil (21%) and Indonesia (6.2%).[24] Germany contributed 2.8% of the world's supply, ranking it among the top five producers and as the European leader.[25]

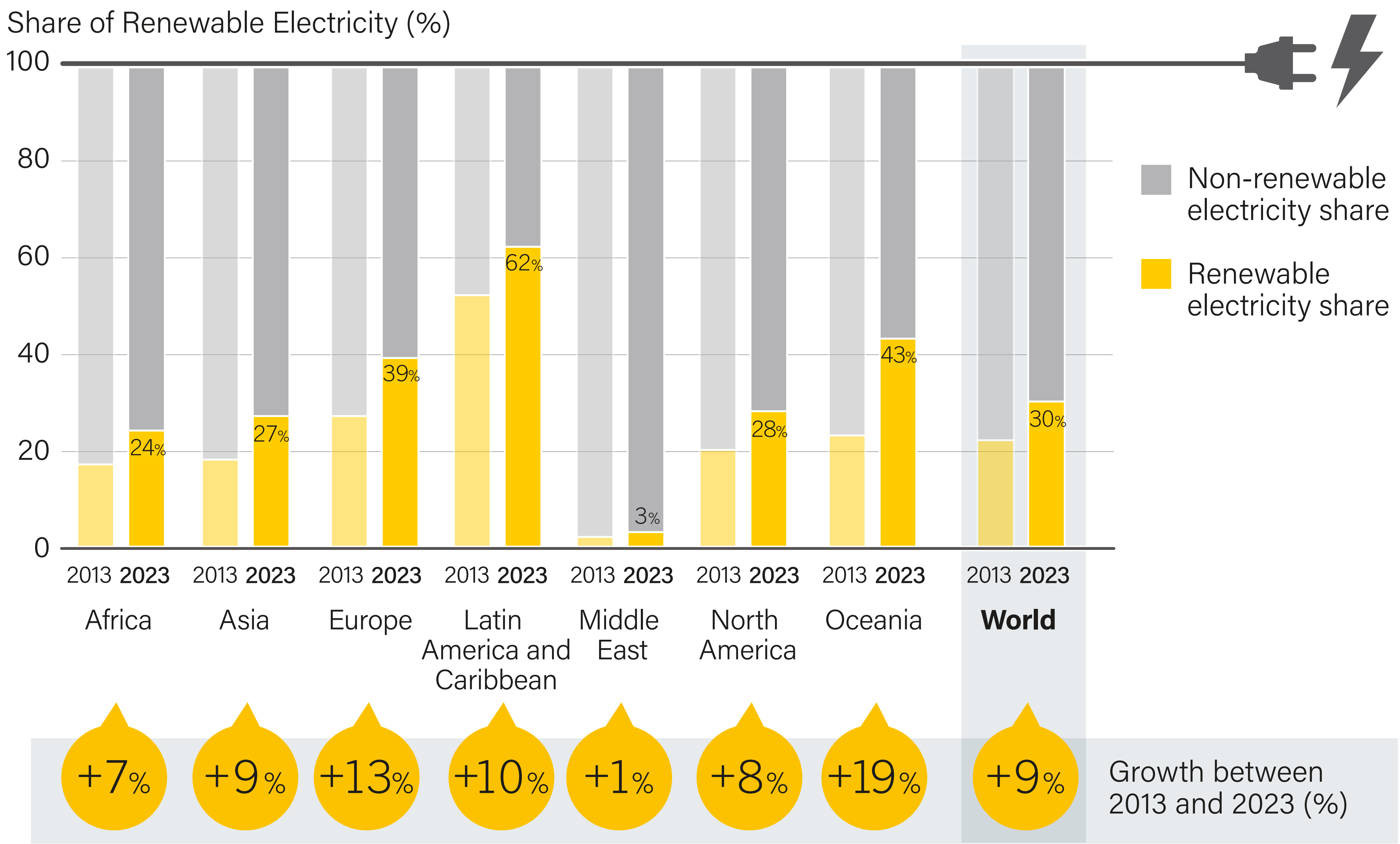
Europe, the Americas and Oceania have emerged as leaders in low-carbon[i] hydrogen production, accounting for more than 80% of the annual total of around 45 million tonnes of announced volumes.[26] China, India and the Middle East showed the highest relative growth in announced low-carbon hydrogen production to 2030.[27] Global growth in renewable hydrogen announcements to 2030 (more than 6.5 million tonnes annually) greatly outpaced low-carbon hydrogen announcements (around 0.4 million tonnes annually).[28] The stronger growth in renewable hydrogen announcements is linked to a greater regulatory focus on renewable hydrogen and to the larger number of regions with attractive resources for production.[29]

Latin America and the Caribbean had the highest regional share of renewables in the electricity mix in 2023, at 62% (up from 52% a decade earlier).[30] (→ *See Figure 5.*) Hydropower continued to dominate the region's electricity supply, contributing 43.2% of total generation and 69.8% of renewable generation.[31] Renewable electricity generation in Latin America and the Caribbean grew 5%.[32]

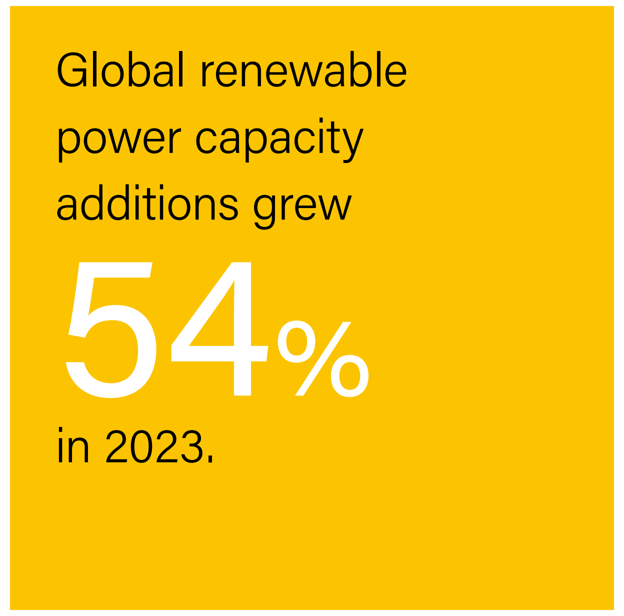
China
led all regions for investment in renewables, accounting for 44% of total global investment in 2023.

i Includes renewable-based hydrogen, nuclear-based hydrogen and fossil fuel-based hydrogen with carbon capture and storage.

FIGURE 5.
Shares of Renewable Electricity Generation by Region, 2013 and 2023



Source: Ember. See endnote 30 for this section.

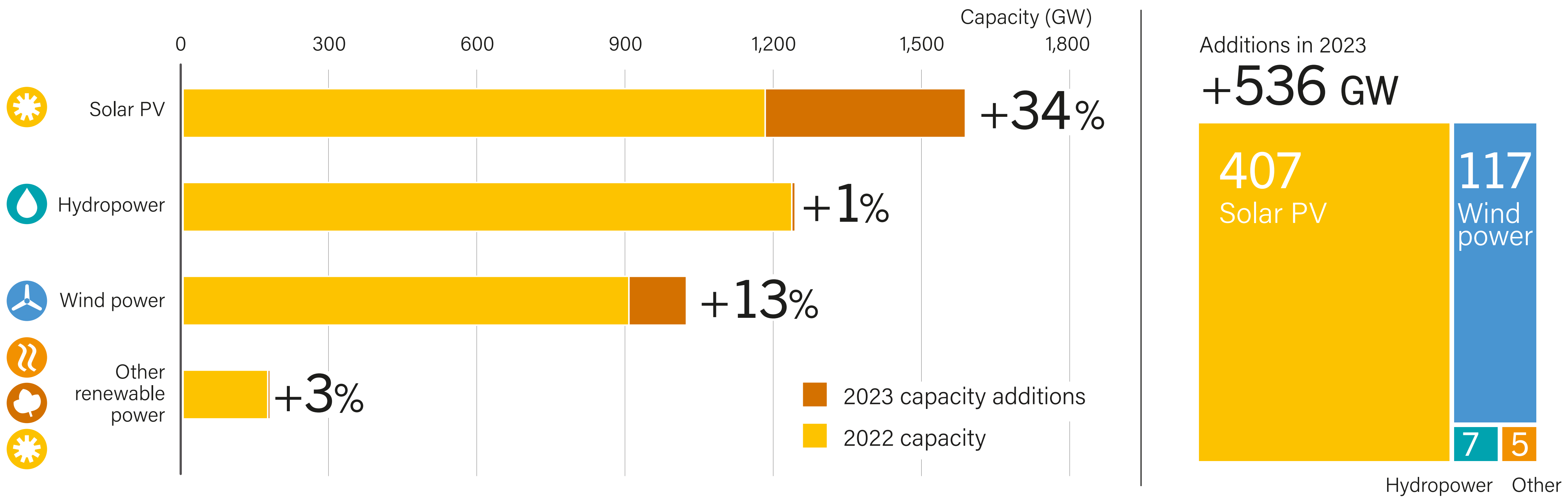


In Oceania, the share of renewables in the electricity mix rose to 43% in 2023 (up from 23% in 2013), due largely to developments in Australia, where renewable electricity generation grew 9% in 2023 alone.[33] This increase is attributed mainly to growth in the combined share of solar PV and wind energy, which rose from 5% to 25% in the region during the decade.[34]

Overall, the global renewable power sector experienced notable growth in 2023, marked by a 54% increase in renewable power capacity additions, reaching 536 GW.[35] Solar PV alone accounted for more than three-quarters of the additions.[36] (→ *see Figure 6.*) Significant contributions came from Europe, the United States, Brazil and particularly China.[37] (→ *see Figure 7.*)

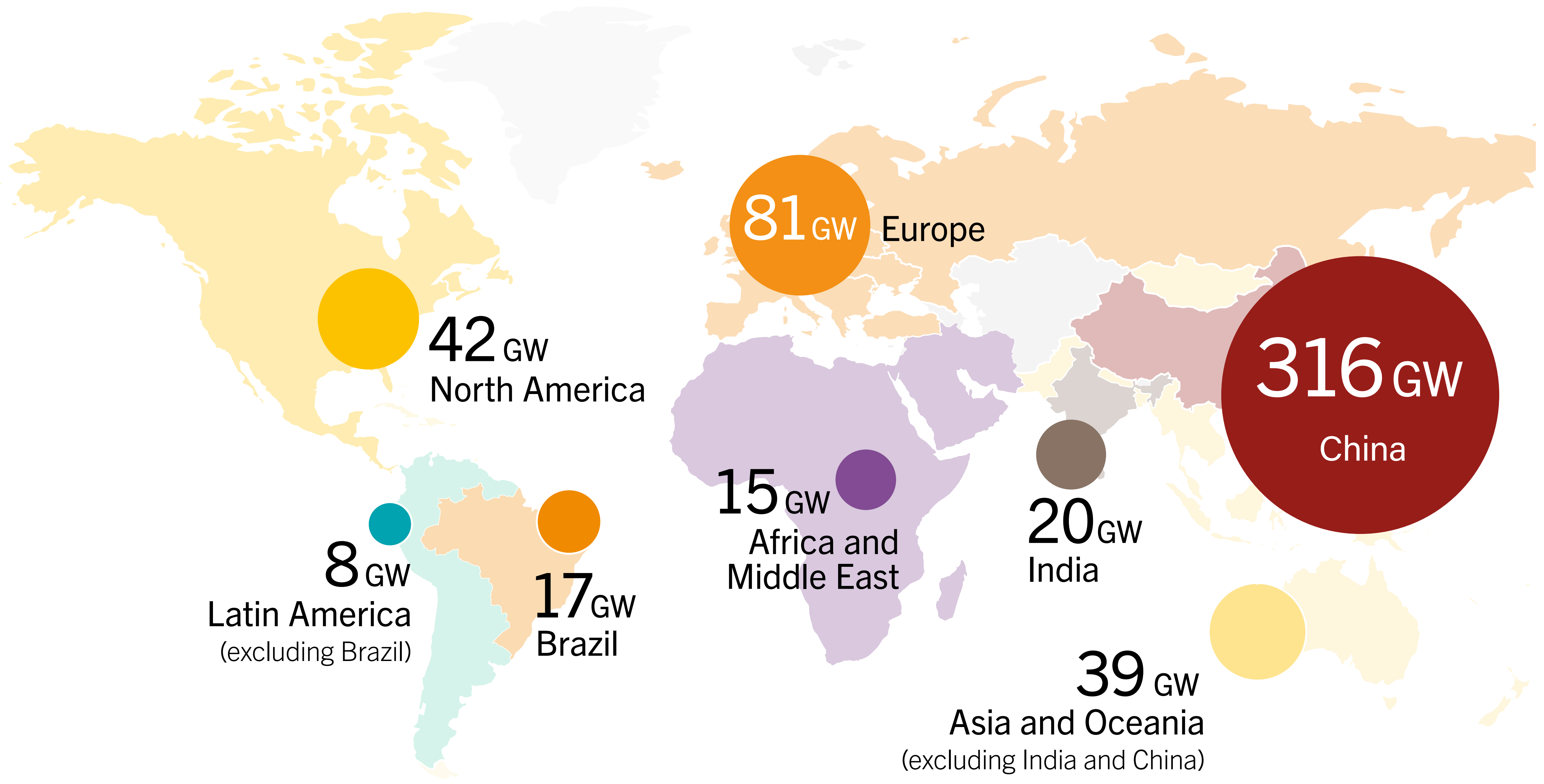
Despite advancements, the renewables sector faced challenges from geopolitical conflicts, protectionism, and rising greenhouse gas emissions, highlighting the complexity and ongoing risks in the global energy landscape.[38] Europe and the United States have sought to reduce reliance on China for renewable energy components, while many countries continue to prioritise fossil fuels for energy security.[39] The global energy transition remains uneven, marked by persistent inequality.[40] (→ *See Table 1.*)

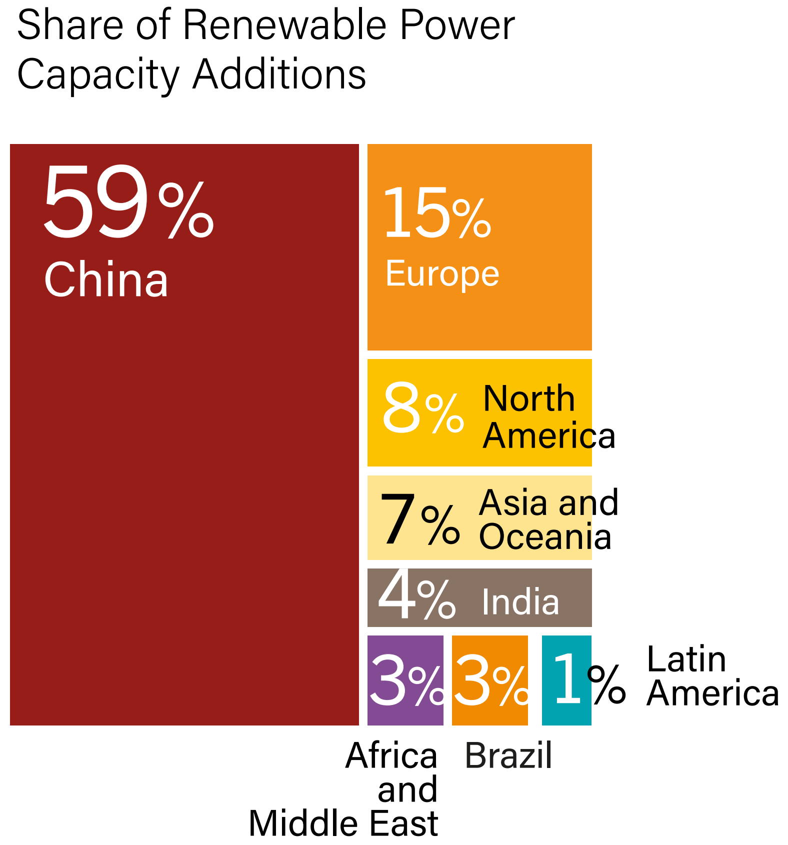
FIGURE 6.
Renewable Power Total Installed Capacity and Additions, by Technology, 2023



Note: Data is for capacity that is grid-connected and in operation.
Source: See endnote 36 for this section.

FIGURE 7.
Renewable Power Capacity Additions, by Region/Country, 2023





Note: Capacity may not exactly add up to 536 GW due to rounding.
Source: See endnote 37 for this section.

Latin America, Africa, Asia and Oceania (excl. China) represented **18%** of total additions despite representing **over 2/3 of global population.**

TABLE 1.
Top 5 Countries for Renewable Energy Capacity and Additions, 2023

Total Renewable Power Capacity as of End-2023

	1	2	3	4	5
POWER					
Total renewable capacity	China	United States	Brazil	India	Germany
Total renewable capacity (excl. hydropower)	China	United States	Germany	India	Japan
Total renewable capacity per capita (excl. hydropower)	Sweden	Denmark	Austria (+1)	Netherlands	Iceland (-2)
Bio-power	China	Brazil	United States	India	Germany
Geothermal	United States	Indonesia	Philippines	Turkiye	New Zealand
Hydropower	China	Brazil	Canada	United States	Russian Federation
Solar PV	China	United States	India (+1)	Japan (-1)	Germany
Concentrated solar thermal power (CSP)	Spain	United States	United Arab Emirates (+4)	China (-1)	Morocco (-1)
Wind	China	United States	Germany	India	Spain
HEAT					
Solar water heating collector capacity	China	Türkiye	United States	Brazil (+1)	Germany (-1)
Geothermal heat output	China	Türkiye	Iceland	Japan	New Zealand

Capacity Additions in 2023

	1	2	3	4	5
ANNUAL ADDITIONS BY TECHNOLOGY					
Bio-power	China	Japan	Brazil	Uruguay (+40)	Turkiye
Geothermal power	Indonesia (+1)	Kenya (-1)	Chile (+3)	United States (-1)	El Salvador (+7)
Hydropower	Nigeria (+38)	Colombia (+4)	Lao PDR (-1)	China (-3)	Nepal (+8)
Solar PV	China	United States	India	Germany (+2)	Brazil (-1)
CSP	United Arab Emirates (+1)	–	–	–	–
Wind power	China	United States	Brazil	Germany	India (+3)
Solar water heating collector capacity	China	India	Brazil (+1)	Turkiye (-1)	United States

Notes: Per capita renewable power capacity (not including hydropower) ranking based on IRENA and IHA and on 2022 population data from the World Bank. Solar water heating collector ranking for total capacity is for year-end 2023 and is based on capacity of water (glazed and unglazed) collectors only. Data from International Energy Agency Solar Heating and Cooling Programme. The number in brackets represents the change from the 2022 ranking. Rankings for 2022 have been updated with the latest capacity data and may be different from the tables in GSR 2023.

Source: See endnote 40 for this section.

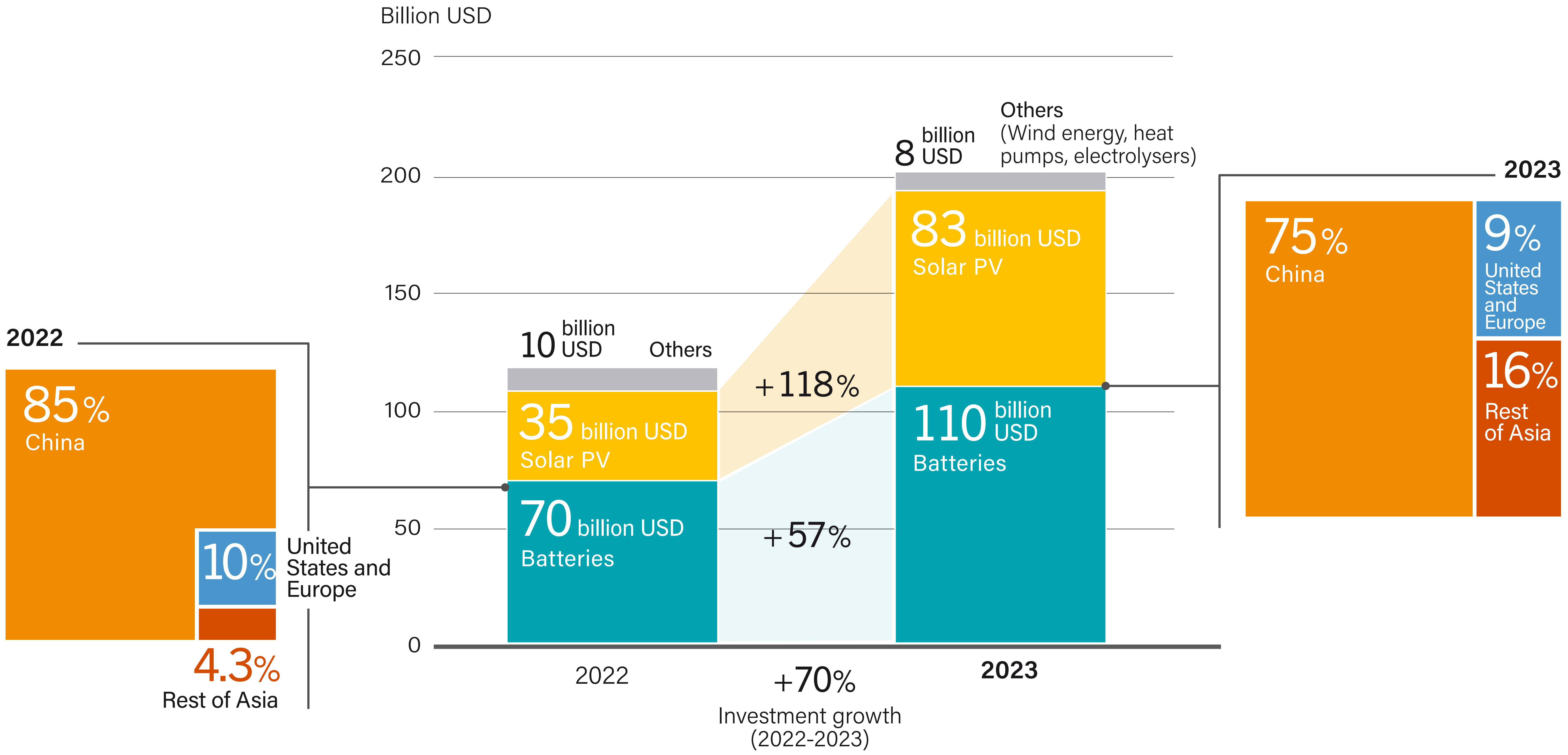
RENEWABLE ENERGY MANUFACTURING

Investment in global manufacturing of renewable energy and enabling technologies grew 70% in 2023 to reach nearly USD 200 billion.[41] Solar PV and battery manufacturing installations dominated investments, together representing 95% of the total.[42] China accounted for three-quarters of global investment in renewable and enabling technologies, down from 85% in 2022, as investments in the United States and Europe grew strongly (especially for battery manufacturing).[43] (→ *See Figure 8.*)

Investment in other clean energy technologies – wind, heat pumps and electrolysers – accounted for a much smaller fraction of total investment, at around 7% in 2022 and 4% in 2023.[44] Investment in wind energy manufacturing, including in nacelle, blade, and tower production facilities, fell slightly in absolute terms in 2023.[45] China accounted for virtually all of the investment in wind manufacturing facilities.[46] For electrolyser and heat pump manufacturing, the EU and the United States together accounted for a larger share of investment than China, with virtually no investments in manufacturing for these technologies occurring elsewhere during the year.[47]

Integrating industrial and energy policies is crucial for advancing the renewable energy transition. Strengthening local manufacturing is needed to reduce import reliance and support domestic industries. Better balancing between supply and demand can help ensure more stable and efficient energy systems. This requires enhancements to grid infrastructure and the deployment of storage technologies, as well as international and regional co-ordination.[48] (→ *See Sidebar 1.*)

FIGURE 8.
Investment in Manufacturing of Renewable Energy and Enabling Technologies, 2022 and 2023



Note: Rest of Asia comprises India, Japan, the Republic of Korea and South-East Asia.

Source: See endnote 43 for this section.

SIDEBAR 1. Grid Upgrades and Storage Solutions for a Renewables-based Power System

Renewable energy technologies have come a long way in just 20 years, especially through the rapid growth of solar PV and wind power. However, integrating and expanding renewables to achieve high shares in utility grids remains a major challenge, especially as the share of variable renewable energy (wind and solar power) exceeds 13% globally.

In 2023, several countries experienced much higher shares of variable renewable generation than the global average. Denmark led with 67% of gross electricity from variable renewables (57% wind, 10% solar), and five other countries achieved shares above 40%: Lithuania (46% wind, 12% solar), Greece (22% wind, 19% solar), the Netherlands (24% wind, 17% solar), Spain (24% wind, 17% solar) and Portugal (29% wind, 10% solar). The top countries with high shares of variable renewables are mostly concentrated in Europe, with the notable exceptions of Uruguay (36% wind, 3% solar), Chile (12% wind, 20% solar) and Australia (12% wind, 17% solar).

Energy storage technologies can help tackle the variability of wind and solar energy by storing surplus energy generated during times of high output but low electricity demand, and then making it available during times of lower output but high electricity demand. Integrating energy storage systems (such as pumped storage and batteries) with variable renewable energy can provide better balance to the overall system, depending on the grid operator requirements.

In 2023, worldwide **utility-scale battery storage** capacity increased a robust 65% to reach 29.2 GW. Investment in battery storage worldwide continued to grow substantially, rising 76.8% to USD 36.3 billion in 2023. China dominated with USD 14.5 billion (up 203% over 2022), followed by the United States with USD 9.6 billion (up 18.8%) and Germany with USD 3.3 billion (up 61.2%). Energy storage investments also surged in Italy (USD 2.2 billion) and Australia (USD 1.0 billion).

Pumped storage added 6.48 GW in 2023 – down 38% from the previous year's additions – for a global total of 179 GW. Pumped storage remains the most common and cost-effective solution for large-scale utility storage, although new capacity often requires transmission extensions due to the geographical distance from generation or load centres.

Grids remain a major bottleneck for implementing high shares of renewables in the power system. Connection queues worldwide amounted to an estimated 3 terawatts in 2023 (equivalent to six times the capacity of solar PV and wind power added during the year). Grids take longer to build and require careful planning to keep pace with the growth of renewables. In 2023, global grid investment increased 5.3% to an estimated USD 310.2 billion. More than half of this growth was in the United States (up 27.9% to USD 86.5 billion) and China (up 25.4% to USD 78.9 billion), and other top countries included Germany, Canada and India. Investment in electricity networks in developing countries has been impeded by the weak financial situation of some distribution companies, the lack of adequate investment frameworks (such as performance-based regulation), the lack of least-cost system plans, and high operational and commercial losses.

Regional interconnection and market integration are essential to increase grid reliability and security as well as quality of supply. Positive developments emerged in Southeast Asia, where four countries (Lao People's Democratic Republic, Thailand, Malaysia and Singapore) agreed to a Power Integration Project during the 41st ASEAN Ministry of Energy Meeting in August 2023. In Europe, work began in July 2023 on the Celtic interconnector project to facilitate electricity exchange between Ireland and France.

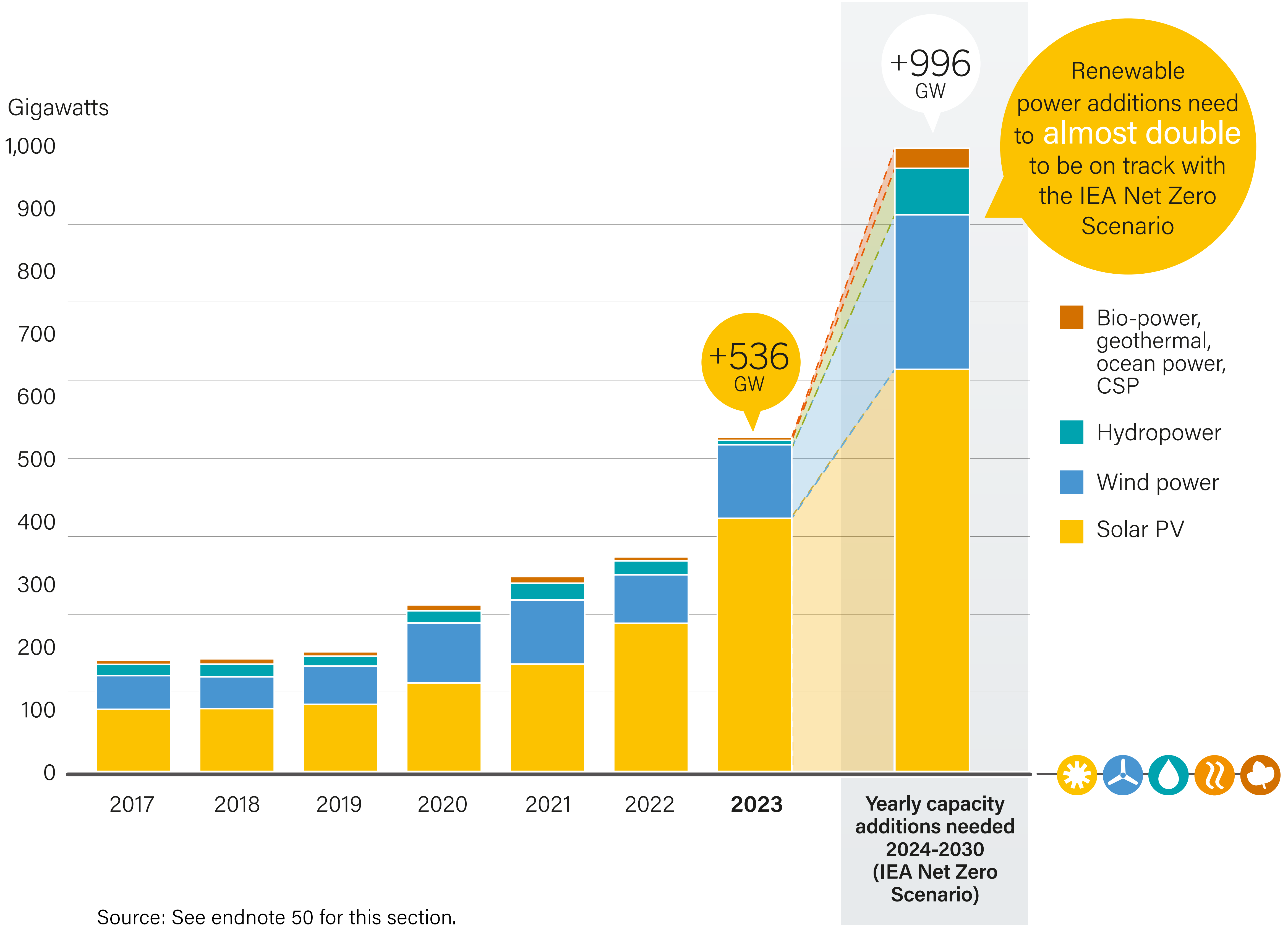
Source: See endnote 48 for this section.

TRACKING PROGRESS TOWARDS THE GLOBAL TARGET

At the 2023 United Nations Climate Change Conference (COP 28) in Dubai, United Arab Emirates, governments agreed to triple renewable power capacity and double energy efficiency improvements by 2030.[49] At the current rate of capacity additions, the world will not achieve the tripling target, reaching 8,000 GW by 2030, short of the 11,000 GW of the target.[50] (→ *See Figure 9.*) As countries prepare to update their Nationally Determined Contributions (NDCs) towards reducing greenhouse gas emissions under the Paris Agreement, there is a window of opportunity to make clear commitments and raise ambition.[51] As of early 2023, only 14 countries had explicit renewable capacity targets for 2030 in their NDCs, and commitments across NDCs amounted to only around 1,300 GW.[52]

Among major country commitments, the EU and the United States aim to be climate neutral by 2050, China by 2060 and India by 2070.[53]

FIGURE 9.
Annual Additions of Renewable Power Capacity, by Technology, 2017-2023,
and Yearly Additions Needed to Achieve the International Energy Agency's Net Zero Scenario by 2030



Source: See endnote 50 for this section.

POLICY AND TARGETS

Many countries re-evaluated their renewable energy targets during 2023. Policy measures to integrate renewables into existing energy supply systems range from the promotion of renewable electricity to a focus on renewable heating and fuels. Policies include state/provincial and national targets, auctions and tendering, fiscal and financial incentives, and mandates such as renewable portfolio standards (RPS), feed-in tariffs (FITs), building mandates requiring solar thermal collectors and biofuel blending[i].

Policies enacted to support expanded renewable energy supply for electricity, heat and fuels demonstrated several notable trends during the year. Developed countries continued to scale back mandates such as net metering and FITs, having met their initial goals for the adoption of renewables, while these measures are still popular in developing countries. Meanwhile, competitive auctions and tendering struggled to attract bidders in many markets, prompting some countries to raise price caps to entice more participants.

Most countries have in place some sort of renewable energy legislation, although the supply of renewables is concentrated strongly in North America, Europe, China and India. Although policy support for renewable energy continued to grow in 2023, policy support for fossil fuel provision also continued.

By the end of 2023, 90 countries had in place economy-wide targets for renewable energy, although only 7 countries had targets for 100% renewables, with most of these aimed at distant time horizons.[1] (→ *See Table 2*.) Only three countries – Albania, Italy and Uganda – and the European Union (EU) announced new or updated targets in 2023.[2] The EU's New Renewable Energy Directive raised the 2030 target for renewables in total final energy consumption from 32% to 42.5%.[3] As EU Member States updated their National Energy and Climate Plans, some included targets for renewable generation, or installed capacity by technology, as well as thermal energy targets by 2030.[4]

At the 2023 United Nations Climate Change Conference (COP 28) in Dubai, United Arab Emirates, more than 130 countries[ii] pledged to triple the global installed capacity of renewable energy by 2030, to reach at least 11 terawatts, along with doubling the annual rate of global energy efficiency improvement from 2% to 4%.[5] This target was also included in the final conference text.[6] During the event, the Latin American and Caribbean Renewables Hub announced that it would raise its 2030 target for renewable energy in total electricity generation from 70% to 80%.[7]

i This section covers a diverse array of policies enacted or revised in 2023, but it is not exhaustive.

ii A list of signatories to the Global Renewable Energy and Energy Efficiency Pledge is available at https://www.cop28.com/en/global-renewables-and-energy-efficiency-pledge.

TABLE 2.
Key Renewable Energy Policy and Investment Indicators, 2023

		2023
INVESTMENT		
New investment (annual) in renewable power and fuels[1]	Billion USD	**623**
POLICIES[2]		
Countries with renewable energy targets	#	**182**
Countries with 100% renewable energy targets	#	**7**
Countries with renewable energy policies	#	**101**
Countries with 100% renewable heating and cooling targets	#	**2**
Countries with 100% renewable transport targets	#	**2**
Countries with 100% renewable electricity targets	#	**44**
Countries with regulatory policies in buildings (power, heating and cooling and transport)	#	**30**
Countries with biofuel mandates[3]	#	**60**
Countries with feed-in policies[4]	#	**63**
Countries with net metering policies[4]	#	**92**

Notes:

1 Data are from BloombergNEF and include investment in new capacity of all biomass, geothermal and wind power projects of more than 1 MW; all hydropower projects of between 1 and 50 MW; all solar power projects, with those less than 1 MW estimated separately; all ocean power projects; and all biofuel projects with an annual production capacity of 1 million litres or more. Total investment values include estimates for undisclosed deals as well as company investment (venture capital, corporate and government research and development, private equity and public market new equity).

2 A country is counted a single time if it has at least one national or state/provincial target or policy.

3 Biofuel policies include policies listed in the GSR 2024 Demand Module Data Pack (Figure 17), available at https://www.ren21.net/gsr2024-data-pack/demand.

4 Data reflect all countries where the policies have been used at any time up through the year of focus at the national or state/provincial level. See the GSR 2024 Supply Module Data Pack, available at https://www.ren21.net/gsr2024-data-pack/supply.

Source: See endnote 1 for this section.

ELECTRICITY

In 2023, for the first time ever, renewables generated 30% of global electricity, up from 21.7% in 2013, with the increased share driven mainly by growth in the installed capacities of solar PV and wind power.[8] The increase in renewable electricity requires strong policy ambition, and countries have increasingly updated their **targets for renewable electricity supply**. In 2023, 24 countries updated their targets for the renewable share in electricity generation or in installed capacity.[9] This brought the total number of countries with a renewable electricity target to 152 by year's end.[10] Some countries have technology-specific targets as well.[11] (→ *See Figure 10.*)

In Africa, Egypt updated its Nationally Determined Contribution (NDC) for renewables to reach 42% of installed power capacity by 2030, instead of 2035.[12] The energy ministry announced plans for renewables to total 60% of power installed capacity by 2040, but this target was not yet included in policy documents.[13] Uganda's 2023 National Energy Policy included expanding electricity consumption 14% annually, with the goal of keeping the renewable share above 95%.[14] South Africa's new South African Renewable Energy Master Plan included a target of 41% renewables in electricity generation by 2030.[15]

In Latin America, Argentina updated its target to add 10 gigawatts (GW) of renewable energy capacity by 2030 and to reach 57% renewable electricity generation.[16] Chile set a target of 80% renewable energy in power generation by 2030 in its latest Action Plan for Power Sector Decarbonisation.[17] In Europe, France published a national plan on greening the power sector, which targets 33% renewable generation by 2030.[18] Italy's new National Climate and Energy Plan is aimed at reaching 72% renewable generation by 2030.[19]

However, most countries risk falling short of their ambitious renewable energy targets unless they update their regulatory frameworks.[20] As of December 2023, China was the only country on track to meet its target of an additional 1,200 GW of renewable capacity by 2030, with the country already exceeding the annual capacity addition required to meet this target.[21]

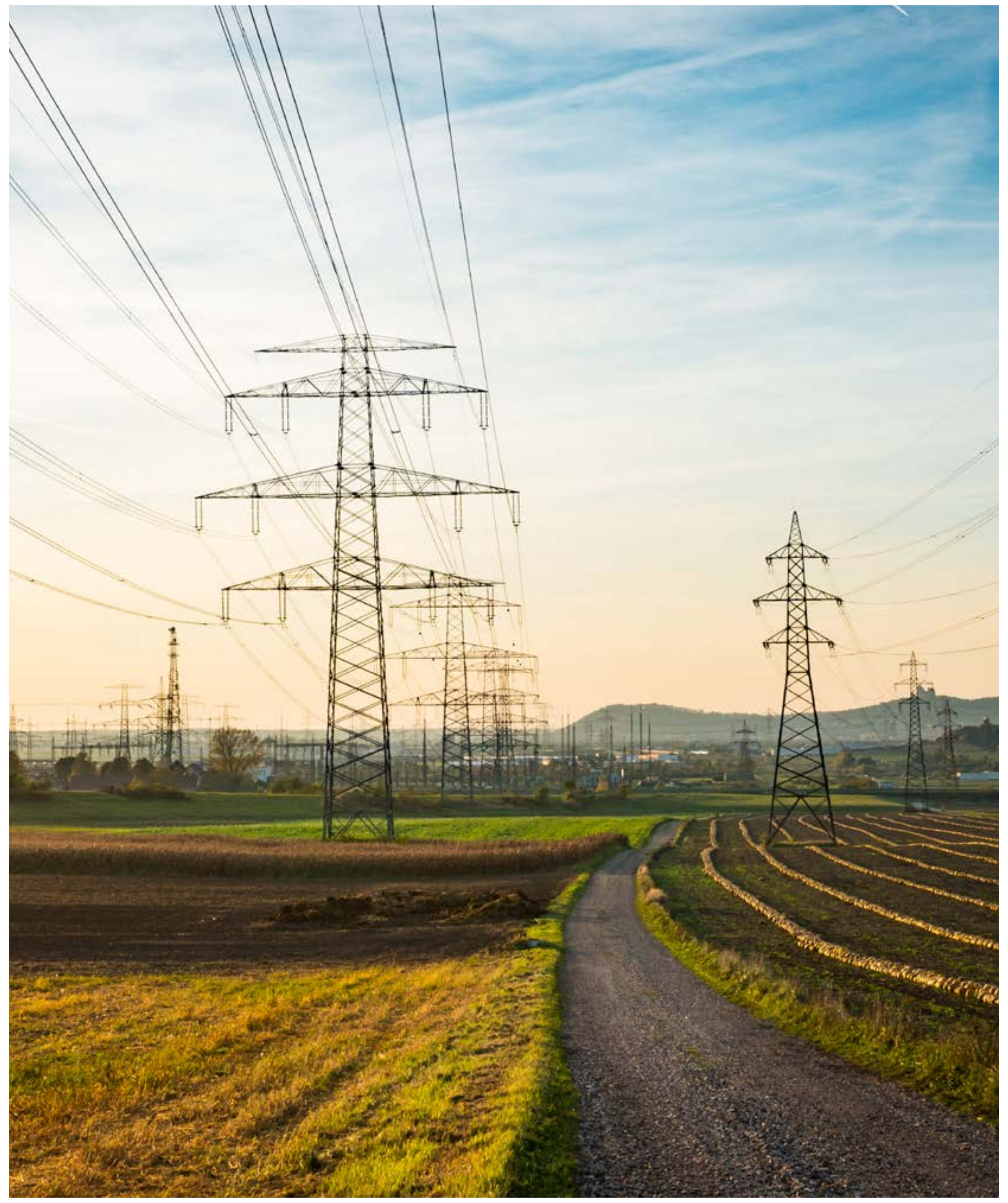
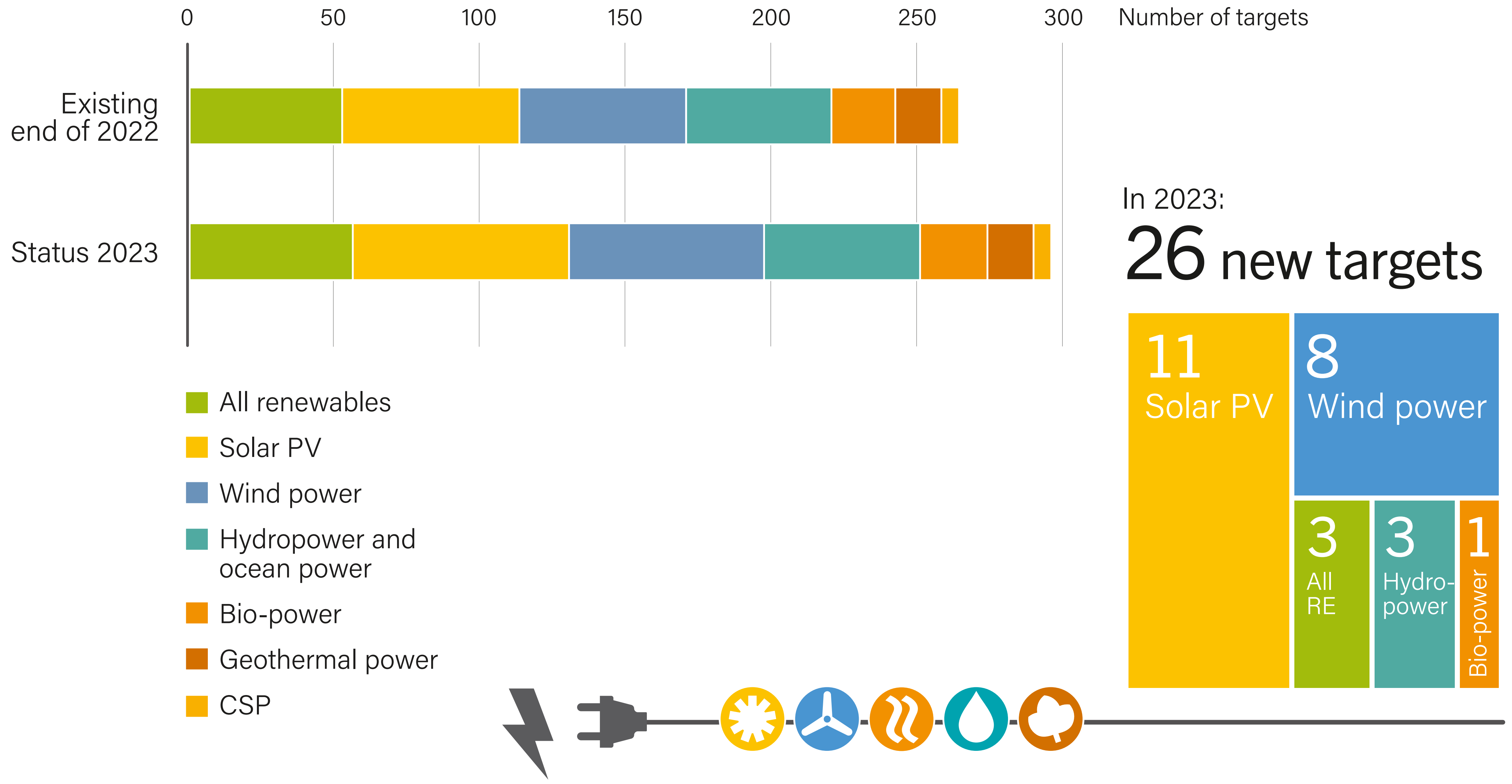


FIGURE 10.
Number of Targets for Installed Renewable Power Capacity, by Technology, 2022 and 2023



In 2023,
24 countries
updated their targets for the renewable share in electricity.

Notes:

Data are not comparable to previous years due to improvements in methodology and adding targets from previous years that were not previously found.

Ukraine's target for all renewables excludes hydropower.

Targets for solar PV installed capacity include targets for floating solar.

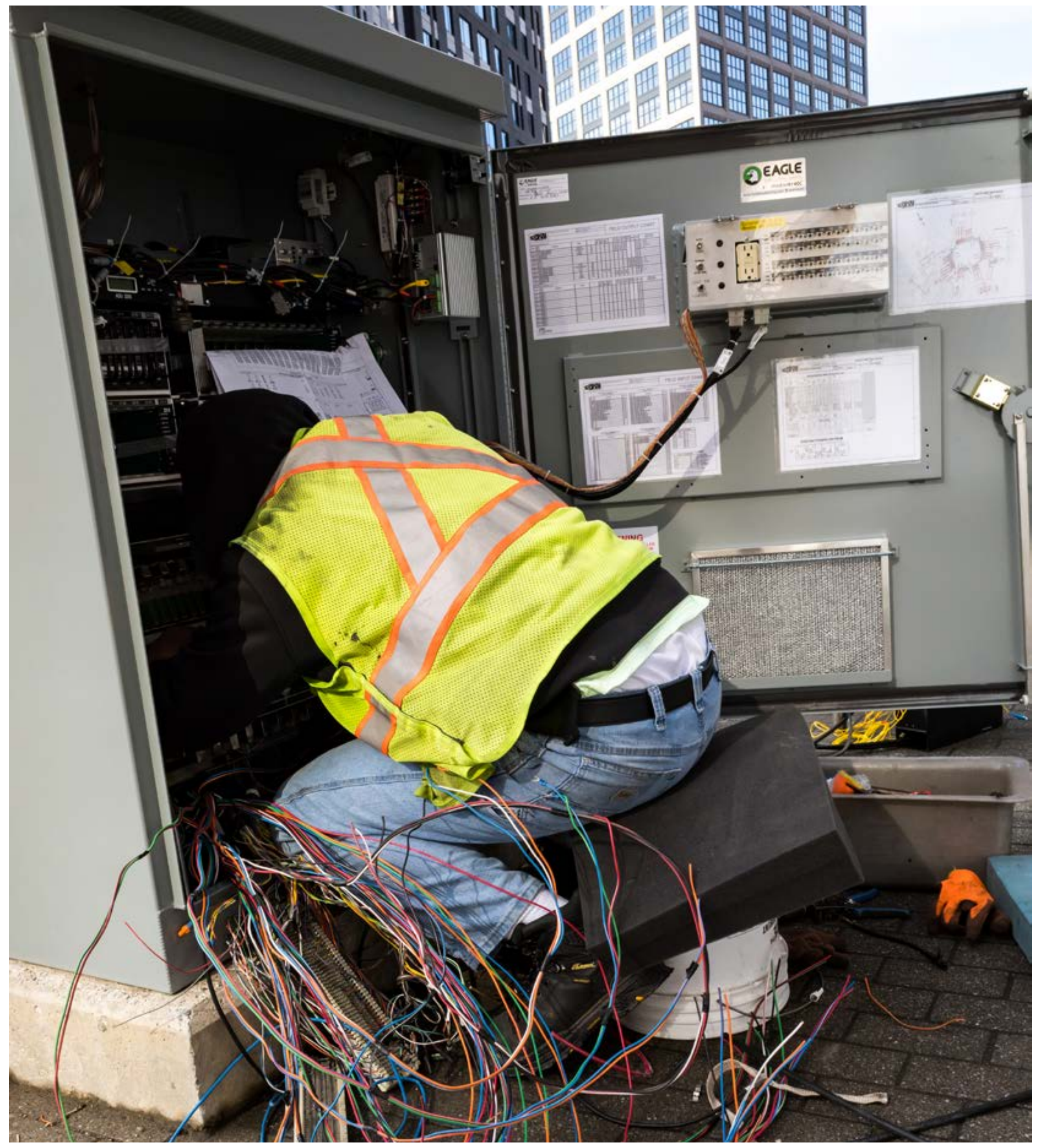
Some capacity targets include a combined target for multiple technologies; in these cases the country with the target is counted once for each technology where a capacity target exists. For example, Lao PDR has a target for 1 GW of installed capacity of solar PV and wind power, but the breakdown of how much capacity each technology will generate is unspecified.

Countries with multiple targets for the same technology are only counted once.

Source: See endnote 11 for this section.

Feed-in tariffs and premiums remained popular during the year, with some countries announcing new FITs for systems of various sizes.[22] (→ *See Figure 11.*) Serbia issued new rules for feed-in tariffs and premiums as part of the organisation of renewable energy auctions.[23] France announced new FIT rates for rooftop solar PV, raising the maximum size of eligible systems from 100 kilowatts (kW) to 500 kW.[24] Türkiye announced new ten-year FITs for solar PV, wind, hydro, biomass, and geothermal power, as well as energy storage, after the previous scheme expired in 2021.[25] Viet Nam set new rules stipulating a mechanism for establishing annual electricity pricing frameworks, and FITs for wind and solar PV projects (including floating solar PV).[26] To attract investors, Ukraine is implementing a feed-in-premium for renewable electricity projects.[27] Poland enacted its Renewable Energy Act in early 2024, which also provides rules for FITs for small systems up to 10 kW, including hydropower, wind power, solar PV and biogas.[28] In early 2024, Japan updated its FITs for residential and commercial solar PV.[29]

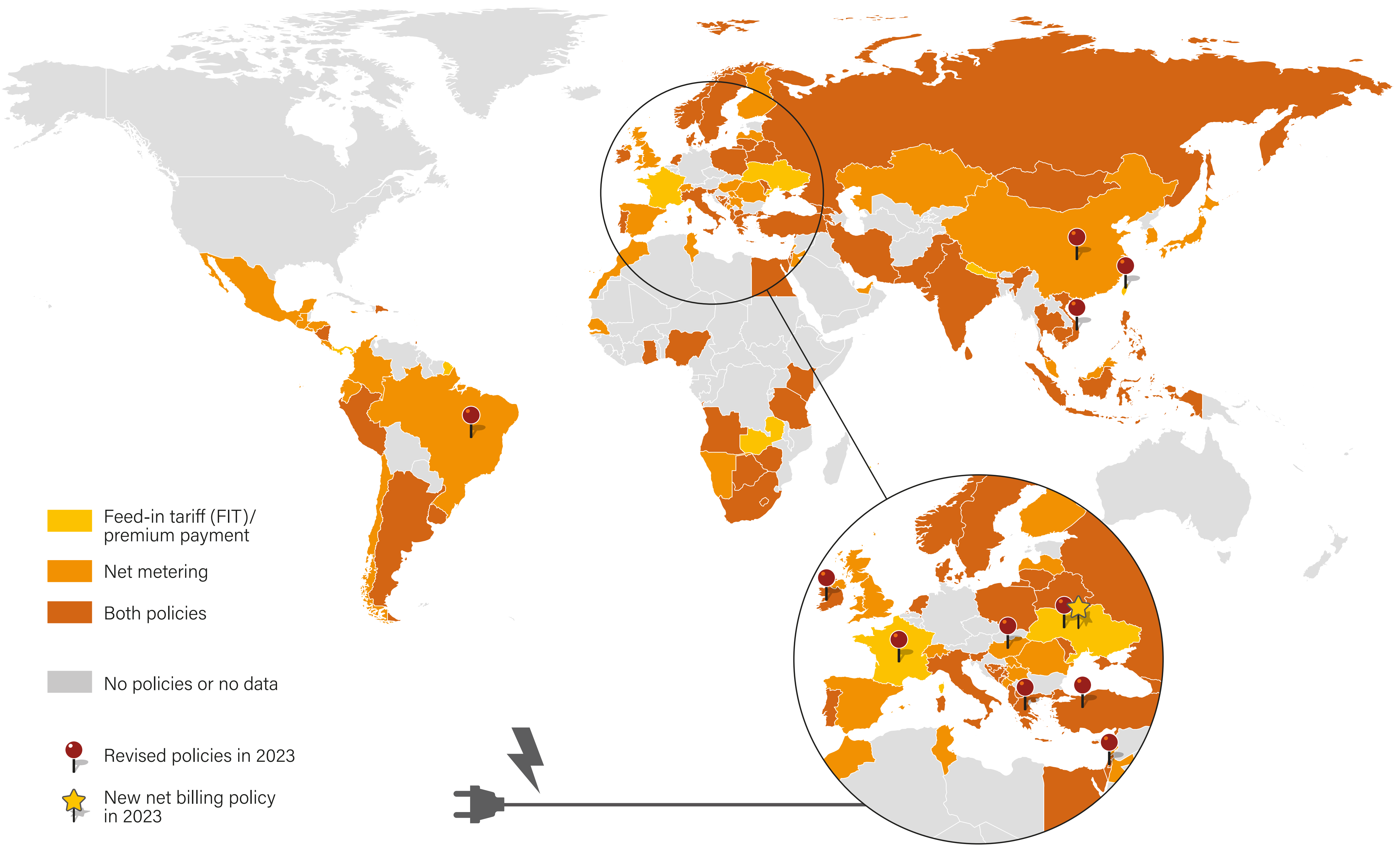
Net metering received mixed policy attention in 2023, with some countries announcing new schemes and others turning away from these policies in an attempt to incentivise the battery storage market. (→ *See Figure 11.*) Greece passed a law reducing the maximum capacity of systems to be eligible for the net metering scheme from 3 megawatts (MW) to 10 kW for households and 100 kW for commercial and industrial clients.[30] Ukraine adopted a net billing system for systems above 50 kW.[31]



In the United States, the state of Massachusetts expanded its net metering scheme to apply to a broader customer base, whereas Idaho and California turned away from net metering to embrace net billing[i].[32] North Carolina scaled down its net metering policy, which results in lower savings for customers33 Maine cut back on its net billing scheme after experiencing higher adoption than expected, which had an inflationary effect on electricity prices.[34]

i Under net billing, customers typically receive credit for excess electricity at a rate that is lower than the retail electricity price. Different jurisdictions may apply these terms in different ways, however.

FIGURE 11.
Renewable Energy Feed-in Tariffs and Net Metering Policies by Country/Region, as of 2023



Notes:

Data should not be compared with previous years because of revisions due to adjusted data or methodology.

All countries with round circles have removed FIT policies except for the Netherlands, where the net metering policy was removed after parliament voted to end the measure.

Japan removed its FIT in 2022 (announced in 2021) and transitioned to a feed-in premium.

Malaysia discontinued its FIT policy in 2017 and substituted it with a net metering scheme.

In May 2024, the Netherlands announced that the net metering programme would phase out in 2027.

Poland replaced its net metering policy in 2022 and transitioned to net billing.

Serbia's previous FIT expired in 2020, but a new FIT scheme opened to small projects (capacity below 500 kW and below 3 MW for wind power plants), according to regulations approved in April 2021. In 2023, the government adopted several changes to the auction procedure for market premiums.

Viet Nam's FIT expired for solar PV projects in 2020 and wind power projects in 2021, but in January 2023, the government provided new FITs for projects that had missed these deadlines.

Source: See endnote 22 for this section.

Auctions and tendering continued to be widely used for large wind and solar PV and CSP power projects, as well as for biomass and geothermal power. Chile announced an auction for 5,400 gigawatt-hours of renewables and storage.[35] Argentina announced the results of its renewable energy generation tender (REnMI2), allocating 633 MW of renewables, of which 501 MW was for solar PV.[36] In the United States, the Bureau of Ocean Management offered several leases[i] for developing offshore wind power through auctions, which resulted in the awarding of the first wind auction in the Gulf of Mexico.[37] Algeria launched an auction for 2 GW of solar PV power capacity.[38]

In Europe, Serbia launched its first renewable auction for 400 MW of wind power capacity and 50 MW of solar PV power capacity, as part of a three-year plan to auction a total of 1,300 MW of renewables.[39] Greece launched several renewable energy auctions during 2023, including a 200 MW cross-border auction[ii] in Bulgaria and Italy for wind and solar power capacity; Greece also announced that 2024 would be the country's last year of holding auctions.[40] Albania announced the results of its first wind auction, held in 2021.[41] Ukraine passed a draft law that includes provisions for renewable energy auctions.[42]

Some auctions continued to be undersubscribed in 2023, either because price caps did not reflect the reality of costs or due to lengthy and costly auction procedures.[43] The Philippines witnessed low turnout at its renewable energy auction, with only one-third of the capacity target receiving bids.[44] Colombia postponed for the second time the deadline for its wind and solar auction, citing the need for more bids.[45] The United Kingdom announced that it would increase the maximum auction price for the next auction round for Contracts for Difference (CfD)[iii] following strong under-subscription from offshore wind project developers.[46] The country raised the price cap for offshore wind power or the next CfD auction round.[47]

Fiscal and financial policies for renewable electricity supply, such as tax credits and rebates, grants, and subsidies, continued to be widely used. In 2023, 20 countries introduced new or updated fiscal and financial policies, bringing the total number of countries with such policies in place to 32.[48]

In Europe, Switzerland announced that it would allocate USD 712 million (CHF 600 million) in subsidies for small- and large-scale solar PV.[49] Greece is providing USD 220,000 million (EUR 200 million) in grants for rooftop solar PV with storage, covering up to 75% of the total installed system cost.[50] France implemented new financial incentives, including grants covering part the cost of renewable energy systems and installation for individuals and businesses, as well as tax credits for private research and development of renewable energy technologies.[51]

In 2023, Brazil announced a new investment plan for the country's green energy transition and published a revised 10-year investment plan for the energy sector.[52] The Brazilian development bank BNDES is providing financing for biogas plants and wind farms.[53] In the Middle East, Egypt secured a concessional loan of USD 100 million from the European Bank for Reconstruction and Development and the Green Climate Fund to finance part of a 500 MW wind farm in the Gulf of Suez region.[54] The Central Bank of Iraq launched a USD 750 million Renewable Energy Financing Initiative that provides near-zero interest loans for individuals and private companies installing solar PV.[55]

India enacted several policies in early 2024 that provide grants and financial aid for the purchase of small-scale solar PV systems.[56] Indonesia earmarked USD 6 million (IDR 94.4 billion) in its 2023 budget for deploying rooftop solar PV to increase electricity access.[57] Canada's 2023 federal budget introduced a tax credit for investments in clean technologies[iv], and extended accelerated capital cost allowances for clean energy equipment.[58]

Renewable portfolio standards[v] (RPS) and clean electricity standards[vi] (CES) have become firmly established in the United States as a key component of state-level energy policy. As of 2023, 39 US states had established RPS or CES, with at least 17 states targeting 100% clean or renewable electricity by 2050.[59] Connecticut aims for 48% renewable power by 2030, and Illinois increased its target to 50% by 2040 and 100% by 2050.[60] Also in 2023, Canada published the first draft of its federal Clean Electricity Regulations, which will limit the emissions intensity of the country's electricity system by 2035.[61]

i These leases are auctions for the right to develop up to a certain amount of capacity in a specific location, not auctions for the actual deployment of capacity or guarantee of generation that the government will later purchase.
ii A cross-border renewable energy auction is a competitive bidding process where multiple countries jointly select and support renewable energy projects across their borders to optimise costs and resource use.
iii Contract for Difference is a pricing mechanism where energy producers receive payments if market prices fall below a certain level, and must pay back when prices exceed a certain level.
iv Clean technologies here refer to technologies that reduce greenhouse gas emissions, including renewable energy, the production of clean hydrogen (electrolysis, natural gas with carbon capture, utilisation and storage), and the manufacturing of equipment related to renewable energy, zero-emission vehicles, energy storage and carbon capture.
v An RPS mandates that electric utilities and other retail electricity suppliers meet a defined minimum percentage (or specific quantity) of their customers' demand through renewable electricity.
vi Clean electricity standards (CES) are regulatory policies aimed at increasing the use of renewable and low-carbon energy sources in electricity generation. These standards mandate that a specified percentage of electricity sold by utilities must come from clean energy sources such as wind, solar, hydroelectric, nuclear, and carbon capture and storage technologies.

HEAT

In 2023, 21 countries updated their **renewable heating targets**, bringing the total number of countries with such targets to 43.[62] As part of its New Renewable Energy Directive, the EU set a target for a 0.8% annual increase in renewables for heating to 2026, and a 1.1% annual increase from 2026 to 2030, with the aim of achieving 43% renewable heating by 2030.[63] As a result, EU Member States have updated their National and Energy Climate Plans, including their targets for renewable heating, as well as renewable energy targets for district heating.[64]

A few countries announced new policies and programmes for the uptake of **solar thermal energy for heating** in 2023. Poland began providing subsidies of up to USD 14,900 (PLN 58,800) per household for the installation of solar collectors for hot water (in addition to air- and ground-source heat pumps), as part of the "My Electricity 5.0" programme.[65] Germany adopted a mandate that all newly installed heating systems in buildings derive at least 65% of their energy from renewable sources starting in January 2024.[66] The Slovak Republic began providing grants totalling USD 172 million (EUR 156 million) to cover up to half the cost and the installation of solar water heaters.[67] Estonia launched subsidies for rooftop solar thermal systems as part of building retrofits covering renewables for heating.[68]

District heating received further policy attention during 2023. The integration of district heating strategies with decarbonisation pledges opens the possibility for the uptake of renewables in heating systems. As part of the New Renewable Energy Directive, EU Member States updated their targets for district heating.[69] Some individual EU countries also set specific targets or enacted other policies to support the uptake of renewables in district heating, with Denmark targeting 85% by 2030.[70] In addition, Denmark put in place subsidies of USD 3.5 million (DKK 24 million) to decarbonise district heating.[71] Croatia set a target to increase its renewable share in district heating 1.3% annually to 2030.[72] The United Kingdom issued an Energy Security Bill with regulations and zoning for heat networks, with a focus on decarbonising the network through renewables, and awarded USD 493 million (GBP 388 million) for a Green Heat Network fund, which disbursed its first funds in early 2023.[73]

Heat pumps are not renewable energy technologies, but they provide an energy-efficient solution to heating and cooling and enable the use of renewable electricity in the thermal energy sector. They rely on ambient air, ground, or water (surface or ground water) and provide heating and cooling by transferring thermal energy between the indoors and the ambient environment.

As of 2023, 17 countries had in place policies to support the installation of heat pumps, with 10 countries updating or announcing new policies during the year.[74] Ireland extended its grants for renewable heat to cover heat pump installations.[75] Poland, as part of its clean air programme, began providing grants for replacing solid fuel heating sources with heat pumps.[76] The United Kingdom updated its "Boiler upgrade scheme" to increase the grant allocation for purchasing a heat pump unit from USD 6,300 (GBP 5,000) to USD 9,500 (GBP 7,500).[77] The EU postponed by one year the publication of its Heat Pump Action Plan.[78]

At the sub-national level, the US state of Maine hit its goal of 100,000 heat pumps sold two years early, and announced a new target of installing an additional 175,000 units by 2027.[79] Also in 2023, the state of Oregon launched a subsidy to support the installation of heat pumps in rental properties.[80]

> The US state of Maine hit its goal of
> **100,000**
> heat pumps sold two years early.

FUELS

Through regulations that limit fossil fuel extraction and/or use, governments aim to simultaneously discourage reliance on these non-renewable resources and incentivise the adoption of cleaner alternatives. Policies encouraging the uptake of renewable fuels also have gained attention.

Several international agreements and pledges target the **phase-out of fossil fuels**, and received moderate attention from governments during 2023. The Powering Past Coal Alliance, which aims to accelerate the phase-out of unabated coal power, had 60 signatories by year's end, after 9 countries joined during COP 28 (Cyprus, the Czech Republic, the Dominican Republic, Iceland, Kosovo, Norway, Malta, the United Arab Emirates and the United States).[81] Three countries – Kenya, Samoa and Spain – joined the Beyond Oil and Gas Alliance, bringing the total to 19 countries; the alliance seeks to facilitate the managed decline of oil and gas production.[82] The Fossil Fuel Non-proliferation Treaty, which aims to end the expansion of fossil fuel production and to fast-track solutions for a just transition to renewables, grew to 11 signatory countries, with Colombia becoming the first major oil-exporting country to join (during COP 28).[83] These alliances indirectly support renewables by encouraging a shift away from fossil fuel dependency and towards renewable energy alternatives.[84]

A few countries enacted policies and regulations **banning fossil fuels** in specific sectors, effectively incentivising renewable energy or nuclear power. New Zealand banned new baseload electricity generation from fossil fuels.[85] Sweden banned all new extraction of coal, oil and fossil gas.[86] Numerous countries adopted policies shifting away from fossil fuels for heating. In Germany, a regulation targets eliminating all heating systems that rely on fossil fuels by 2045.[87] Switzerland's Heat Strategy 2050 aims to decarbonise the heating supply by replacing fossil fuels with renewables by 2050.[88] Austria banned gas boilers in new buildings as of 2023.[89] By contrast, France, which initiated a ban on oil and coal heaters starting in 2022, revoked its ban on gas boilers for existing buildings (originally set to begin in 2024), while retaining its ban on gas boilers in new buildings.[90]

Phasing out fossil fuel subsidies helps to reveal the true costs of fossil fuels and to enhance the market competitiveness of renewables.[91] By the end of 2023, seven countries[i] included eliminating subsidies for fossil fuels in their climate plans.[92] Nigeria announced removing petrol subsidies to address economic inefficiencies and environmental concerns.[93] France removed all subsidies related to gas used for gas boilers, and for the boiler itself.[94] Starting in July 2023, Canada implemented a ban on subsidies to the oil and gas sector as a step towards fulfilling its pledge from the 2009 G20 agreement to eliminate inefficient fossil fuel subsidies.[95]

To shield customers from rising energy prices, some countries have increased fossil fuel subsidies to mitigate the effects of the energy crisis and inflation. Fossil fuel subsidies in the G20 countries grew to a record USD 1.4 trillion in 2022, more than twice the pre-pandemic level of 2019.[96] Globally, the volume of fossil fuel subsidies reached USD 7 trillion, with China contributing the highest share.[97] This surge in funding was primarily in the form of direct subsidies, investments by state-owned enterprises and lending from public financial institutions.[98]

Governments have increasingly focused on policies to shift from fossil fuel use to **renewable fuels**[ii], including renewable hydrogen – especially for transport and heating. A few countries have adopted policies for the deployment of renewable fuels. The EU New Renewable Energy Directive calls for at least 42% of the hydrogen used in industry (most of it not for energy purposes) to come from renewable fuels of non-biological origin (RFNBO) by 2030, and 60% by 2035.[99] The EU also emphasises the use of these fuels for maritime transport, setting a binding target of 1.2% RFNBOs for shipping.[100]

Renewable fuels such as biomass and RFNBOs can be beneficial in the transport sector because they can be readily integrated into existing vehicle technologies and fuel infrastructure. Several countries adjusted their biofuel blending mandates in 2023. The United States changed the rule within the existing legislation to increase its biofuel blend mandates slightly over a three-year period, excluding ethanol.[101] Indonesia raised its biofuel blending mandate for 2030 from 30% to 35%, and Malaysia increased its 2030 mandate from 20% to 30%.[102] India announced a phased mandatory blending of biogas with compressed natural gas for transport.[103] Brazil increased its mandatory biodiesel blend from 13% to 14% as of March 2024.[104] Continuing its countertrend from 2022, Sweden reduced a biofuel blending mandate in response to the ongoing cost-of-living crisis.[105]

Fossil fuel subsidies in the G20 countries grew to a record **USD 1.4 trillion** in 2022, more than twice the pre-pandemic level of 2019.

i Austria, Belgium, Canada, Finland, Ireland, the Netherlands and Spain.

ii Renewable fuels are traditionally derived from biomass but can also be of non-biological origin (RFNBOs). RFNBOs is a broad term for all renewable gaseous and liquid fuels not derived from biomass. The primary method for creating these renewable fuels involves using electrolysis, powered by renewable electricity, to generate hydrogen. This hydrogen can be mixed with substances like nitrogen to create ammonia or with carbon to produce different synthetic hydrocarbons, such as e-methanol, e-kerosene, e-diesel, and e-petrol, also known as power-to-liquids.

INVESTMENT AND FINANCE

Global new investment in renewable power and fuels (not including hydropower projects larger than 50 megawatts, MW) reached a record high of an estimated USD 622.5 billion[i] in 2023.[1] Investment increased 8.1% from 2022, due largely to the global rise in solar photovoltaic (PV) installations.[2] These estimates do not include investment in renewable heating technologies, for which data are not collected systematically. Global investment in heat pumps[ii] fell 3.7% in 2023 to USD 63.1 billion, linked in part to consumer uncertainty around government policies and subsidies as well as to falling natural gas prices.[3] (→ *See Buildings section in Energy Demand module.*)

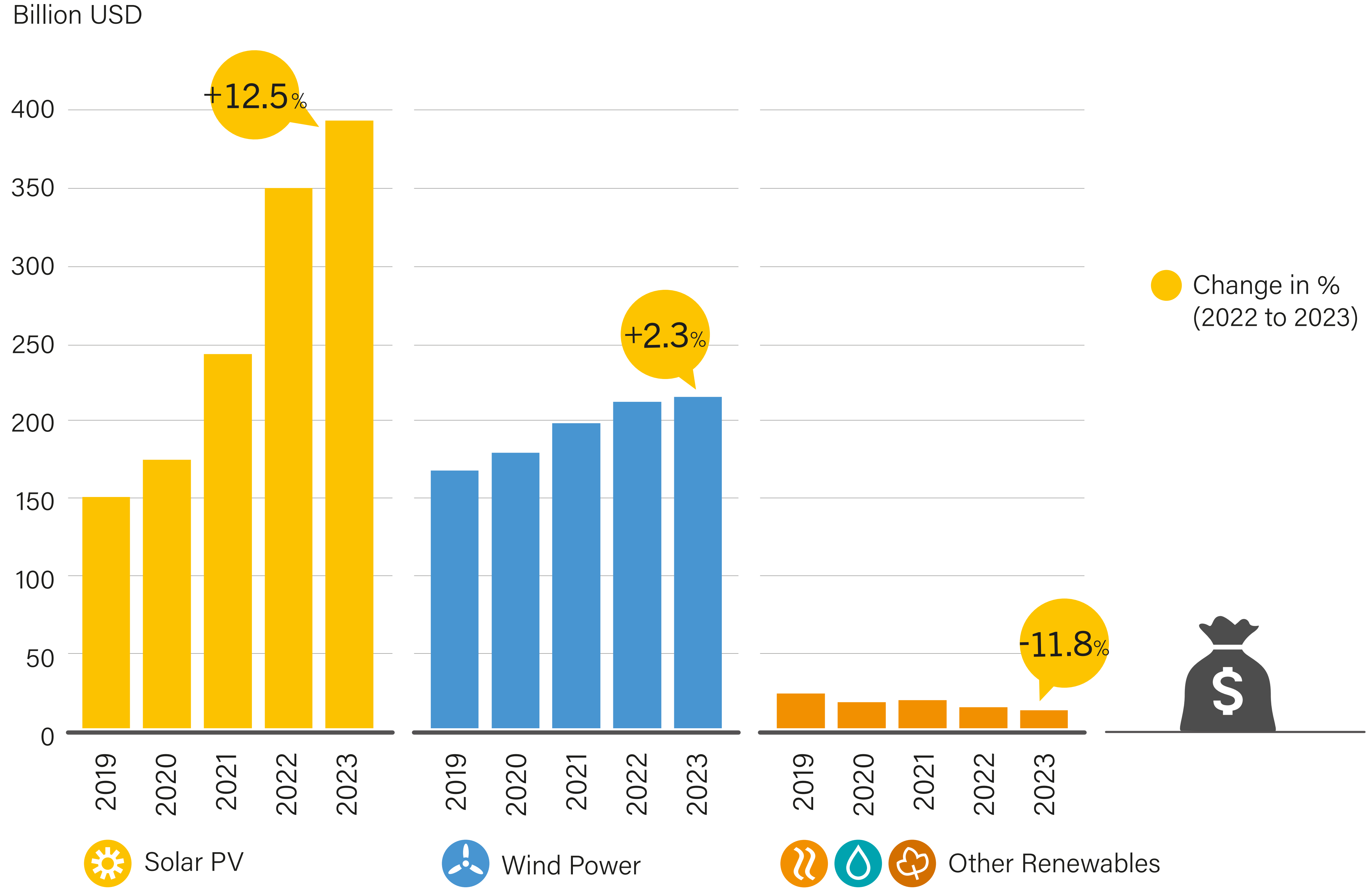
Factors contributing to rising renewable energy investment in recent years include the global energy crisis, ongoing recovery from the COVID 19 pandemic, as well as alignment across climate change policy ambition, energy security goals and industrial strategies.[4] Together with declining unit costs, this has created a supportive investment environment for renewables. However, challenges that complicated the market in 2023 included high interest rates (outside of China) and higher input costs for key raw materials, including critical minerals.[5]

Declining costs for renewables in the last decade have meant that a dollar invested today translates into higher capacity installed than it did in years past.[6] Without these cost reductions, much more investment would be needed to bring the same level of capacity online.[7]

INVESTMENT BY TECHNOLOGY

Solar PV and wind power continued to dominate new investment in renewables, with solar PV accounting for 63% of the 2023 total and wind power for 35%, almost mirroring the shares of 2022.[8] Solar PV investment increased 12.5% to reach USD 392.7 billion, showing much slower growth compared to 2021 (39%) and 2022 (44%).[9] (→ *See Figure 12.*) Nearly half (47.4%) of solar PV investment was in China.[10] Wind power investment increased 2.3% to USD 216.6 billion, down from more robust growth in 2021 (11%) and 2022 (7%).[11] Investment in offshore wind power surged 79% to USD 76.7 billion, offsetting a 17% decline in onshore wind power investment.[12] China, the United States and the United Kingdom together accounted for 66.5% of global wind power investment in 2023.[13]

FIGURE 12.
Global Investment in Renewable Power and Fuels, by Technology, 2019-2023



Source: See endnote 9 for this section.

i Data are from BloombergNEF 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.

Investment in **geothermal energy** expanded nearly 27-fold in 2023 to USD 8.0 billion, with more than half of this in the United States (USD 4.3 billion).[14] Investment in **biofuels** fell 82.7% to USD 1.0 billion and in **biomass and waste** fell 52.5% to USD 2.0 billion.[15] Investment in **small hydropower** continued its downward trend of the past five years, falling 69.5% to USD 0.2 billion, due mainly to slowdowns in projects in China, Latin America and Europe.[16] **Large hydropower** investment (including projects above 50 MW) has hovered at around USD 8 billion for several years, although data remain limited.[17]

The private sector (mainly commercial financial institutions and corporations) 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.[18] The private sector accounted for the bulk of investment in solar PV technologies (around 83% in 2020, the latest data available), as these technologies are commercially viable and highly competitive.[19]

In contrast, geothermal and hydropower technologies relied mostly on public finance, with private finance representing only around 32% and 3%, respectively.[20] 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.[21]

The link between investment and installed capacity reflects these differences in technology. Solar PV investments track fairly closely with the capacity installed, whereas investments for many other renewable technologies, such as offshore wind power, geothermal and hydropower installations, have a greater time lag (of one to several years depending on the technology and project specifics) from initial investment to project commissioning.

INVESTMENT BY ECONOMY

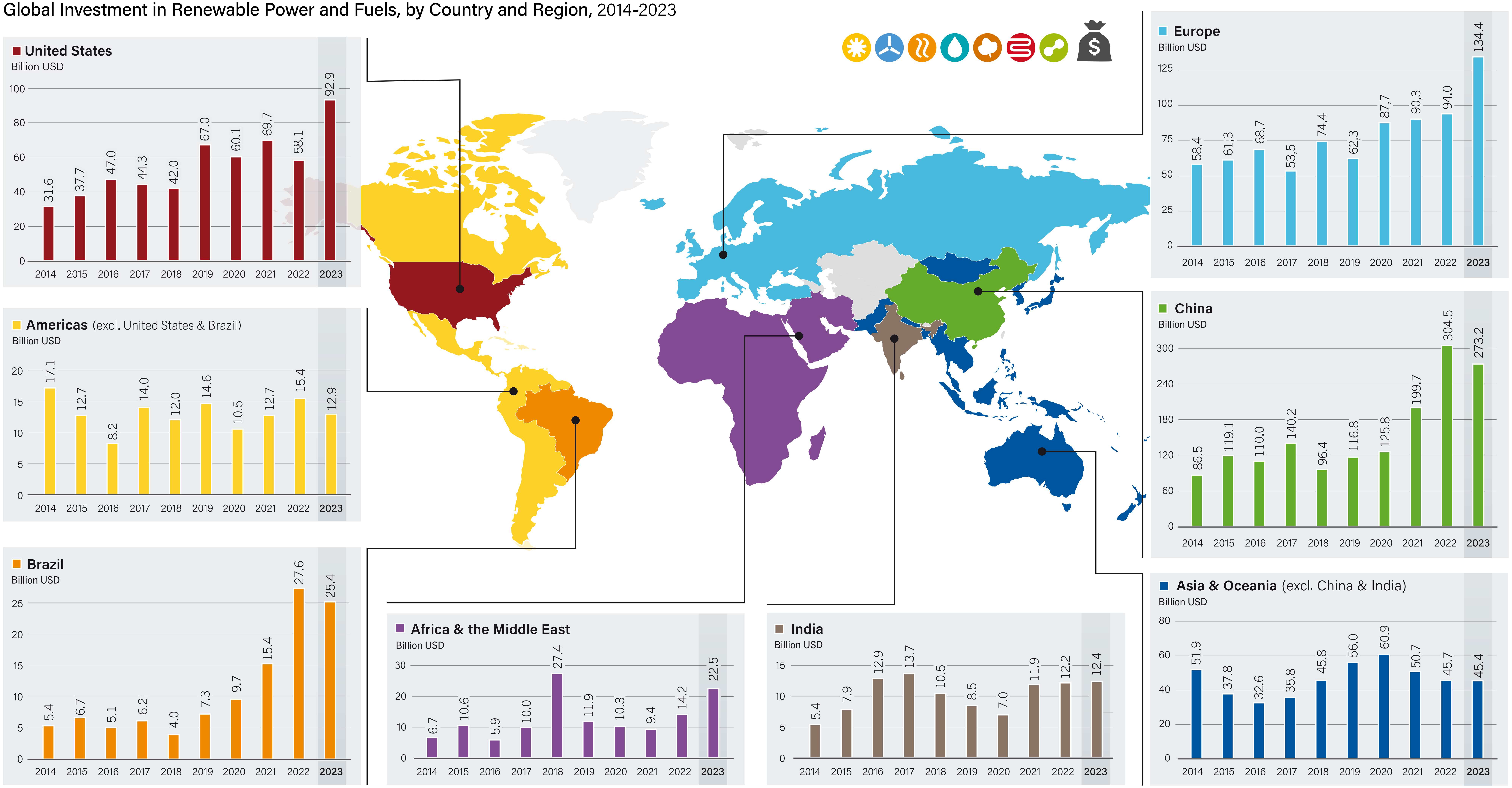
Investment in renewable power and fuels varied by region in 2023, increasing dramatically in Europe, the United States, and the Middle East and Africa, but falling in China and Brazil.[22] (→ *See Figure 13.*) China continued to account for the largest share of global renewable energy investment (excluding hydropower larger than 50 MW) at 44%, followed by Europe (20.9%) and the United States (15%).[23] All other world regions accounted for 7% or less of the total.[24]

China's overall investment in renewables fell 10.3% to USD 273.2 billion in 2023.[25] Although the country's investment in solar PV capacity rose 8.9% to USD 186.2 billion, its investment in wind power fell 34.5% to USD 86.6 billion, and investment in all other renewable energy technologies was marginal by comparison.[26] Renewable energy investment in China is driven in part by the country's long-term decarbonisation goals and by rising electricity demand.[27] Investment in solar PV has been supported by Chinese provincial and local governments, as well as by growing commercial and industrial interest in distributed solar PV.[28] In 2023, in response to a slowdown in the real estate sector, the central government introduced a policy to encourage the use of solar power on unused and existing construction lands, further bolstering investment in the technology.[29]

In **Europe**, investment in renewable energy projects jumped 42.9% in 2023 to USD 134.4 billion.[30] Many countries showed remarkable investment growth: in the United Kingdom, renewable energy investment increased more than six-fold to USD 23.2 billion, the highest level in the region.[31] Most of this increase was in wind energy, which received a boost during the year when the government announced a 66% increase in the maximum prices for offshore wind auctions.[32] Germany came in second in investment (up 35% to reach USD 20.4 billion), followed by Spain (up 14.4% to reach USD 18.5 billion).[33] The highest growth rates in renewable energy investment in Europe were in the Czech Republic (up 246%), Denmark (up 172%), and Bulgaria (up 145%), although starting from lower levels.[34]

The **United States** continued to attract the most renewable energy investment among developed economies.[35] Reversing the decline of the previous year, investment in renewables in the country jumped 60% in 2023 to reach USD 92.9 billion.[36] Investment in solar PV dominated (up 41.2% to USD 50.6 billion), although wind power experienced much higher growth (up 174.3% to USD 37.1 billion).[37] Investment also supported renewable energy manufacturing facilities and facility expansions, including 6 planned offshore wind turbine component facilities (ranging from USD 100 million to USD 1.7 billion in investment), 11 new onshore wind component facilities (ranging from USD 20 million to USD 60 million) and 50 new solar PV manufacturing plants (ranging from USD 11.25 million to USD 2.5 billion).[38] (→ *See Economic and Social Value Creation module.*) Policy support from the federal Inflation Reduction Act and accompanying tax credits was a key driver of the boom in US renewable energy investment.[39] Geothermal investment grew substantially in 2023, supported by new investment and production tax credits on the federal level.[40]

FIGURE 13.
Global Investment in Renewable Power and Fuels, by Country and Region, 2014-2023



Source: See endnote 22 for this section.

In **Asia-Oceania** (excluding China and India), the decline in renewable energy investment continued in 2023 but fell only 0.8% to USD 45.4 billion.[41] Investment in wind power in the region increased 4% to USD 14.8 billion, whereas solar PV investment was down a slight 1.2% to USD 29.3 billion.[42] A contributing factor to the negative solar PV trend was the ongoing decline in PV investment in Viet Nam, the region's largest PV market, following the discontinuation of the country's feed-in tariff at the end of 2020.[43] In Japan, where investment in renewables had been declining since 2020, investment again increased in 2023, rising 3.2% to USD 10.5 billion.[44]

In **India**, total new investment in renewables increased a moderate 1.4% to USD 12.4 billion.[45] Investment in solar PV fell 17.7% to USD 7.9 billion, but investment in wind power surged 85.6% to USD 4.8 billion.[46] The stark change in solar PV investment in India from 2022 (when investment rose 19%) is linked to land acquisition challenges, transmission and connectivity issues, and policy uncertainty, including the introduction of facilitation charges for open access projects.[47]

Brazil's total investment in renewables fell 8.1% to USD 25.4 billion, with investments declining in both wind energy (down 39.4% to USD 4.5 billion) and solar power (down slightly to USD 19.7 billion).[48] Despite legislation as of June 2023 that gradually introduces grid-use charges for residential and commercial system owners, investment in small-scale PV has remained robust and has grown substantially from very low levels just five years ago.[49] Investment in wind energy has declined in large part due to transmission constraints and bottlenecks.[50] To combat this, Brazil has hosted regular transmission auctions, which have driven around USD 43 billion in investment in the transmission infrastructure in the past decade, and USD 7.5 billion in 2023.[51]

Outside Brazil and the United States, renewable energy investment in the **Americas** was down 16.3% to USD 12.9 billion.[52] Investment fell in both solar PV (down 15.8% to USD 8.0 billion) and wind power (down 18.8% to USD 4.3 billion).[53] Investment in renewables was impacted by inflation, the discontinuation of COVID-19 stimulus packages, weak local currencies and slow economic growth.[54]

In Argentina, renewable energy projects have struggled to secure investment in recent years in the face of macroeconomic turmoil. With limited auctions and severe transmission bottlenecks, the development of renewables in the country is now driven mainly by the MATER mechanism, which awards priority dispatch to renewable plants holding corporate power purchase agreements (PPAs).[55]

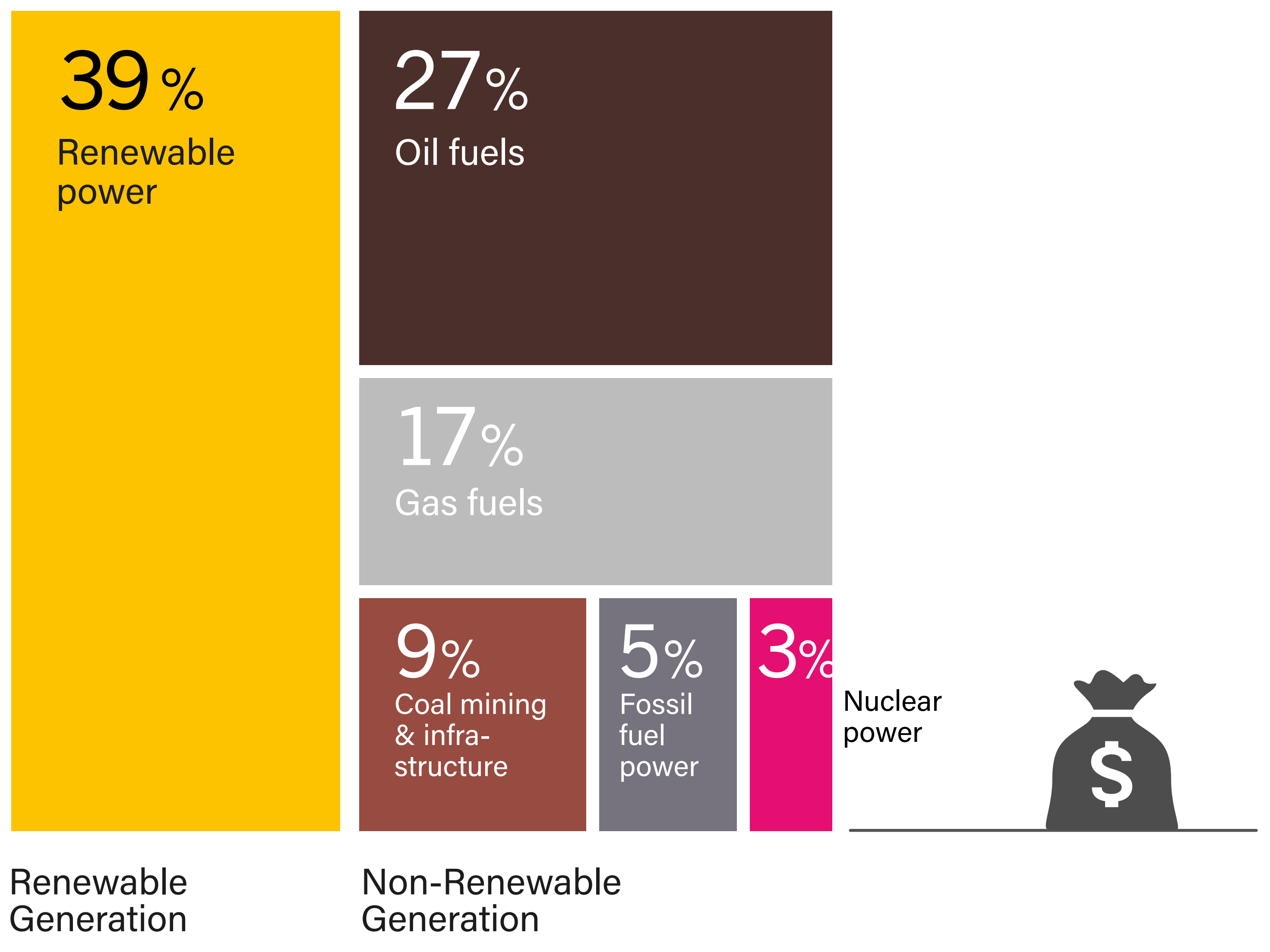
In Chile, where renewable energy investment has been limited by rising transmission constraints, the country has facilitated investments in utility-scale batteries and become a regional leader in storage.[56] In Mexico, investment in renewables has stalled in recent years due mainly to political resistance.[57]

Investment in renewables in the **Middle East and Africa** jumped 59% to reach USD 22.5 billion in 2023.[58] Saudi Arabia became the region's new leader with a marked 691% increase in investment to reach USD 6.6 billion.[59] In second place, South Africa saw a slight 1.7% increase in renewable energy investment to USD 5.3 billion.[60] Kenya also emerged as a regional leader, with investment in renewables rising nearly 28-fold to USD 3.3 billion.[61] In the Middle East and Africa, public funds from multilateral development banks have played a more substantial role in renewable energy investment than in other world regions, and also help facilitate private investments.[62]

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.[63] Country-related risks and underdeveloped local financial systems also can directly affect the cost of capital.[64] As recently as 2021, nominal financing costs could be up to seven times higher in emerging and developing countries than in developed countries, such as the United States and countries in Europe.[65] (→ *See Global Overview module.*)

Global investment in renewable power and fuels reached **an all-time high** in 2023, despite high interest rates and higher costs of raw materials.

FIGURE 14.
Global Investment in New Energy Supply Infrastructure by Type, 2023



Source: See endnote 67 for this section.

RENEWABLE ENERGY INVESTMENT IN PERSPECTIVE

Renewable power installations attracted far more investment than fossil fuel power plants did in 2023.[66] Investment in new renewable power capacity accounted for 82% of the total global investment in new power generation, including fossil fuels and nuclear but excluding grids and storage.[67] (→ *See Figure 14.*) Capital expenditures on fossil fuel-based power declined by 10% to USD 90 billion during the year, due largely to decreased spending on coal-fired power.[68] Investments in fossil fuels, such as oil and gas, were impacted by geopolitical uncertainty reflecting the evolving situation in Europe and the Middle East, as well as inflation and high interest rates.[69]

Countering the trend seen in power infrastructure, when both upstream and downstream oil, gas and coal and related infrastructure investments are considered, the combined total annual investment in fossil fuels dwarfs that in renewable power and fuels.[70] Investment in upstream oil and gas increased 9% in 2023 to around USD 538 billion; national oil companies in the Middle East and Asia were responsible for nearly all of the increase.[71] Investment in fuel supply increased 6% to USD 162 billion in 2023, led by China, India and South-East Asia.[72] More than three-quarters (76%) of the financing for coal projects worldwide was in China, despite the country's pledges to reduce coal consumption by mid-decade.[73] The Chinese government began supporting more coal- and gas-fired power investment following a severe electricity supply crisis in late 2021 and continued market strains amid a heatwave in 2022.[74]

MARKET AND INDUSTRY TRENDS

Despite high interest rates, inflation, and supply chain disruptions, the renewable energy sector saw another record year of capacity additions.

1.6 TW of solar PV capacity was installed in 2023, surpassing hydropower for the first time

82% of global renewable power additions were in China, Europe and United States in 2023

134 countries were benefiting from solar thermal systems as of 2023

TECHNOLOGIES

- BIOENERGY
- CONCENTRATED SOLAR THERMAL POWER (CSP)
- GEOTHERMAL POWER AND HEAT
- HEAT PUMPS
- HYDROPOWER
- OCEAN POWER
- SOLAR PHOTOVOLTAICS (PV)
- SOLAR THERMAL HEATING
- WIND POWER

KEY FACTS
BIOENERGY

- Bioenergy accounted for **12.1%** of the world's **total final energy consumption** in 2021, totalling 45.9 exajoules (EJ).
- Modern bioenergy produced **1.3 EJ of derived heat in 2021**, with solid biomass accounting for over half of the production.
- **Biofuels** achieved a new record high in 2022 as production reached **170 billion litres** (4.3 EJ), with ethanol representing nearly two-thirds of the total biofuel production.
- Global **biogas and biomethane production exceeded 1.6 EJ** in 2022, and nearly half of this production was in Europe.

Bioenergy refers to the energy derived from organic materials (biomass), obtained from recently living organisms or their by-products.[1] The production of bioenergy involves different conversion processes – such as biological, chemical, thermal and hybrid methods – and employs a wide array of feedstocks, including agricultural residues (rice husks, bagasse, etc.), forestry residues (wood chips, sawdust, etc.), energy crops, and the renewable fraction of municipal and industrial waste.

As a versatile energy source, bioenergy extends into sectors such as heating, cooling, electricity generation and transport fuels. By substituting conventional fossil fuel sources, it can reduce energy-related greenhouse gas emissions.[2]

Bioenergy accounted for 12.1% of the world's total final energy consumption in 2021 (latest data available), amounting to 45.9 EJ.[3] (→ *See Figure 15.*) More than half of this was the use of traditional biomass (24.3 EJ), which typically entails the direct burning of biomass in inefficient heating and cooking devices, mainly in developing Africa and Asia.[4] Demand for modern bioenergy totalled 21.5 EJ, representing nearly 6% of total final energy consumption, and was distributed among industry, buildings, transport, electricity and agriculture.[5] (→ *See Figure 15.*)

Bioenergy is playing a key role in addressing climate change, securing energy supply and providing income through local biomass supply chains.[6] Between 2010 and 2022, the use of modern bioenergy increased by around 3% annually.[7]

BIOHEAT

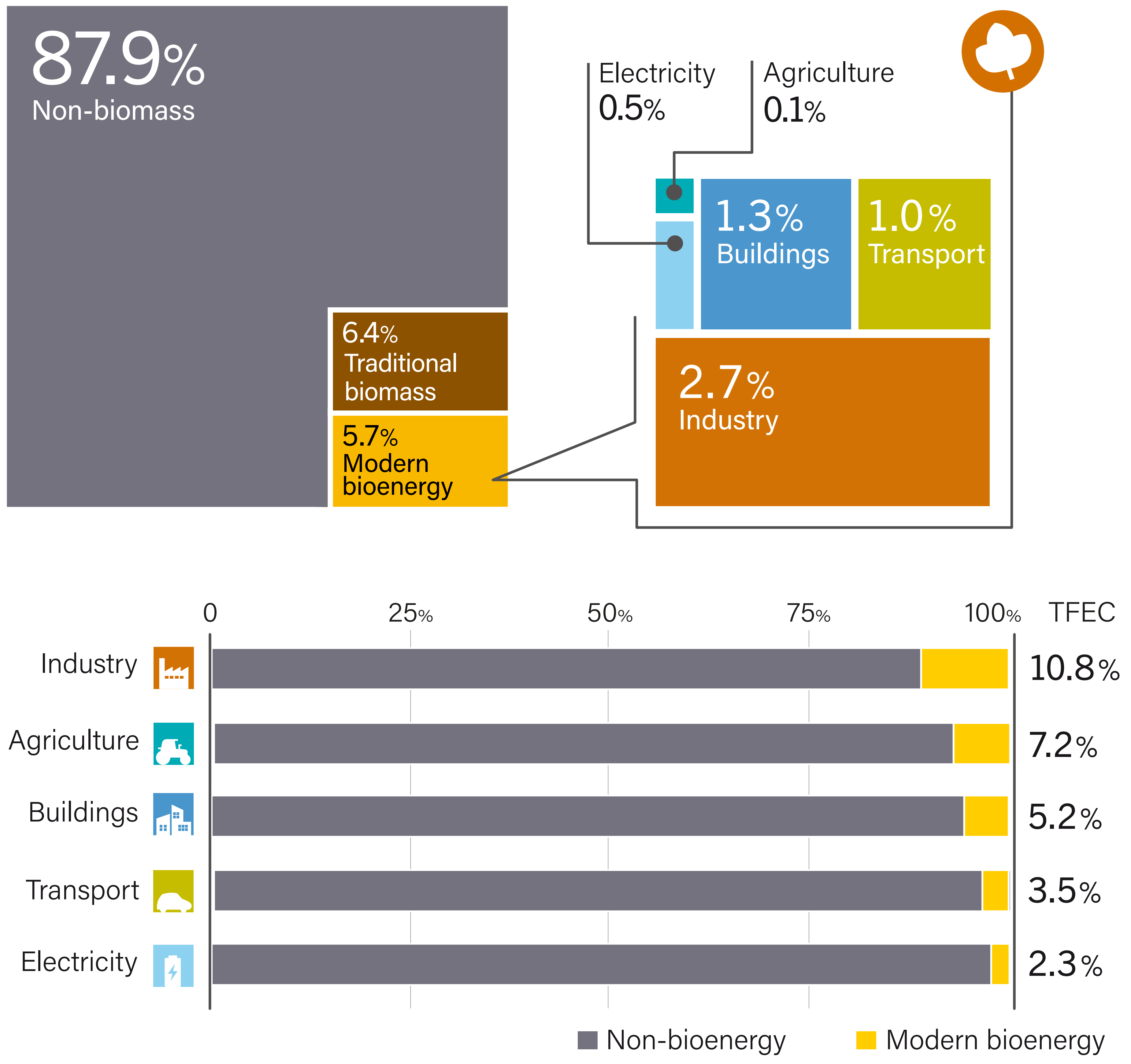
Biomass is used to provide heat in various ways – including through direct combustion in boilers and stoves – as well as for electricity generation, which sometimes coincides with the production of usable heat (combined heat and power, or CHP). Biomass also can be used for process heat in industrial processes and can be converted into liquid and gaseous biofuels for use in heating systems.[8]

In 2021, modern bioenergy produced 1.3 EJ of **derived heat**, as part of CHP plants or heat-only plants.[9] This was a 9% increase from 2020, with solid biomass (wood chips, pellets, etc.) accounting for more than half of the production, followed by waste-to-energy (43%) and biogas (only 4%).[10] Bioenergy accounted for 15.6 EJ of the world's total heat consumption (including district heating networks), or around 8% of the total heat consumed in 2021.[11]

In the European Union (EU), Sweden was the largest consumer of solid biomass for heating purposes in 2022, representing more than 20% of EU consumption, followed by Finland (15.8%) and Denmark (13.1%).[12] Germany was the only EU country where gross heat production from solid biofuels (especially from wood pellets) increased notably.[13]

The use of bioenergy for heat in the **buildings sector** totalled 29 EJ in 2021, and nearly 5 EJ of this was modern bioenergy, representing 5% of the sector's total heat energy consumption.[14] In the **industry sector**, bioenergy provided around 10 EJ of renewable heat, or 10.8% of the final heat demand.[15] The use of industrial bioheat increased 3% in 2021, continuing a two-decade upward trend.[16]

FIGURE 15.
Share of Bioenergy in Total Final Energy Consumption (TFEC), by End-Use Sector, 2021



Source: See endnote 3 for this section.

In pursuit of decarbonisation, industries across sectors are using biomass in their processes, mainly to meet heat demand. During 2017-2022, bioenergy accounted for more than two-thirds of the global growth in renewable heat use, especially in the industry sector.[17] In Europe, the paper, pulp, and print industry, together with the wood and wood product industry, accounted for 79% of the biomass use for energy in 2021.[18]

District heating involves generating heat in a centralised location and then distributing it to local residences, businesses and industries. District heating networks offer great potential for efficient, cost-effective and flexible large-scale use of low-carbon energy for heating.[19] In 2022, district heating production met around 9% of the global final heating need in buildings and industry.[20] However, nearly 90% of all district heat is still generated from fossil fuels.[21] In 2021, bioenergy contributed nearly 0.8 EJ to this production.[22]

In the EU, the countries with the largest shares of bioheat use in district heating in 2021 were Luxembourg (78%), Denmark (65%) and Lithuania (45%).[23] In 2023, the EU provided USD 434 million (EUR 401 million) to the Czech Republic's green district heating scheme, supporting the installation of around 500 kilowatts (kW) of heat generation units based on biomass and waste, for around 345 megawatts-thermal (MW_{th}) of bioheat capacity.[24] In Sweden, Sölor Bioenergy Group completed a new briquette storage facility in Floby that will supply the district heating plant (around 11,000 MW_{th} annually) with briquettes sourced from the local wood industry, with the ash returned to the forest.[25]

Bioenergy also can support greater access to **clean cooking** fuels. Clean cooking solutions include solar, electric, biogas, ethanol and advanced biomass/pellet stoves.[26] Pellet-fed gasifier stoves are among the most innovative of these technologies, bringing the potential for greater accessibility and affordability.[27] Gasifier stoves use pellets instead of raw biomass and can lower emissions and ensure highly efficient combustion.[28] As of May 2023, the world's only mass-produced biomass stove, the Mimi Moto, had sold 68,000 units across 23 countries in Sub-Saharan Africa and South-East Asia.[29]

BIOFUELS

Biofuels provide fuel alternatives for use in light-duty vehicles, heavy-duty tracks, ships and aircraft. In 2022, biofuels supplied more than 3.5% of global transport energy demand, mainly for road transport, and accounted for nearly 90% of the total renewable energy use in the sector.[30]

Biofuel demand increased 6% in 2022, continuing a growth trend and reaching a new record high of 170 billion litres (4.3 EJ).[31] (→ *See Figure 16.*) Ethanol accounted for 106 billion litres (2.6 EJ), or nearly two-thirds of the total biofuel demand.[32] Biodiesel production was 45.1 billion litres (1.6 EJ), followed by hydrotreated vegetable oil (HVO) or renewable diesel at 13.3 billion litres (0.47 EJ).[33] Although production of biojet (sustainable aviation fuel) is at an early stage, demand increased to 200 million litres in 2022.[34]

Most biofuel production today relies on conventional feedstocks such as sugar cane, maize and soya. However, expanding production of biofuels calls for a diversification of feedstocks, such as wastes, residues, used cooking oil and waste animal fats. In 2023, maize was used to produce 66.2 billion litres of liquid biofuels, followed by sugars (38.6 billion litres), oils (45.8 billion), other crops (10.7 billion), used cooking oil (10.7 billion) and animal fats and other wastes (8.4 billion).[35]

The United States was the world's leading biofuel producer by country in 2022, generating 70.7 billion litres, or nearly 40% of the global total.[36] In second and third place were Brazil (37.5 billion litres) and Indonesia (11.1 billion litres).[37] Biofuel production in Germany reached around 5.1 billion litres, ranking it among the top five producers and as the European leader.[38]

Ethanol continued to be the dominant biofuel produced. In 2022, the United States and Brazil accounted for more than 80% of global production, supplying 58 billion litres and 32.9 billion litres respectively, followed by the EU with 6.1 billion litres.[39] India surpassed China to become the fourth largest ethanol producer, with 5.3 billion litres.[40] The main feedstocks for ethanol production are maize in the United States and sugarcane in Brazil.

US blending mandates vary among E10 (10% ethanol), E15 and E85 (51-83% ethanol) depending on the state and the type of vehicle.[41] Brazil has a mandate of E27 but plans to increase it to E30 in the future.[42] India's Ethanol Blended Petrol Programme (EBP) achieved 12% blending (E12) as of 2023 and has a target of E20 by 2025.[43] Indonesia's state-owned energy company Pertamina launched an E5 petrol product in June 2023, and the country aims to produce 1.2 billion litres of ethanol from domestic sugar cane by 2030.[44] In the EU, Poland was the latest Member State to adopt the E10 petrol blend, bringing the total number of EU countries (plus the United Kingdom) with this target to 19.[45]

Fatty acid methyl ester (FAME) **biodiesel** is a renewable fuel made from vegetable oils, animal fats, or waste cooking oils, and is used as a blending component in diesel fuels. In 2022, global biodiesel production neared 59 billion litres, with the EU generating the largest share at 26% (based on crops such as rapeseed oil and sunflower oil), followed by the United States with nearly 20% (based on soya oil) and Indonesia with 19% (based on palm oil).[46] Primary feedstocks vary by region, but vegetable oils are the most used, with palm oil accounting for 36% of global production, soya oil for 23%, and rapeseed oil for 14%, whereas waste (used cooking oil and others) supplies 14% and animal fats 5%.[47]

The EU is the largest producer and consumer of FAME biodiesel, producing around 12 billion litres in 2022, based predominantly on rapeseed oil, followed by used cooking oil.[48] Germany, Spain and France together contributed more than half of total EU FAME production.[49]

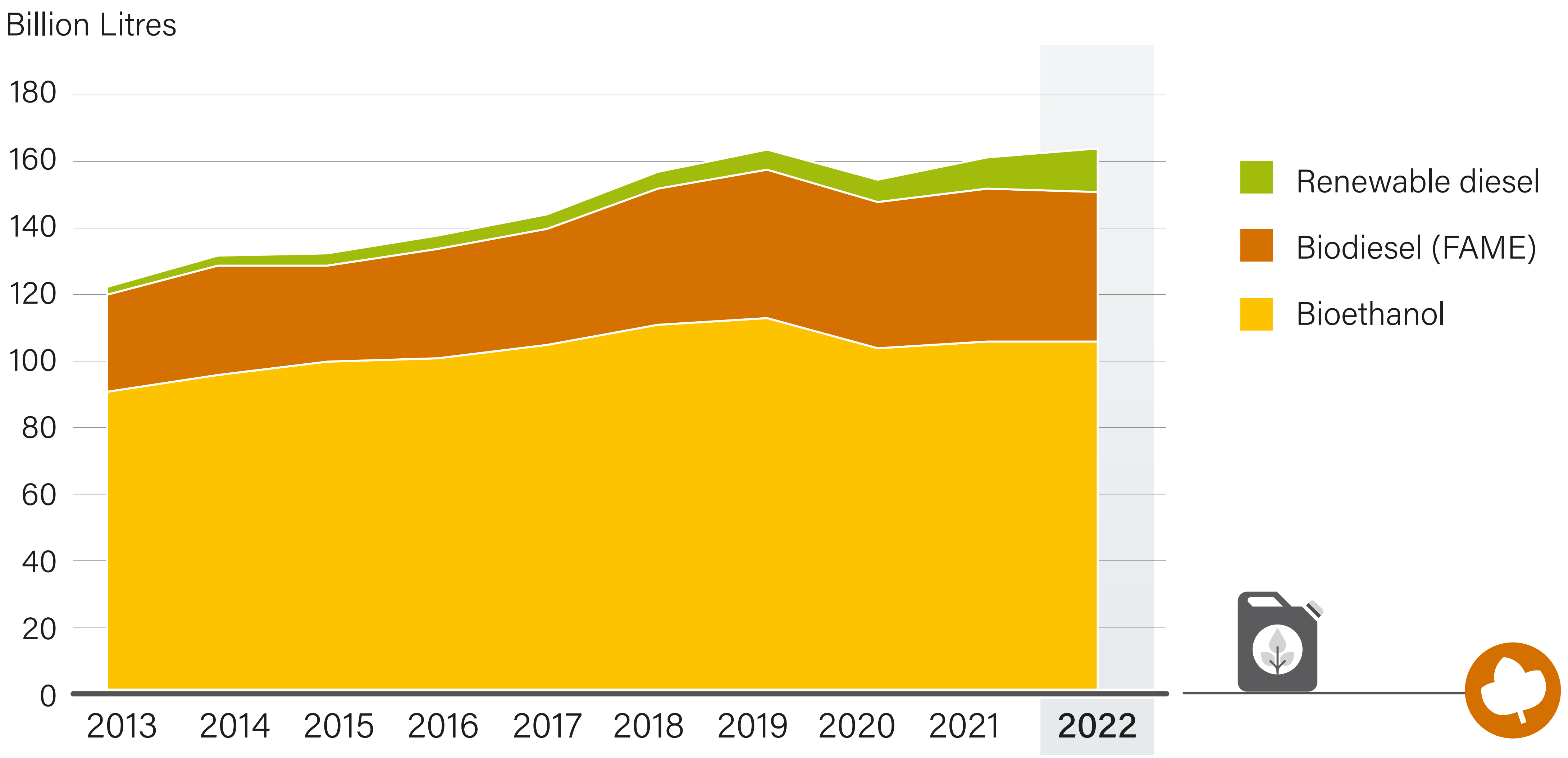
In 2023, Indonesia raised its biodiesel blending mandate from B30 to B35, with plans to increase it to B40 in the next few years, based on palm-based FAME.[50] The government implemented a quota policy to address supply surpluses and price pressures in vegetable oil markets.[51] Brazil is expanding its biodiesel blending from 12% in 2023 to 15% by 2026 under its RenovaBio incentive programme.[52]

A new generation of bio-based diesel, known as **hydrotreated vegetable oil (HVO)** or **renewable diesel**, can be used as a renewable fuel in existing diesel engine vehicles, either in pure form or blended. The United States was the largest HVO producer in 2022, producing around 5.7 billion litres.[53]

US demand is driven by the federal Renewable Fuel Standard (RFS2), California's Low Carbon Fuel Standard (LCFS) and the re-introduced Blenders Tax Credit.[54] In 2022, HVO production in the EU was nearly 4 billion litres.[55]

Neste, the world's largest producer of HVO, expanded its US operations in 2023 by starting production of renewable diesel at Marathon Petroleum's refinery in Martinez, California.[56] In Canada, the 2022 Clean Fuel Regulation focuses on liquid biofuels and has driven renewable diesel production. Canada's first renewable diesel facility, the Tidewater Midstream facility, started operations in June 2023.[57]

FIGURE 16.
Global Production of Ethanol, Biodiesel (FAME) and Renewable Diesel, 2013-2022



Source: See endnote 31 for this section.

Production of biodiesel increased

55%

during 2013-2022.

BIOGAS

Biogas fuel is produced mainly through anaerobic digestion of organic wastes and residues. It is used mostly to provide heat and power and can be upgraded by removing carbon dioxide (CO_2) to produce biomethane, which can be injected into gas grids or used as a transport fuel.[58] Global biogas and biomethane production increased 3% in 2022 to surpass 1.6 EJ.[59] **Europe** accounted for nearly half of this production, with **Germany** alone representing close to 20% of the world's consumption.[60] **China** had a production share of 21%, followed by the **United States** (12%) and **India** (9%).[61]

In **India**, diverse programmes aim to boost biogas use in the energy sector. The government introduced a mandate requiring a 5% biomethane blend both in compressed natural gas (CNG) for transport and in piped gas for homes by 2028, with incremental increases starting from 1% in 2025.[62] Comprehensive Indian support policies include the Sustainable Alternative Towards Affordable Transportation (SATAT) scheme, the Waste to Energy Programme and the Biogas Programme.[63]

Automaker Scania of Sweden has introduced new biogas engines with 5% improved fuel efficiency.[64] Meanwhile, the Swedish energy company E.ON planned to launch its first biogas plant in Poland in 2024, capable of producing 8 gigawatt-hours of energy annually from agricultural waste.[65] In New South Wales, Australia, the companies Jemena and Optimal Renewable Gas (ORG) will jointly build three new biomethane plants, with the aim of injecting up to 1.5 petajoules (PJ) into the gas network; ORG plans to expand production to 2-4 PJ annually and to establish 10 plants nationwide by 2030.[66]

SUSTAINABLE AVIATION FUEL

Sustainable aviation fuel (SAF) refers to aviation fuel produced from biomass-based sources using technologies such as hydro-processed esters and fatty acids (HEFA), HVO, and alcohol-to-jet.[67]

The United States, Europe, and Japan are at the forefront of SAF growth, propelled by strong policy support.[68] The ReFuelEU Aviation legislation sets binding blending obligations for 2% of the EU's jet fuel to come from SAF by 2025 and 6% by 2030, gradually increasing to 70% by 2050.[69] Japan has a goal of 10% SAF by 2030, and the United States, through its SAF Grand Challenge, aims to supply sufficient SAF to meet 100% of aviation fuel demand by 2050.[70] India plans to invest in SAF production using sugarcane molasses as an indigenous feedstock, with indicative targets of 1% SAF blending in jet fuel for domestic airlines by 2025, although no policies were in place as of 2023.[71]

Airlines have committed to using nearly 35 billion litres of SAF annually over the next 20 years.[72] In 2023, the Finnish refiner Neste completed the expansion of its USD 1.7 (EUR 1.6 billion) Singapore Expansion project, able to produce up to 1 million tonnes of SAF.[73] Canada provided USD 5 million in support to Azure Sustainable Fuels Corp. to build and operate an SAF facility in Ontario.[74] Despite rapid expansion of production, SAF represented less than 0.1% of total global aviation fuel as of 2023, and growth may slow in the coming years due to high costs, limited clear policy support and low feedstock availability.[75]

The **maritime** sector has witnessed growing interest in biofuels. Despite comprising less than 1% of tested marine fuels in 2023, biofuel use is on the rise.[76] The European Council's adoption of the FuelEU maritime regulation in July 2023 aims to boost demand for renewable and low-carbon fuels while reducing greenhouse gas emissions from shipping.[77] The FUEL-UP project, funded by the EU's Horizon programme and commencing in 2024, seeks to convert biogenic waste into advanced biofuels for decarbonising aviation and marine transport.[78]

The Global Biofuel Alliance, formed at the 2023 G20 Summit in India, aims to boost biofuel supply and demand globally. Bringing together 19 countries including the United States, Brazil, India, and the United Arab Emirates, the global partnership is focused on advancing biofuel technologies, promoting sustainable use across industries and establishing robust standards.[79]

BIOPOWER

Biopower refers to the capacity to generate electricity from biomass. Bio-electricity can be generated continuously by burning organic materials such as wood chips, agricultural residues, and the organic portion of municipal solid waste.[80] Biopower production also can be combined with carbon capture and storage to create bioenergy with carbon capture and storage (BECCS), a technology that not only produces renewable energy but also actively removes CO_2 from the atmosphere, thereby contributing to negative emissions and aiding in the fight against climate change.[81] (→ *See Sidebar 2.*)

SIDEBAR 2. Impact of Carbon Dioxide Removal Regulations on the Bioenergy Industry, with a Focus on Bioenergy with Carbon Capture and Storage

Transitioning towards negative emissions is imperative to counter the rising trend in CO_2 emissions, which reached a record high of 37.4 gigatonnes in 2023. Substantial efforts are urgently needed in sectors such as power, heat and industry to achieve the steep emission declines required to achieve global climate goals.

According to the Intergovernmental Panel on Climate Change, deploying carbon dioxide removal (CDR) technologies, such as bioenergy with carbon capture and storage (BECCS), is required to attain net zero CO_2 or greenhouse gas emissions. Negative emissions – through CRD – involve removing more CO_2 from the atmosphere than is being added.

Deploying BECCS on a large scale requires a functioning market or framework for carbon removals, as well as new economic instruments. In 2022, the European Commission presented a proposal for the first EU-wide voluntary framework for the certification of carbon removals. The Carbon Removal Certification Framework (CRCF) proposal sets out criteria to define high-quality carbon removals and establishes processes for monitoring, reporting and verifying the authenticity of these removals.

An increasing amount of capital is being earmarked for the development of BECCS projects. In 2023, the UK government approved a USD 2.5 billion (GBP 1.97 billion) project to add carbon capture units to two generators at a Drax power station in Yorkshire, Northern England. In Canada, Emissions Reduction Alberta announced nearly USD 1.9 million (CAD 2.6 billion) in funding for the Hinton BECCS Project, which is expected to remove 1.3 million tonnes of CO_2 per year. The Swedish energy company Stockholm Exergi plans to capture and store around 800,000 tonnes of CO_2 emissions annually from its CHP plant starting in 2026. In Denmark, Ørsted aims to capture more than 0.4 million tonnes of CO_2 emissions annually from burning straw and wood chips at two CHP plants, starting in 2026.

Source: See endnote 81 for this section.

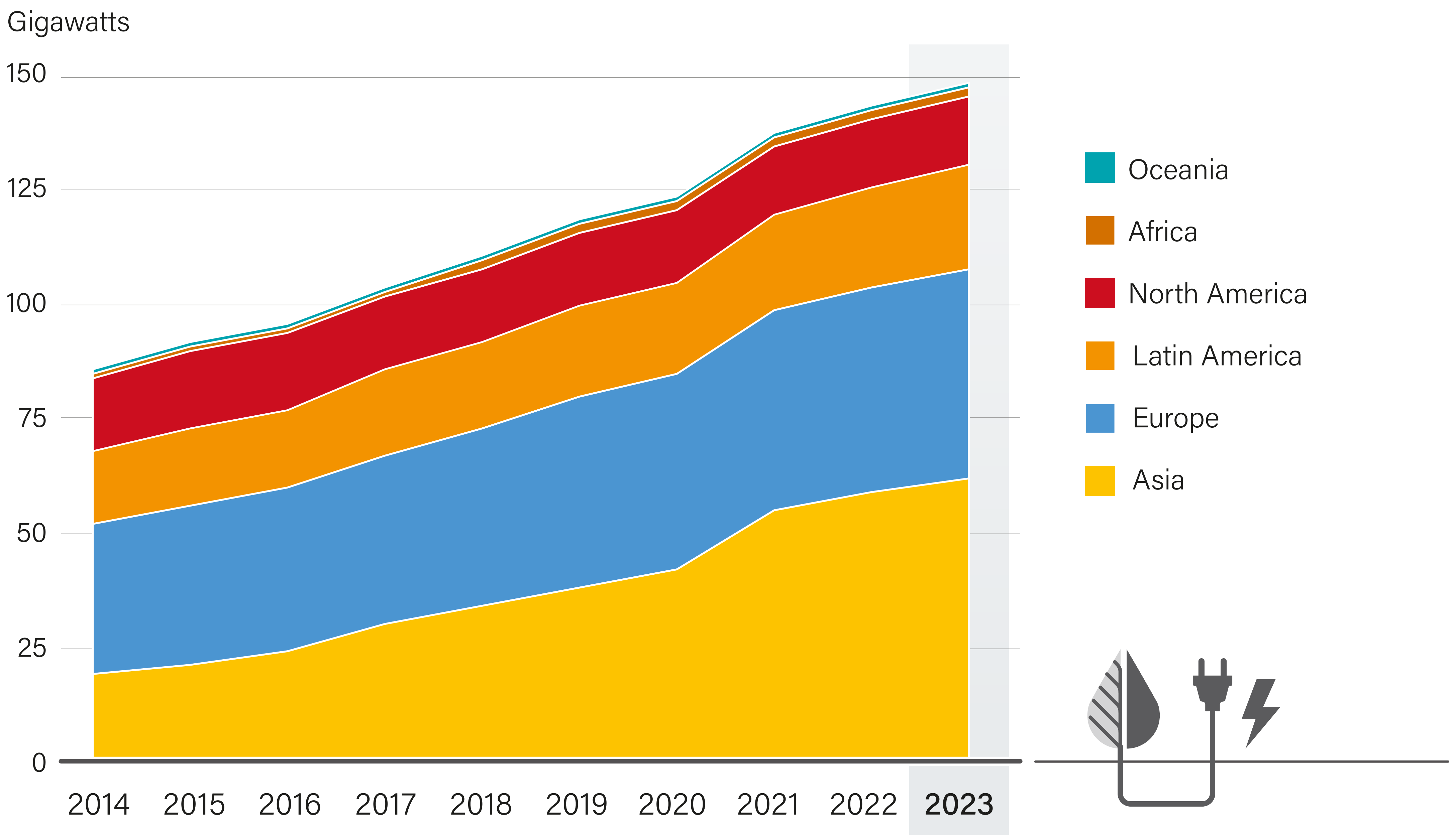
In 2023, bioenergy accounted for 2.4% of the world's electricity, producing 697 terawatt-hours (TWh), up 3.1% from 676 TWh in 2022.[82] The majority of bio-electricity was produced through the combustion of solid biomass sources, including diverse materials such as wood pellets, wood chips and sugarcane bagasse. Other contributors to biopower production include the organic portion of urban municipal and industrial waste, and biogas.[83]

China generated more than a quarter (204 TWh) of the world's biopower in 2023, followed by Brazil (54 TWh) and Japan (49 TWh).[84] Eighteen countries generated more than 10% of their electricity from bioenergy during the year, led by Denmark (at 21%), Finland (14%) and the United Kingdom (12%).[85]

Installed biopower capacity reached 149 gigawatts (GW) in 2023, accounting for around 4% of total renewable power capacity.[86] (→ *See Figure 17.*) Biopower capacity increased only 3% for the year, the slowest rate in the last decade.[87] The leading countries for biopower capacity were China (31 GW), Brazil (18 GW), the United States (11 GW) and India (10.7 GW).[88] Regionally, Asia led with a 5% increase in biopower capacity, and Japan had the highest annual capacity increase (18%).[89] In Brazil, bioenergy's share in electricity generation reached 7.7%, using sugarcane bagasse as the main feedstock.[90]

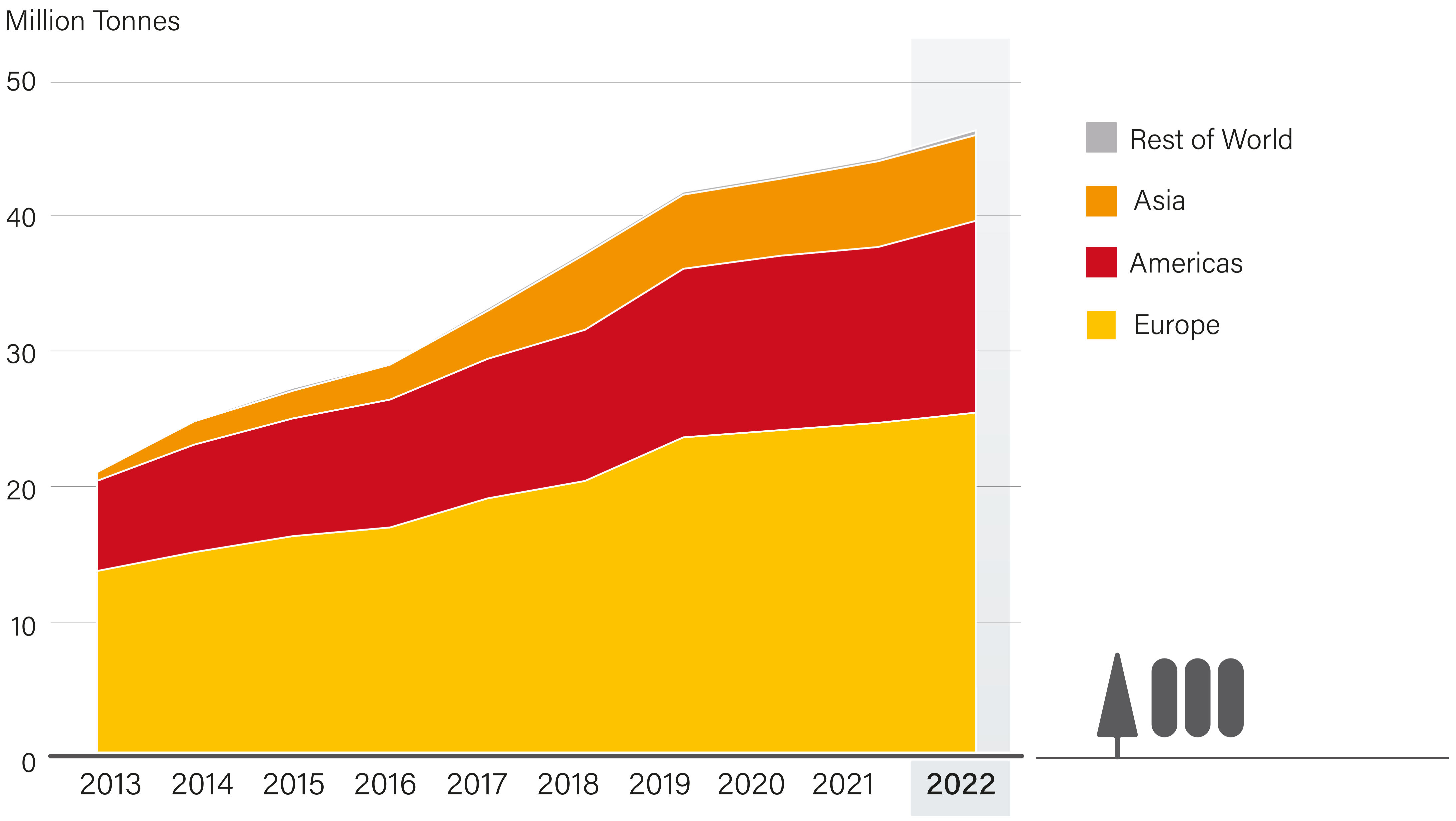
Globally, bio-electricity installed capacity increased **65%** during 2014-2023.

FIGURE 17.
Global Bio-Electricity Installed Capacity, by Region, 2014-2023



Source: See endnote 86 for this section.

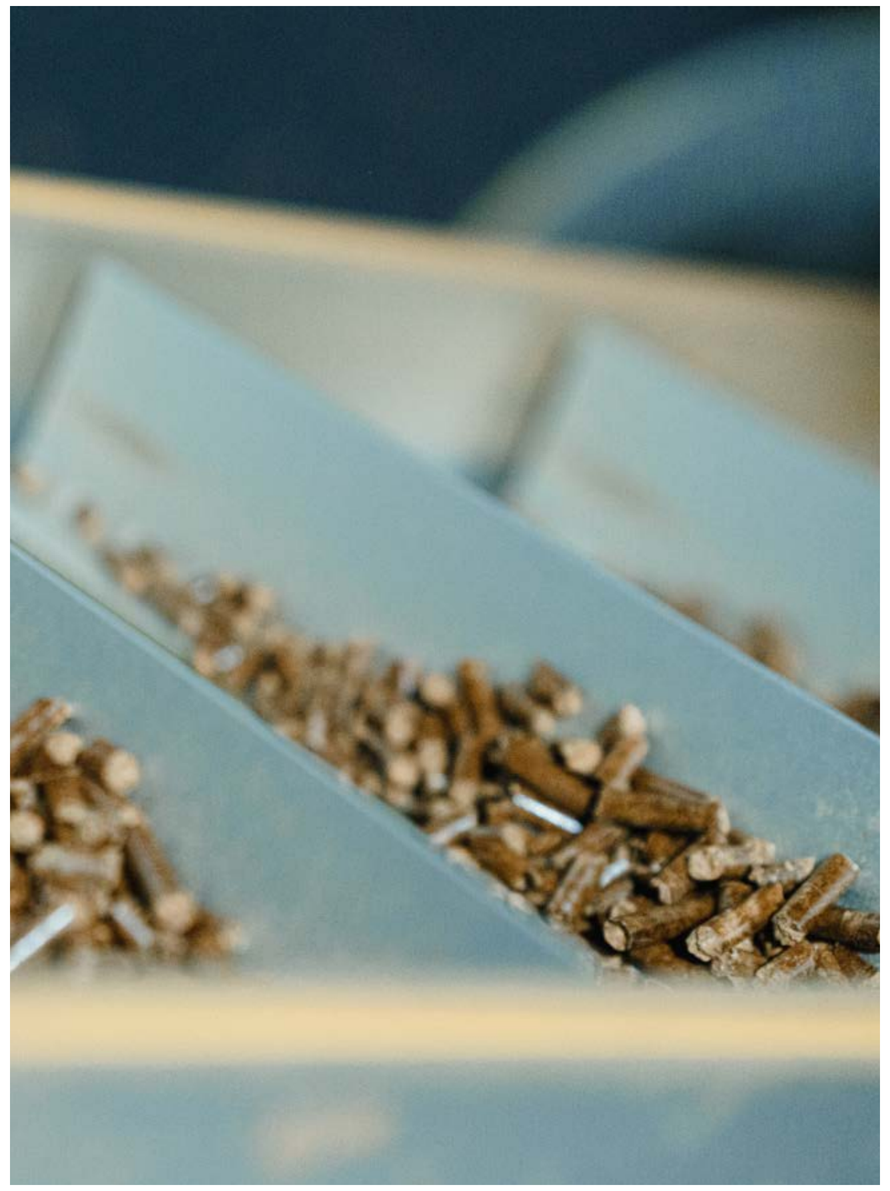
FIGURE 18.
Global Wood Pellet Production, by Region, 2013-2022



Source: See endnote 91 for this section.

The rising use of wood pellets has fuelled substantial growth in global bio-electricity production, particularly in the EU and North America.[91] (→ *See Figure 18.*) The EU led global wood pellet production in 2022, producing nearly 25 million tonnes, followed by North America with 14.6 million tonnes.[92] The EU generated 87.6 TWh of electricity from biopower facilities using solid biofuels, with the top producers in 2022 being Finland, Sweden and Germany.[93]

Asia experienced a surge in wood pellet demand as Japan and Viet Nam invested in more infrastructure for biopower generation from pellet combustion. Japan's Omaezakikou biomass power plant, which began commercial operation in July 2023, is expected to produce 530 million kilowatt-hours of electricity annually, enough to power 70,000 households.[94] RENOVA's 755 megawatt (MW) Morinomiyako Biomass Power Plant in Sendai City, which started operations in November 2023, is fuelled by wood pellets and palm kernel shells and is expected to meet the power needs of 170,000 households annually.[95]



KEY FACTS

CONCENTRATED SOLAR THERMAL POWER (CSP)

- **The world's largest CSP plant**, Noor Energy 1 in the United Arab Emirates, added 400 MW in 2023, bringing the total global **CSP installed capacity to 6.7 GW**.
- **China had 40 new CSP projects under various stages of construction and commissioning** as of the end of 2023.
- **High-temperature third-generation CSP** is entering the scene, with several pilot stations under construction.

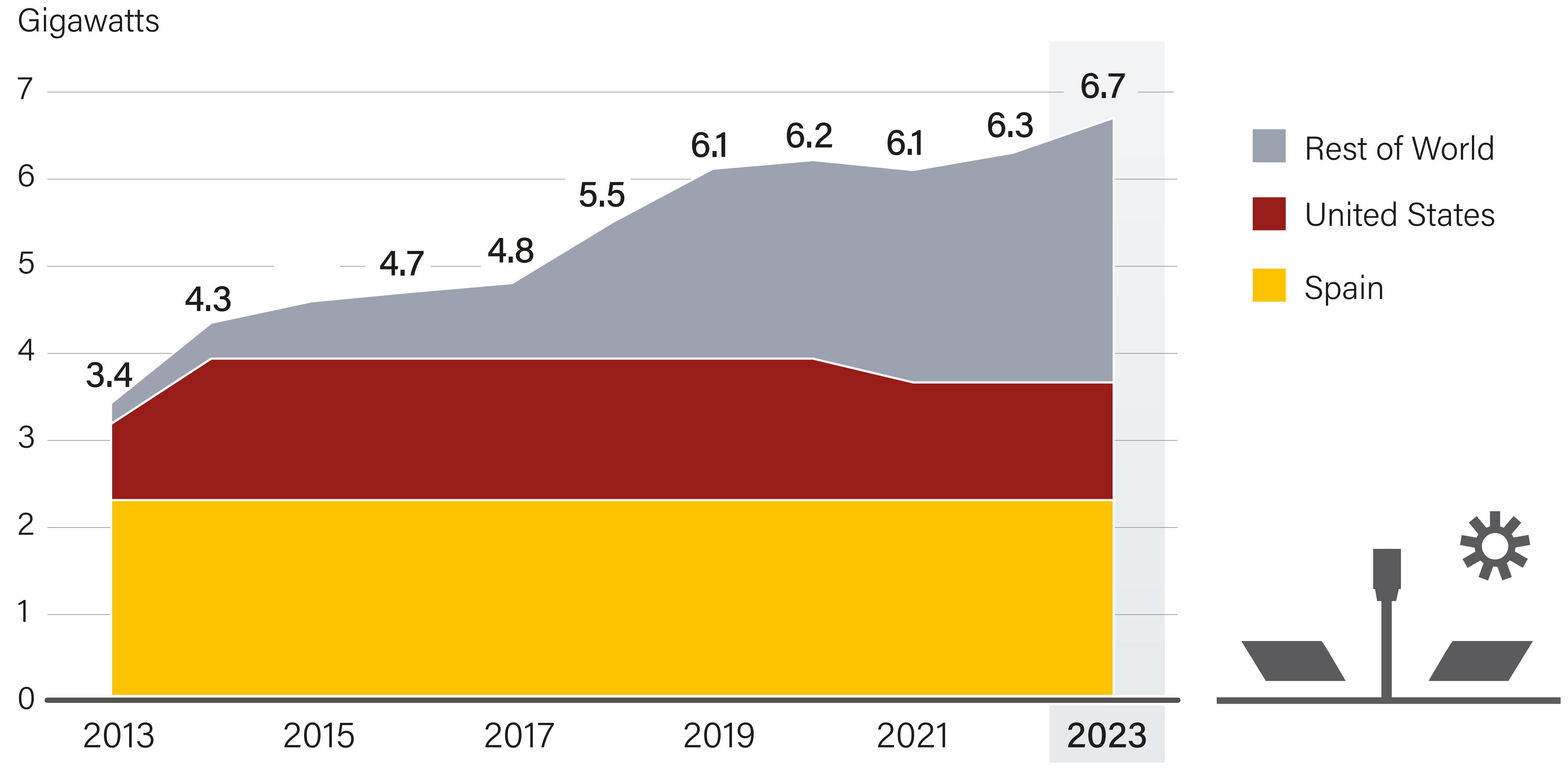
In 2023, the total installed capacity of concentrated solar thermal power (CSP) grew 400 megawatts (MW) to reach 6.7 GW.[1] (→ *See Figure 19.*) CSP with thermal energy storage is increasingly valued as a variable renewable energy technology that can provide storage and night-time power in synergy with solar PV and wind energy. Although first-generation parabolic trough plants remain the most proven and reliable CSP technology, second-generation CSP plants using molten-salt towers are increasingly being deployed, primarily in China.[2]

The global CSP market has shown signs of a renewed dynamic. In 2023, the Noor Energy 1 project, a 950 MW hybrid PV-CSP plant, was inaugurated during the United Nations Climate Change Conference (COP 28) in Dubai, United Arab Emirates.[3] Additionally, China initiated several new projects, expanding the pipeline of Chinese CSP plants to more than 1 GW under construction and 3 GW in development.[4] Spain and the United States continued to lead in cumulative CSP installed capacity in 2023, followed closely by the United Arab Emirates and China.[5] If current patterns hold, China is positioned to take the lead in both CSP deployment and supply chain capabilities by the end of the decade.[6]

In 2023, the remaining 400 MW of a 600 MW parabolic trough field came online at the Noor Energy 1 project in the **United Arab Emirates**.[7] The plant is now the world's largest CSP facility, with 700 MW of CSP capacity (including a previously completed 100 MW central receiver tower). It showcases the synergistic deployment of CSP alongside large-scale solar PV installations to deliver solar power through the night. The project uses state-of-the-art US and European second-generation CSP technologies, including large-aperture parabolic troughs and the latest molten-salt towers (with more than 10 hours of thermal energy storage in hot and cold tanks).[8] Noor Energy 1 has a total power storage capacity of 5.9 gigawatt-hours (GWh), making it the largest thermal battery in the world.[9]

In **China**, several key policies related to CSP were implemented at the national and provincial levels during 2023, helping to clarify technical prescriptions and the role of CSP as a peak-shaving resource.[10] The country's total installed CSP capacity remained at 588 MW, the same level as in 2020, as no new capacity was connected to the grid.[11] The first plants of China's "CSP+" projects were expected in 2024 and include mostly 100 MW towers,

FIGURE 19.
Concentrated Solar Thermal Power (CSP) Installed Capacity, by Country, 2013-2023



Source: See endnote 1 for this section.

as well as some troughs and Fresnel plants, co-located with solar PV and wind power capacity.[12] A typical configuration is Cosin Solar's Jinta project, which finished Heliostat assembly at the end of 2023 and deploys a 100 MW molten-salt tower with eight hours of storage alongside 600 MW of solar PV.[13] China announced some 13 additional plants with a combined capacity of 1.35 GW, 5 of which will be located in the high altitudes of the Tibet Autonomous Region.[14]

Italy was the only country in Europe with a CSP plant under construction as of 2023. The CSP 3 Bilancia project in Sicily is the country's third 4 MW Fresnel plant, with 16 hours of storage, and is slated for completion in 2024.[15] The plant is expected to contribute to Italy's goal of 873 MW of CSP capacity by 2030, as outlined in the updated National Energy and Climate Plan (NECP).[16]

Spain had the largest installed CSP capacity globally, at 2.3 GW, and in 2023 CSP plants delivered around 5 TWh, or 2% of the country's electricity needs, to the grid.[17] However, no new activity occurred during the year, challenging Spain's efforts to deliver on its goal of 4.8 GW of CSP by 2025, set out in the 2020 NECP.[18] After the disappointing first-ever 220 MW CSP auction held in 2022, which did not award any projects, no additional or adapted auctions occurred in 2023.[19] Instead, Spain updated its NECP to shift its target year for the 4.8 GW of CSP capacity from 2025 to 2030.[20]

4 GW
of CSP projects were under construction or development in China in 2023.

Elsewhere in the world, no new CSP plants broke ground in 2023. In **South Africa**, the Redstone project was expected to connect to the grid in 2024.[21] No further projects are in sight in the country, as CSP has been excluded from capacity expansions in South Africa's Integrated Resource Plan since 2019.[22]

In **Morocco**, the Noor Midelt project had not started construction as of 2023,, despite having been awarded a power purchase agreement (PPA).[23] Several stakeholders view the technology as too expensive and error prone – pointing to the patchy record and high power generation cost of the country's Noor Ouarzazate project – and have recommended instead substituting CSP with solar PV and batteries.[24]

Several countries announced their intentions to tender new CSP plants. **India** was actively preparing a CSP tender for 2024, which would end a ten-year hiatus and build on the operational experience of several CSP plants completed during the country's National Solar Mission.[25] **Kuwait** launched a request for proposals for 200 MW of CSP for the long-awaited Shagaya project, and **Egypt** has explored using CSP heat and power for desalination.[26] **Botswana** was working on a 200 MW tender for CSP.[27]

CSP costs remain challenging to assess, in part because few successful tenders have occurred, and the new plants being built lack transparent information on cost and financing. Because of its size and its recent completion, Noor 1 is widely regarded as the current CSP cost reference, with a PPA of USD 7.3 cents per kilowatt-hour; however, the project's financing conditions and concessional financing make it likely that CSP is still more expensive elsewhere.[28] In general, it is increasingly difficult to isolate the cost of electricity from CSP, given the trends towards dispatchable generation during only a few hours, and hybridisation with other generators. As with Noor 1, PPAs are usually awarded for all co-located technologies. Moreover, the investment cost for CSP may only be reported for the whole project: for example, China's hybrid CSP plants rarely report the CSP investment cost, although the known investment cost is much lower than in the demonstration plants completed during 2016-2020.[29]

The **CSP industry** has experienced growing differentiation between the Chinese and western supply chains. With few exceptions, China's new projects rely on Chinese intellectual property and supply chains, whereas projects outside of China (such as the Noor 1 project in Dubai and Redstone in South Africa) have relied on the know-how of companies from the early lead markets in the United States and Spain (namely BrightSource for the tower and Abengoa Solar for the parabolic troughs).[30]

Third-generation CSP has received growing attention. Novel CSP designs aim to decrease costs and improve on molten-salt towers by using novel heat transfer media and reaching higher temperatures, potentially above 1000°C.[31] In **Australia**, Vast Solar plans to reach financial close of the VS1 project at Port Augusta. The 30 MW / 288 MWh plant relies on third-generation CSP technology that uses sodium as the heat transfer fluid, and will deliver power for a solar methanol project and could be expanded by another 150 MW in the near future.[32]

In the **United States**, where no commercial-scale CSP plants were under construction as of 2023, the federal Sandia National Laboratories started building a 1 MW demo plant, the G3P3, that will demonstrate the use of falling particle receiver technology (a new solid high-temperature heat transfer medium) to replace molten salts.[33] A 2 MW sister plant is to be located in **Saudi Arabia**.[34]

Third-generation
CSP is receiving growing attention.

KEY FACTS

GEOTHERMAL POWER AND HEAT

- New geothermal power generating capacity of 0.1 GW came online in 2023, bringing **the global total to around 14.8 GW**, marking the second year of decline in new installations.
- Capacity was added in **Indonesia, Japan, Kenya, the United States, and Taiwan**, but not all locations saw a net increase in operational capacity.
- **Geothermal direct-use** (which does not include heat pumps) reached an estimated 205 TWh (737 PJ) in 2023, around one-third higher than the previous year's estimate (155 TWh).
- **China is the world's fastest-growing** geothermal heat market.

In 2023, the term "next-generation" was an increasingly common qualifier in references to geothermal energy[i]. Following decades of minuscule absolute growth relative to global energy supply and demand, ongoing advances and cost reductions in both drilling technologies and methods of geothermal field enhancement – along with further refinements in energy extraction and generation technology – have driven a somewhat renewed sense of optimism for the future of geothermal heat and power. While geothermal energy is theoretically ubiquitous, it has been technically and economically prohibitive in most places other than where the Earth's lithospheric plates meet. New technologies and improving economics suggest that this may change.

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 2023, geothermal electricity generation totalled an estimated 97.3 TWh, and direct useful thermal energy supply totalled an estimated 205 TWh (737 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]

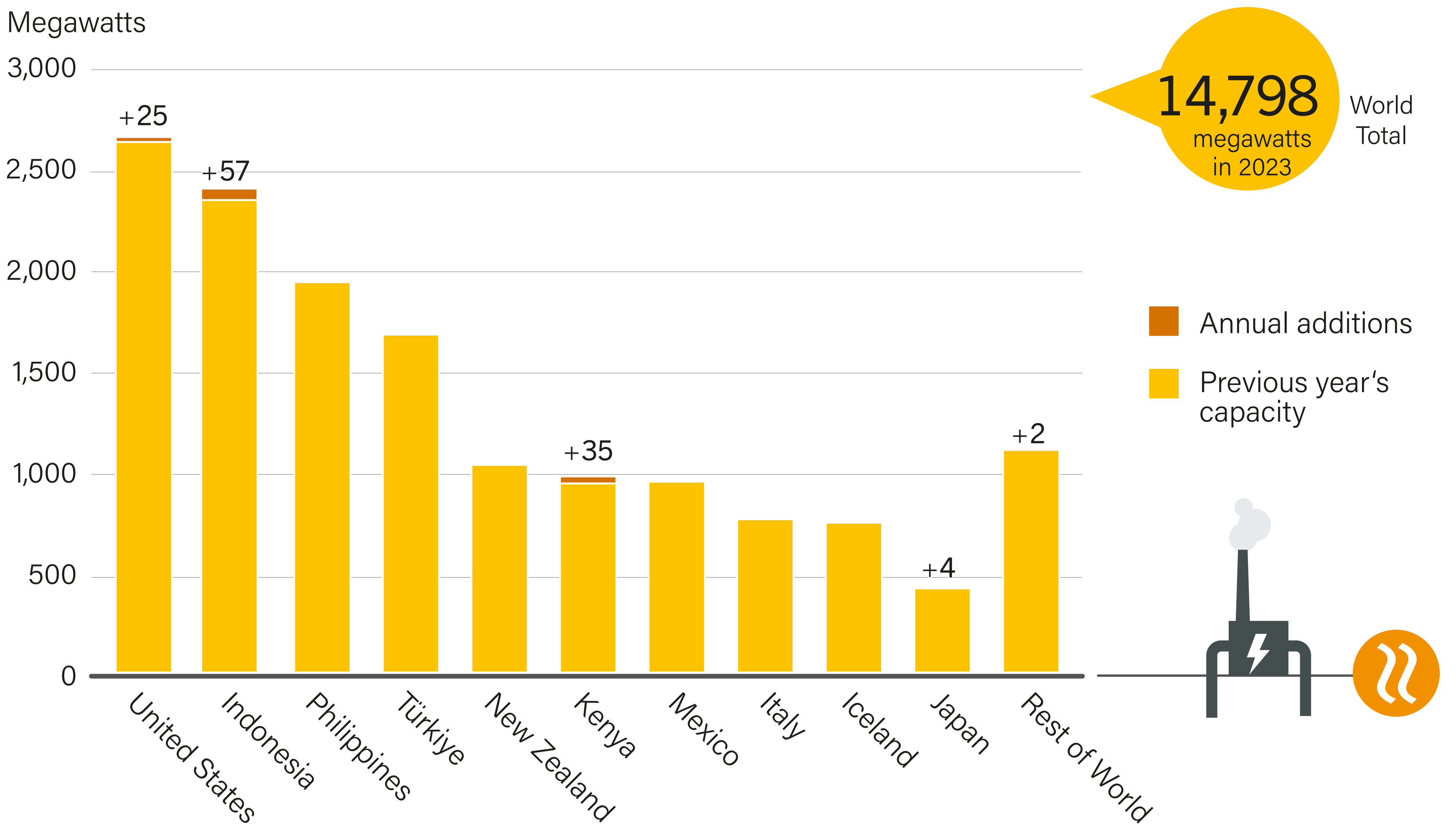
GEOTHERMAL POWER

For electricity generation, 0.1 GW[ii] of new geothermal power capacity was added in 2023, bringing the global total to around 14.8 GW.[3] This marked the second year of decline in new installations and was below the five-year average of 0.4 GW for the years 2018-2022, with contraction in Türkiye weighing most heavily in recent years.[4] Capacity was added in Indonesia, Japan, Kenya, the United States, and Taiwan, but not all locations saw a net increase in operational capacity.[5] (→ *See Figure 20.*)

i Here, the term refers mostly to energy derived from medium-to-high enthalpy (>100 degrees Celsius (°C)) hydrothermal or 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 20.
Geothermal Power Capacity and Additions, Top 10 Countries and Rest of World, 2023



Source: See endnote 5 for this section.

The **US government** is actively pursuing "next-generation" technology advancement and cost reduction for closed loop and enhanced geothermal systems (EGS).

The top 10 countries for geothermal power capacity at the end of 2023 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, and values for some countries may be greatly overstated relative to actual achievable output.[7]

Indonesia's stated installed geothermal power capacity expanded in 2023 by 57 MW, similar to the previous year's growth.[8] On North Sumatra, the fourth unit (50 MW) was completed at the Sorik Marapi project following a commensurate expansion the preceding year, bringing the plant to 140 MW.[9] Earlier in the year, a second unit (3 MW) was added at the Sokoria development.[10] In the western part of Java, a 15 MW binary-cycle[i] expansion project was nearing completion at year's end.[11] The developer noted that additional opportunities on Java were somewhat limited.[12]

During the five-year period 2018-2023, geothermal capacity in Indonesia grew 24% (average of 94 MW annually), from 1.9 GW to more than 2.4 GW.[13] The government of Indonesia envisions geothermal power capacity to grow as much as 10-fold by 2060 (to 23 GW), which represents the limit of the current assessed resource potential.[14] To achieve this goal, the country hopes to improve data on geothermal resource potential, in addition to financing and other risk mitigation efforts, to attract further investment.[15] At the same time, the government is mindful of environmental impacts of geothermal development, as most resources are found in ecologically sensitive forest areas.[16] In 2022, Indonesia's geothermal power generation totalled 16.7 GWh (up from 14.0 GWh in 2018), or 5% of the country's total grid supply (down from 5.2% in 2018).[17]

Kenya added the first of three 35 MW plants to be completed in the Menengai geothermal field.[18] Difficulty in securing financing for this public-private partnership had delayed construction despite partial risk guarantees from the African Development Fund, as well as the Kenyan government's development of the geothermal steam resources, beginning with the first well drilled in 2011.[19] Upgrades at other facilities are expected to yield an incremental 140 MW of geothermal capacity by the end of 2026.[20] Poor hydrological conditions have hampered hydropower production in recent years and underscored the need to develop more of the country's geothermal resources to meet growing demand and government goals to displace fossil fuel use.[21] Kenya's stated geothermal capacity was just under 1 GW in 2023, providing around half of the electricity supply.[22]

i 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 high-enthalpy applications.

In the **United States**, a 25 MW binary-cycle power plant, along with a dedicated 95 kilometre transmission line, was completed in North Valley, Nevada.[23] This 1% increase in installed geothermal power, to nearly 2.7 GW, is in line with the recent trend: during the five-year period of 2017-2022, net capacity increased 6.7%.[24] However, this modest growth in capacity resulted in only a 1% increase in geothermal generation over the period, suggesting a relative decline in output from older facilities.[25] While installed generator capacity at US geothermal power facilities stands at 4.0 GW, the gradual decline in steam production at older geothermal fields, specifically the Geysers geothermal field in California, has led to significant de-ratings and to effective net operating capacity of merely 2.7 GW.[26] Geothermal power in the United States supplied up to 16.5 TWh[i] in 2023, less than 0.4% of the country's net electricity generation.[27]

The US government is actively pursuing "next-generation" technology advancement and cost reduction for enhanced geothermal systems[ii] (EGS) and closed-loop geothermal systems. The aim is to harness energy from ubiquitous dry hot rock, found at great depth, instead of being limited to hydrothermal formations that form the basis of conventional geothermal power production, limited to a relatively few locations globally.[28] EGS uses hydraulic fracturing to create a reservoir where fluid flows openly, whereas in closed-loop systems the fluid is restricted to long boreholes.[29] Both approaches depend on wells drilled both vertically and horizontally (using directional drilling technology) that may extend thousands of metres.[30] Advancements during 2021-2023 have reduced US estimated EGS project costs 50%, supporting the objective to achieve levelised costs of electricity of USD 45 per MWh by 2035 and to install 90 GW of new geothermal power capacity by 2050.[31]

Technology companies engaged in developing closed-loop systems made advancements in 2023, including successful drilling projects by Eavor Technologies (Canada) in Germany and the US state of New Mexico, and by Fervo Energy (United States) in the states of Nevada and Utah.[32]

Japan added a few relatively small new and replacement geothermal generating units in 2023, but overall generation capacity did not expand.[33] Among these new units was the replacement of the 14.9 MW Onikobe plant in Miyagi prefecture.[34] After 42 years of operation (built in 1975 but shut down in 2017), the plant was replaced entirely, and new production- and reinjection wells were drilled.[35] The original plant had suffered rapid production decline from the start due to reservoir characteristics and other factors, but the new facility was designed to reflect that experience.[36]

Two small (2 MW) units were completed elsewhere in Japan: a single-flash unit in Kumamoto prefecture and a binary-cycle plant on the island of Hokkaido.[37] The binary unit is somewhat similar in conception to a 150 kW unit installed at a thermal bath facility in the Kumamoto region in 2022, which was designed to utilise, for greater efficiency, unused thermal energy from the geothermal fluid of the existing Mori geothermal plant before the water is reinjected to the ground.[38] By early 2024, Japan added the 14.9 MW Appi geothermal plant in Iwate prefecture.[39] Along with other geothermal projects in the country, the facility benefited from government-funded risk mitigation in the form of debt guarantees for resource development funding.[40] Aside from a feed-in tariff (FIT) for produced energy, government support for Japan's geothermal industry includes direct technology development, low-interest loans, exploration and drilling subsidies, and technical resource assessment.[41]

Despite the modest addition of new capacity in recent years, Japan's overall geothermal capacity portfolio has not expanded.[42] Due to insufficient understanding of reservoir capacities and the installation of oversized turbine generators relative to the actual potential of the reservoirs, geothermal fields declined and total capacity contracted between 2012 and 2018, subsequently seeing some decommissioned capacity replaced with smaller generators.[43] Geothermal power generation in Japan peaked in 1996 and has since been in decline. As of 2022, only around 0.3 GW of the more than 0.5 GW of installed nameplate capacity was running, contributing around 0.2% of the electricity supply.[44]

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.

In **Taiwan**, two small geothermal plants were completed: a 1 MW Sihuangziping binary-cycle plant in New Taipei City (to be followed by a larger 4 MW unit at the same location) and a 840 kW Renze facility in Yilan County.[45] With only a few megawatts of installed capacity, geothermal power provided only 0.01% of Taiwan's electricity supply.[46]

By one measure, the **Philippines** continued to rank third globally for total installed geothermal power capacity at 1.9 GW (generator nameplate), despite very little new development in the industry in recent years.[47] Of that total, only 1.7 GW was operating capacity, and only 64% of that (1.1 GW) was available for dispatch at the end of 2023.[48] Further, operating capacity appeared to have declined overall by net 55 MW during the year.[49] Only 86 MW of new capacity was added since 2008, when legislation supporting renewable energy deployment was passed.[50] A 3.6 MW binary add-on unit, completed in 2022, was the first new capacity in four years, and no capacity expansion was recorded for 2023.[51]

Nonetheless, at year's end, at least three geothermal power plants were nearing completion in the Philippines: the 17 MW Tiwi and 29 MW Palayan plants, and an initial 2 MW on the island of Biliran.[52] Additionally, the 20 MW Tanawon and 5.6 MW Bago units were expected to be online in 2024.[53] Most of these units will operate on a closed-loop binary cycle (Tanawon is a traditional hydrothermal flash-steam unit) and, as has been common in recent years, some are designed to utilise residual heat contained in the fluid effluent of existing geothermal installations to produce additional electricity, without necessarily requiring additional steam generation.[54]

Steam production from geothermal fields is a limiting factor for some existing plants in the Philippines (as in other locations globally), especially some older facilities in Luzon where operating capacity has been in decline since 2018 and the average availability factor[i] was merely 57% in 2023.[55] Plants on the Visayan Islands performed better, with 75% availability and little loss of operating capacity in recent years.[56] Geothermal generating assets in the Philippines are favoured for baseload power and were dispatched near or at available capacity in 2023.[57] This allowed geothermal power to provide around 9% of the electricity supply in 2023.[58]

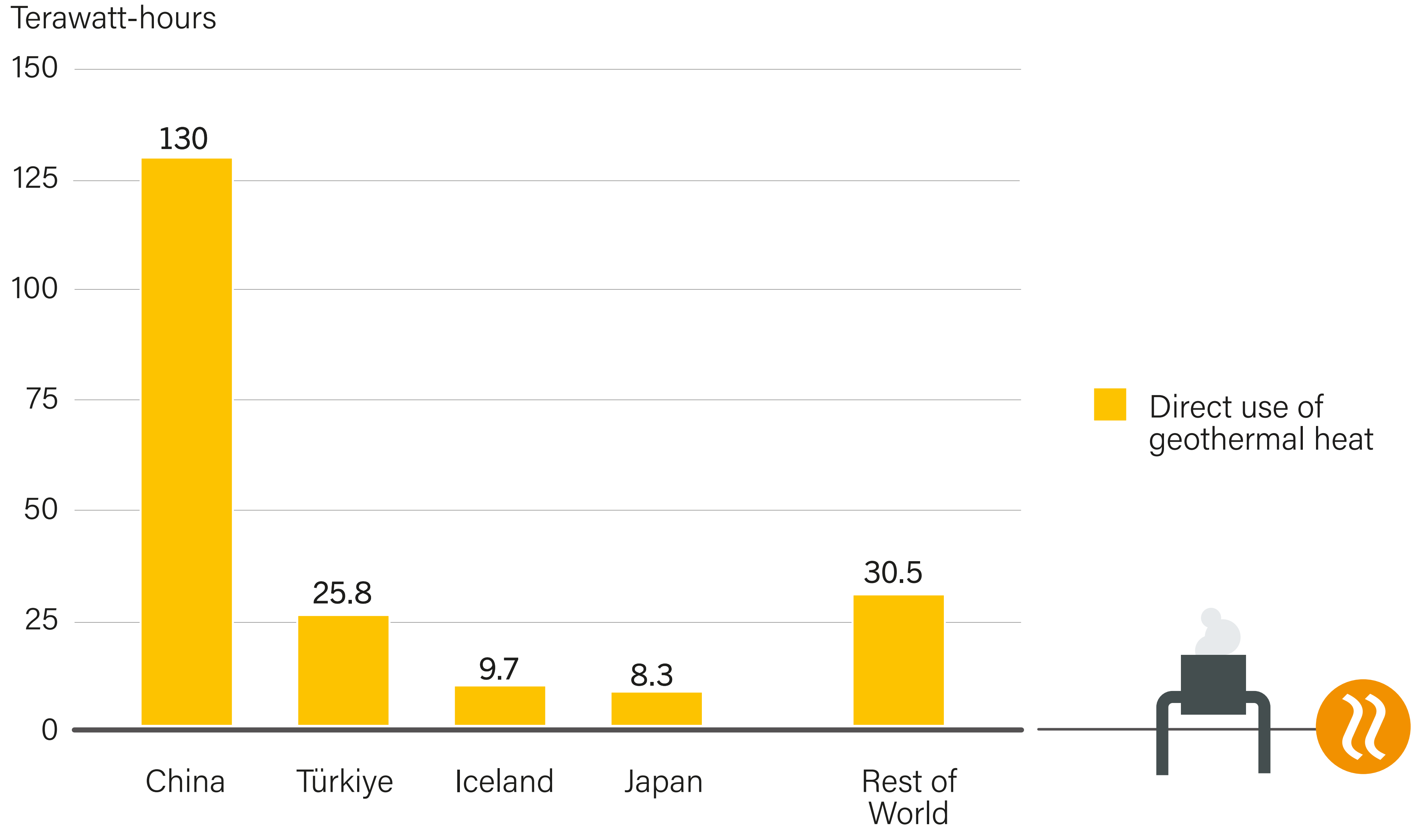
Türkiye added no geothermal power capacity in 2023, as in the previous year.[59] This is significant because Türkiye was the world's most active geothermal power market from 2008 through 2019, when capacity grew from merely 30 MW to 1.5 GW, most of which (1.1 GW) was installed in the latter five years of that period.[60] Capacity growth then contracted to 99 MW in 2020 and 63 MW in 2021 before coming to a complete halt.[61] Yet, as of 2023, Türkiye had 15 geothermal plants in the pre-licensing stage, totalling 320 MW.[62]

In late 2023, the Turkish government issued a revamped renewable electricity FIT, which was expected to spur new growth in the sector.[63] The previous FIT, introduced in early 2021, was deemed insufficient to maintain the investment levels of the earlier period.[64] In 2023, geothermal power in Türkiye provided 11 TWh of electricity or 3.4% of total supply.[65]

A few technology companies are working towards **commercial success** of closed-loop systems in more marginal resource locations.

i The availability factor equals the total number of hours a unit is available for dispatch in a given period (service hours plus reserve shutdown hours) divided by the total number of hours in the same period.

FIGURE 21.
Geothermal Direct Use, Top 4 Countries and Rest of World, 2023



Source: See endnote 68 for this section.

Growth in geothermal heat use is dominated by China and Türkiye.

GEOTHERMAL HEAT

Global geothermal direct use[i] – direct extraction of geothermal energy for thermal applications – reached an estimated 205 TWh (737 PJ) in 2023, around one-third higher than the previous year's estimate (155 TWh).[66] The 2022 estimate was an extrapolation based on reported values for 2019 and the preceding five-year growth rate, which appears to have underestimated growth in the two largest markets, China and Türkiye. The 2023 estimate is based on reported capacities in each of the four largest markets (by installed capacity), which together comprise an estimated 85% of the world total.[67]

The top countries for geothermal direct use in 2023 were (in descending order) China, Türkiye, Iceland and Japan.[68] (→ *See Figure 21.*) Geothermal direct use remained highly concentrated in these four markets (and further localised within each country); other notable users were (in descending order) New Zealand, Hungary, the Russian Federation, Italy, the United States and Brazil.[69]

China has remained the world's fastest growing geothermal heat market, with compound annual growth exceeding 21% during the years 2015-2019, reaching 14.2 GW of capacity (and 197 PJ of energy) in 2019.[70]

For the 2023-2024 heating season, Sinopec[ii] reported a 15% increase in geothermal heating capacity, serving an additional 95 million square metres of space.[71] Based on stated assumptions for average thermal demand per square metre, this suggests total annual direct use of as much as 469 PJ, but this value is subject to great uncertainty due to imprecise reporting methods and the assumptions[iii] required for energy conversion.[72] This implies some acceleration of direct use for space heating relative to the earlier period, a very robust 24.2% compound annual growth from 2019 through 2023.[73] 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.[74]

In **Türkiye**, reported geothermal heat use grew 3.8% annually on average during 2015-2019, reaching 3.5 GW of capacity and 54.4 PJ of energy use in 2019.[75] This growth appears to have accelerated significantly since then, as total capacity was reported to reach 5.2 GW by 2022.[76] Based on the ratio of energy use per unit capacity in 2019, this updated capacity value suggests that geothermal direct use may have reached 93 PJ in 2023, at a compound annual growth of more than 14% since 2019.[77]

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.*)

ii Developer of hydrothermal resources for district heating in China.

iii See endnote for assumptions and sources.

Iceland continued to rank third globally in the use of geothermal heat.[78] The country's estimated geothermal heat consumption for 2022 was essentially unchanged from the preceding year at 35 PJ (1.4% average growth annually since 2019), from an installed capacity of around 2.5 gigawatts-thermal (GW_{th}).[79] Residential use was the largest consumer (16.3 PJ), followed by commercial and public services (12.9 PJ).[80] Other uses included fisheries (4.1 PJ), industry (1.1 PJ) and agriculture (0.6 PJ).[81] Across these categories, space heating accounted for the bulk of geothermal direct use (24.2 PJ).[82]

For **Japan**, which ranked fourth for geothermal direct use, no apparent data were available indicating any capacity expansion in recent years.[83] Capacity remained at 2.4 GW_{th} and energy use was just under 30 PJ (virtually no growth since 2019).[84]

On continental Europe, geothermal heat development has been highly localised and coincides mostly with the richest hydrothermal locations. These include, in particular, southern regions of Germany (Bavaria), some parts of France, and various locations in Hungary, Italy and the Netherlands.[85] As geothermal technologies advance, development appears to be expanding to more locations. Of the more than 300 projects under consideration or development at the end of 2022, more than a third was located elsewhere in Europe, including Poland, the Balkans and the United Kingdom.[86]

In **Germany**, one new geothermal plant came online in 2023 with a thermal capacity of 8 megawatts-thermal.[87] This represented a 2% increase to the installed base of around 400 MW of geothermal heat capacity, which provided 6.5 PJ (1.8 TWh) of heat in 2023.[88] The new plant is notable for being the largest (albeit small) heat plant outside resource-rich Bavaria, where 95% of Germany's geothermal heat capacity is located.[89] Serving around 2,000 households in Schwerin, the plant draws on relatively cool water (56°C) from a depth of nearly 1,300 metres.[90] The plant uses heat pumps to achieve higher temperatures suitable for district heating systems (80°C), requiring 1.7 MW of power from the on-site gas-fired generator.[91] Biomethane is expected to eventually substitute for the natural gas supply, allowing the plant's renewable output to reach 100%.[92]

In the **Netherlands**, geothermal heat production increased again by 6% (as in the previous year), reaching 6.8 PJ.[93] This heat output was produced from 39 well pairs (production and re-injection wells) at 27 locations and is sufficient to supply around 165,000 households, equivalent to the city of Utrecht.[94] The Netherlands' richest hydrothermal sources are at around 3 kilometres depth, where temperatures reach 90-100°C.[95]

In **France,** development of direct-use systems (mostly district heat) has been concentrated in the Paris region (Île-de-France), as well as to the south-west in Aquitaine and to the east in Alsace.[96]

Multiple geothermal district heat systems have been developed in and around Paris in recent years, but the only plant inaugurated in 2023 was a low-temperature (shallow) ground-source heat pump application, serving the Pleyel district in Saint-Denis.[97] Designed to supply both heating and cooling networks simultaneously, the project relies on source water of merely 14°C (from a shallow depth of 50-70 metres), making it fully dependent on electrically driven heat pumps to serve positive thermal load (space heating) in buildings.[98]

In the Netherlands, geothermal heat production grew 6% for the second year running.

KEY FACTS
HEAT PUMPS

- Heat pumps are considerably **more efficient** than conventional technologies, providing 3-4 units of heat per unit of electricity, especially when driven by renewable energy.
- **The market remains strong**, despite a slight slowdown in key regions.
- **China remains the largest heat pump market**, with 12% growth in 2023. Sales in Germany and Belgium increased 60% and 72% respectively.
- Heat pumps have proven **popular with residential consumers.** Industrial applications and networked systems are under development.

Heat pumps commonly meet heating and cooling demands in buildings and industrial processes. 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] When the energy used to drive a heat pump is renewable, so is the full heat provided.[i]

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]

Growth slowed in 2023, notably in Europe, due largely to political indecision and to the challenges of a maturing industry that lacks a large workforce and a local manufacturing base.[4] Rather than opt for regulation to set a clear path for heat pump deployment in buildings, many countries boosted subsidies amid a landscape of rising costs.

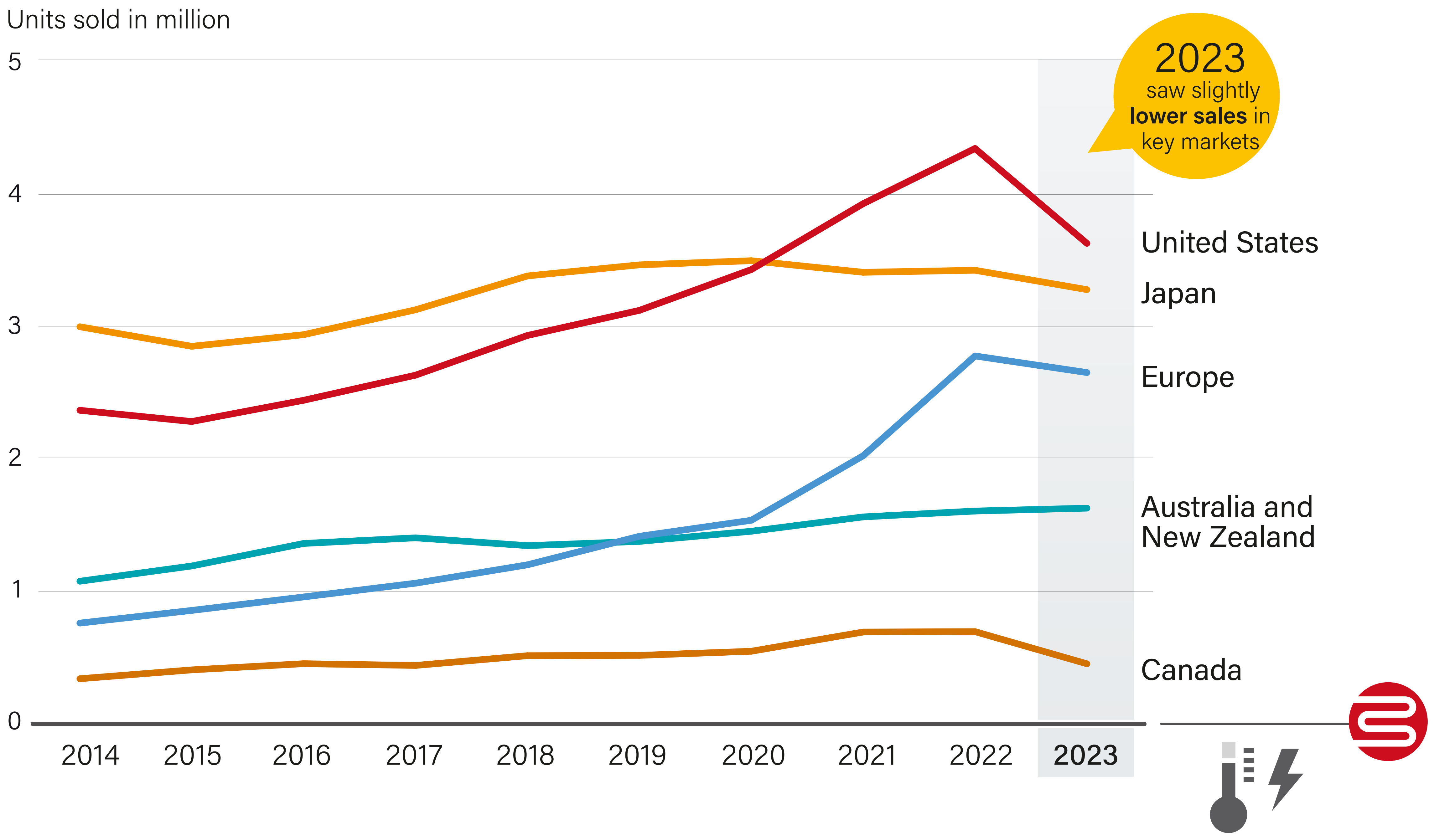
ANNUAL ADDITIONS AND TOP COUNTRIES

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.[5]

Although many of the world's leading heat pump installing regions, such as the United States and Europe, have experienced strong market growth in recent years, some of these markets contracted during 2023.[6] (→ *See Figure 22.*)

i See GSR 2023 for a discussion on the renewable classification of heat pumps, and previous GSR editions for explanations of their operation.

FIGURE 22.
Heat Pump Sales in Major Markets, 2014-2023



Note: Rest of Europe includes Austria, Belgium, Denmark, Finland, Norway, Poland, Portugal and Switzerland. China is the world's largest heat pump market by a wide margin. However, data from China are highly uncertain and difficult to report in terms of units sold. To compare smaller markets, China has been excluded from this figure.

Source: See endnote 6 for this section.

In Asia, heat pump sales in **China** grew an estimated 12% in 2023, accounting for around 8% of heating equipment sales for buildings.[7] China has become the world's largest market for air-source heat pumps by a wide margin.[8] Part of the popularity of heat pumps in the country is related to cost: in many regions, heat pumps typically have a six-year payback period when added to a home with solar photovoltaics (PV).[9] **Japan's** market for home air conditioners for heating[i] and heat pump water heaters fell 4% in 2023, although the market grew around 9% during the decade 2014-2023.[10]

In **North America**, shipments of heat pumps in the United States fell 17% in 2023 to reach around 3.6 million units, despite incentives provided under the Inflation Reduction Act.[11] Nearly all US states have passed local- or state-level electrification mandates or restrictions on fossil gas, or have passed legislation that prohibits the adoption of such measures.[12] However, the decline in heat pumps occurred during an overall downturn in the heating market, where heat pumps have outsold gas furnaces by an increasing margin.[13] The American Institute of Architects noted a doubling in the completion of all-electric building projects by its members between 2021 and 2023.[14]

The US outlook for heat pumps is further bolstered by an initiative of nine states committed to ensuring that heat pumps account for a rising share of residential heating and cooling sales: 65% by 2030 and 90% by 2040.[15] In addition, as of 2023, a total of 25 US state governments had pledged to pursue decarbonisation policies for buildings, and a group of large corporations called for an increase in such policies.[16] Air-to-air heat pumps were found to be cost-effective without subsidies in 59% of US homes.[17]

In Canada, heat pump sales dropped around 36% in 2023 to 440,000 units, amid a harsher political climate.[18] The country paused its carbon tax on heating oil during 2023 and announced the end of the Greener Home Grants subsidy scheme due to a lack of remaining funds, as the programme exceeded government expectations.[19]

i Around 30% of home air conditioner sales in Japan are estimated to be used as a primary heating device. See endnote 10 for this section.

In **Europe**, despite the European Union (EU) aiming to install an additional 10 million units by 2027, overall heat pump sales fell 5% in 2023, totalling around 2.6 million units.[20] Sales in Poland declined 45%, from 208,000 to 113,000 units, and in Finland they fell 43% from 200,000 to 114,000 units.[21] Italy's heat pump sales declined 33%, dropping to around 345,000 units.[22] Several countries nonetheless saw impressive growth in heat pump sales during the year. Germany's sales surged, increasing almost 60%, to 439,000 units.[23] In the Netherlands, sales increased 53%, with 154,000 units sold.[24] (→ *See Snapshot: The Netherlands*.) Belgium recorded the largest market upswing in Europe with an unprecedented 72% increase, surpassing the 100,000 unit sales mark for the first time.[25]

Recent backpedalling by the European Commission on the heat pump action plan has raised concerns, and more than 60 chief executive officers have warned that USD 7.7 (EUR 7 billion) of investment is at risk.[26] However, the EU's Renewable Energy Directive, revised in 2023, counts the renewable electricity used to power heat pumps towards each country's renewable energy targets.[27] Other EU legislative frameworks – such as the Energy Performance of Buildings Directive and the Net-Zero Industry Act – may also play a significant role in the deployment and manufacturing of heat pumps.[28]

At the national level, several European countries delayed or weakened their policy action. The United Kingdom delayed adopting a clean heat market mechanism but increased the country's main grant programme, the Boiler Upgrade Scheme.[29] France decided not to apply new heat pump regulations, and in early 2024 it announced a significant reduction in funding.[30] Germany faced setbacks with a new buildings law and decided to reduce subsidies, while in the Netherlands a requirement for homeowners to switch to a hybrid heat pump when replacing boilers has been removed.[31]

In **Australia**, single-split heat pump systems are widely used for both heating and cooling. Sales were expected to reach around 1.37 million units in 2023, up from 1.32 million in 2022 and 43% greater than in 2014.[32] **New Zealand's** heat pump and air conditioner sales fell 11% in 2023 to reach around 241,000 units, although this is still more than double the level of a decade earlier (2014), when only around 100,000 units were sold.[33]

A growing number of large-scale heat pumps are being used in **district heating.**

HEAT PUMP APPLICATIONS AND TRENDS

Heat pumps have become increasingly prevalent in both residential and commercial buildings, driven partly by a desire for more renewable heat, but also spurred by comfort and cost considerations.[34] A growing number of large-scale heat pumps are being used for district heating purposes, offering a solution that can serve entire communities or specific industrial sectors.[35]

The financial aspects of adopting heat pumps involve initial capital costs, operating expenses, and payback times, which are critical factors for homeowners and businesses. The capital cost of heat pumps, while often higher than fossil fuel heating systems, can be offset by lower operating costs due to the high efficiency of heat pumps.[36] Payback periods vary depending on several factors, including notably the relative prices of electricity and fossil heating fuels. Heat pump owners living in regions with high fossil gas prices, for example, and low electricity prices (per kWh) can experience very short payback periods and large savings in running costs.[37] As such, the adoption of heat pumps is closely tied to energy pricing policies, and certain countries have considered reforming their energy taxation policies to support heat pumps.[38]

Heat pumps have proven to be viable in colder climates, challenging the misconception that they are only effective in mild weather conditions.[39] The most heat pumps per household are found in the Nordic countries.[40] Hybrid heat pumps[i], which typically combine fossil fuel-based heating systems with heat pumps, have emerged as a practical solution in extreme climates; they can be combined with renewable energy sources, such as solar PV and solar thermal, as well as bioenergy boilers and furnaces.[41]

i Hybrid heating systems can switch between the heat pump and a fossil heating source, depending on the temperature, ensuring energy efficiency and reliability throughout the year. Typically, the heat pump will provide the majority (around 80%) of the space and water heating demand throughout the year, with the fossil heating system taking over during peak cold periods.

SNAPSHOT THE NETHERLANDS

SUPPORTIVE POLICIES DRIVING STRONG HEAT PUMP SALES

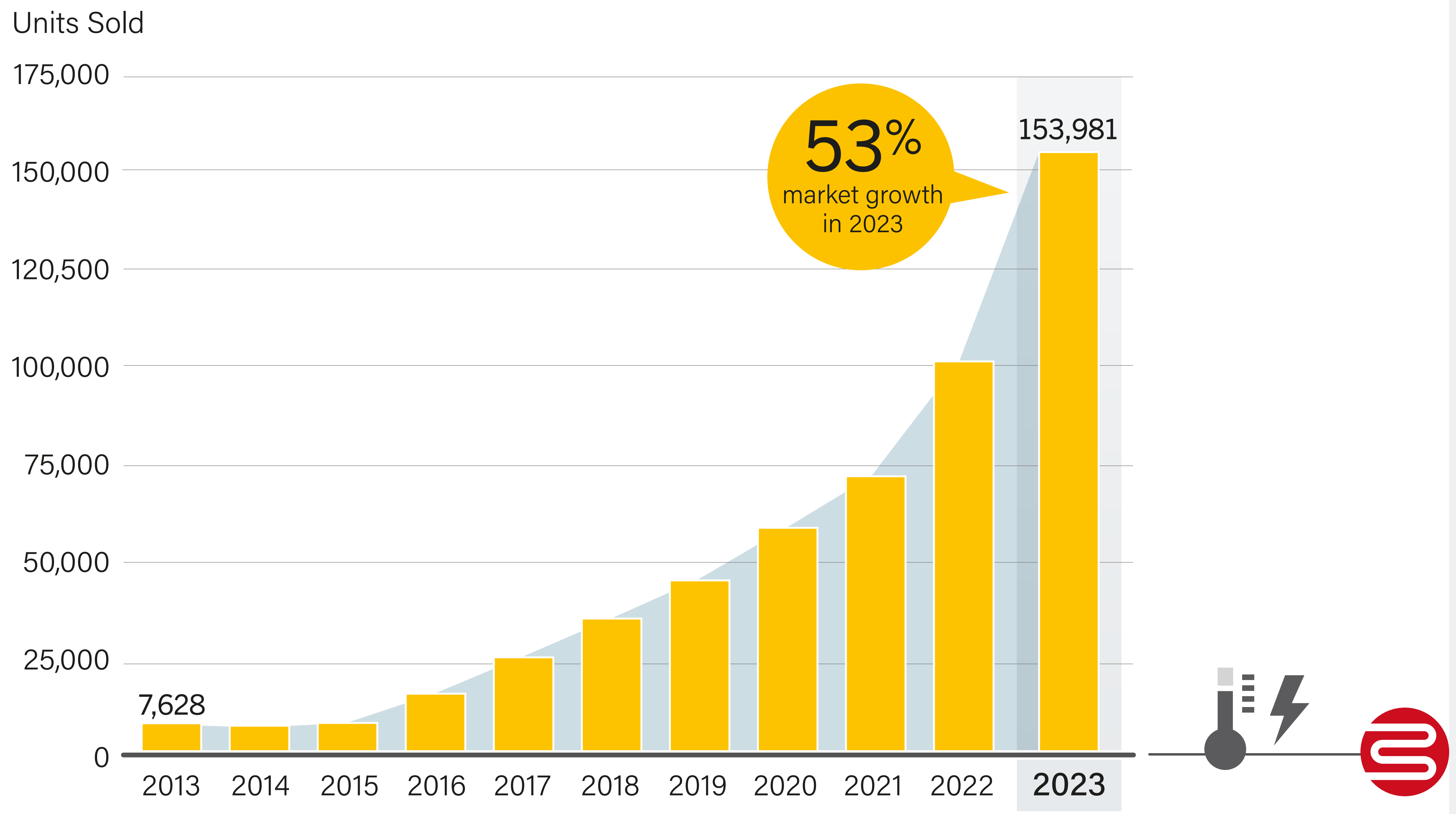
With more than 90% of homes relying on fossil gas for heating, the Netherlands is one of Europe's most gas-dependent countries. Combusting fossil gas in Dutch homes accounted for around 15% of the country's greenhouse gas emissions in 2021. The government plans to take 25% of its 8 million homes off the gas grid by 2030, with a target to remove gas from residential buildings entirely by 2050.

Political and industry leaders have recognised heat pumps as a key renewable energy technology to help transition homes away from fossil gas. In 2023, more than 150,000 heat pump units were sold in the Netherlands, up 53% from 2022 levels. (→ *See Figure 23.*) This occurred at a time when many European countries saw their heat pump sales stagnate or even contract.

Although the ambitious gas phase-out played a role in the Dutch heat pump transition, supportive policy has been crucial. In recent years, the Netherlands has put in place supportive grants (starting in 2016), energy pricing and regulatory reform that resulted in widespread heat pump uptake. Efforts to rebalance energy prices of fossil gas and electricity have allowed heat pumps to become a more economic option for Dutch households, contrary to those in Belgium and Germany.

The Netherlands also announced in 2018 that new buildings must be fossil gas-free, and reached a government agreement in 2021 to make "hybrid heat pumps", a configuration where a heat pump operates in parallel with a gas boiler, the minimum performance standard for existing buildings. This new law was a result of effective collaboration between government, industry and civil society.

FIGURE 23.
Heat Pump Sales in the Netherlands, 2013-2023



Source: See endnote 24 for this section.

In 2023, **the United States and Europe** increased their investment in heat pump manufacturing.

HEAT PUMP INDUSTRY

In 2023, major companies in the heat pump industry made strategic moves to consolidate their positions and enter new markets. Notable mergers and acquisitions included the acquisition by Carrier (United States) of the company Viessmann (Germany), illustrating significant consolidation in the industry; meanwhile, the purchase by EDF (France) of CB Heating (United Kingdom) underscored the rising interest of energy companies in the heating sector.[42] The expansion of Aira (Sweden), a start-up that successfully raised USD 109 million (GBP 86 million) to finance its innovative pan-European sales model, reflected a shift towards more consumer-friendly business models; the company offers direct-to-consumer heat pumps through a monthly subscription.[43] In Germany, the country's largest heating system installer announced that it would stop selling gas boilers.[44]

Investments in heat pump manufacturing continued to surge. The United States announced significant funding, including a USD 63 million initiative and a further USD 169 million in awards to boost heat pump manufacturing.[45] Global competition increased during the year, with Europe's announced future manufacturing capacity of heat pumps reaching three times its existing capacity.[46] The bulk of these investments were in Central and Eastern European countries – such as Poland, the Czech Republic and the Slovak Republic – with numerous companies making further investments and announcements.[47] However, the negative market outlook, coupled with rising inflation, also caused challenges, leading to hundreds of announced lay-offs across European heat pump manufacturers.[48]

The workforce and innovation sectors experienced significant developments as well. New training programmes were introduced to meet the growing demand for skilled heat pump installers.[49]

Innovations in the operation of heat pumps highlight the increasing role of the devices as a flexible energy resource[i],[50] Meanwhile, the industry is navigating complex regulatory landscapes concerning refrigerants to ensure environmental compliance and greenhouse gas neutrality, with debates ongoing about the status and impact of fluorinated gases.[51]

In the realm of research and development, new models and innovations have been reshaping the heat pump industry, with Octopus (United Kingdom) introducing a model cheap enough to have no upfront cost when the UK grant is taken into account, and OVO promising to cut the running costs of heat pumps by half.[52] Meanwhile, companies are releasing new models of cold-climate heat pumps, as well as high-temperature heat pumps that can operate in unrenovated buildings, and heat pumps with more attractive designs or simple installation.[53]

CHALLENGES AND OPPORTUNITIES

The heat pump sector faces several challenges related to ongoing deployment and use. Across most regions, the energy price imbalance between fossil fuels and electricity remains a significant hurdle.[54] Additionally, there is a notable lack of installers, which, coupled with rising costs, could hold back further sales.[55] Permitting problems are particularly prevalent in Europe.[56] Despite these obstacles, and even though political sentiment towards heat pumps appears to be waning, surveys indicate that users of heat pumps generally report high levels of satisfaction and comfort with their devices.[57]

Heat pumps have considerable opportunities to decarbonise buildings and industry when operating using renewable energy sources. They can also be integrated into district heating and cooling networks.[58] (→ *See Snapshot: United States.*) They have been increasingly proven to operate efficiently across a variety of conditions and can bring significant cost savings when energy prices are balanced and the unit is properly installed.[59] Moreover, heat pumps hold large potential for demand response initiatives and are expected to play a crucial role in a smarter, digitised and more electrified energy system.[60] While still in the early stages of development, industrial heat pumps represent a promising and emerging technology in the field.[61]

i One example is Tiko (Switzerland), which aggregates heat pumps and other appliances from numerous customers to form a virtual power plant. By combining resources from more than 7,000 households, Tiko's virtual power plant achieves a capacity of 100 megawatts, ranking it among the most significant virtual power plants in Europe. See endnote 50 for this section.

SNAPSHOT UNITED STATES

INNOVATIVE DISTRICT GEOTHERMAL NETWORK TO DECARBONISE HEATING AND COOLING IN FRAMINGHAM, MASSACHUSETTS

The gas utility Eversource in the US state of Massachusetts is developing a networked geothermal system, leveraging the company's expertise and interests in underground infrastructure and cost-sharing practices from gas pipeline systems. Buildings account for 35% of greenhouse gas emissions in the state, mainly from fossil fuel heating systems, and Massachusetts' climate plan aims to eliminate nearly all emissions from buildings by 2050.

Networked geothermal projects use zero-emission underground heat and reduce the need for costly electricity and gas infrastructure; more than 69,000 kilometres of transmission lines and 410 GW of generation could be avoided by 2050. Interconnected heat pumps and shared infrastructure greatly improve efficiency, optimise energy use and reduce costs. Utility bill savings can also be expected – for example, a similar network at Colorado Mesa University reduced annual energy costs by USD 1 million.

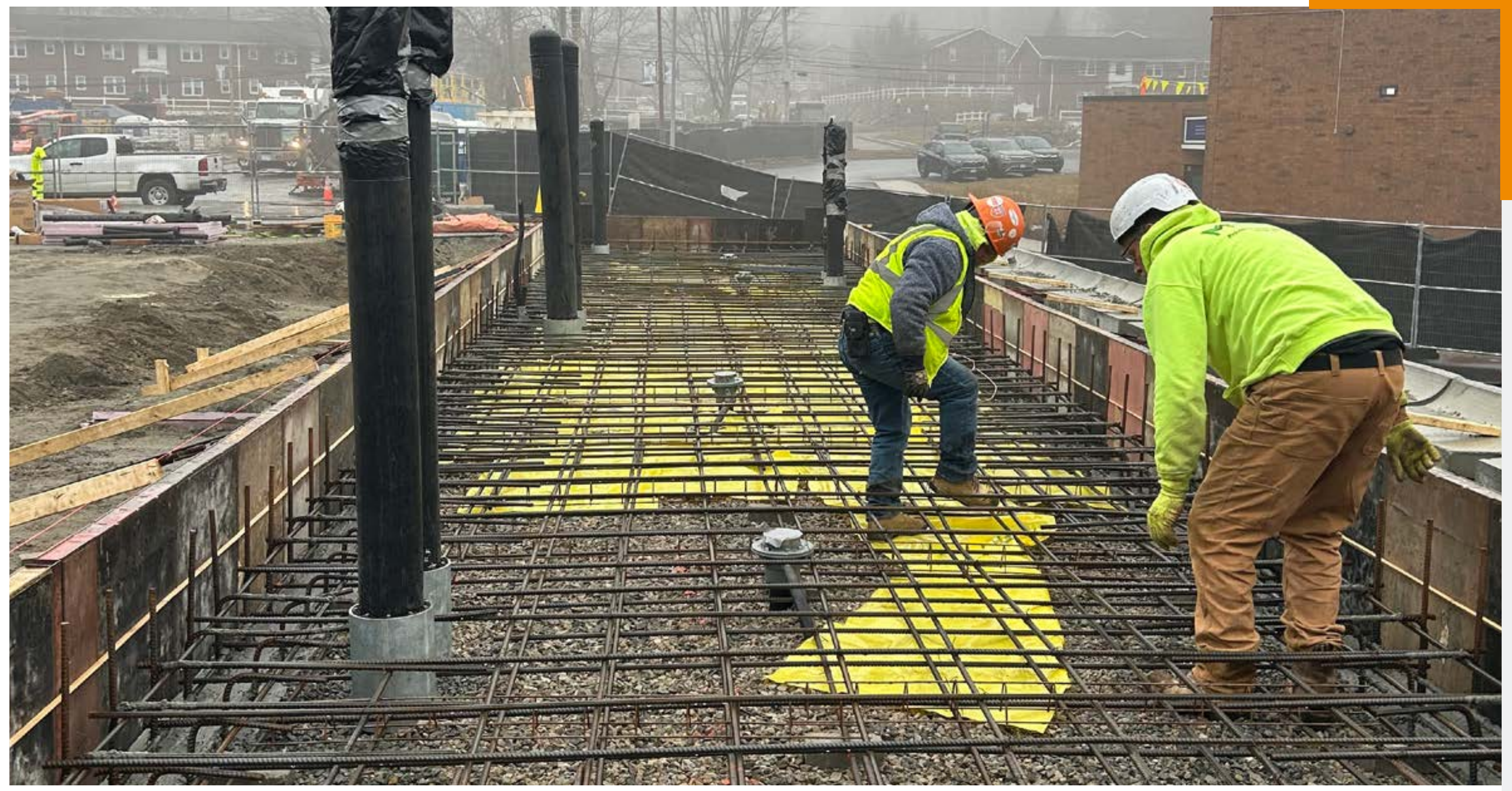
Launched in June 2023, the project will connect 37 buildings – including residences, small businesses and a fire station in the city of Framingham, Massachusetts and will serve 140 low-income residents, reducing their reliance on expensive and ageing gas infrastructure. The project also emphasises community and customer engagement.

A looping pipe system taps into the constant 12.8°C temperature hundreds of metres underground, using heat pumps and condensers to warm buildings during the winter and redirect excess heat back underground for cooling during summer.

The project's budget is USD 14.7 million, but the system will require minimal operating expenditure and costs are expected to decrease as utilities gain more experience, while a cost-sharing model ensures affordability for consumers.

Because US gas companies are mandated to provide natural gas, introducing an alternative energy source requires state approval. Massachusetts granted permission for a pilot programme in 2021, and similar initiatives are under way in Colorado, Minnesota and New York. Notably, New York has required major utilities to propose such projects since 2022, with 17 already in the planning stage, and the US Department of Energy is providing up to USD 13 million to support community-led district geothermal solutions.

Source: See endnote 58 for this section.



KEY FACTS

HYDROPOWER

- The global conventional hydropower market reached **1,237 GW of cumulative capacity** in 2023, up 7.2 GW from 2022.
- **Droughts** in top hydroelectricity generating countries led to a 5% decrease in production in 2023 and a global net capacity factor of 39%.
- **China maintained 30% of the global hydropower capacity** in 2023 and faced extreme drought conditions in top producing provinces, which caused historic lows in production at the beginning of the year.
- **More than half of installed capacity in 2023 was in Asia**. Globally, the three largest additions occurred in Nigeria (740 MW), Colombia (643 MW) and Lao PDR (548 MW).

The global conventional hydropower market[i] added 7.2 GW of installed capacity in 2023[ii] to reach a total of 1,237 GW, a capacity growth 67% lower than the previous year.[1] The top four countries for cumulative installed hydropower capacity were China, Brazil, Canada, and the United States, which collectively had more than 50% of the global total.[2] The top 10 countries for cumulative hydropower capacity represented 69% of the global total.[3] (→ *See Figure 24.*)

The top five countries for capacity additions in 2023 were Nigeria, Colombia, Lao People's Democratic Republic (PDR), China, and Nepal, with 41% of the global total.[4] (→ *See Figure 25.*) China installed just 530 MW of hydropower in 2023, after adding 13 GW (50% of all new capacity) in 2022.[5] More than half of the capacity added globally in 2023 was in Asia.[6] The top 10 markets for installed capacity – China, Brazil, Canada, the United States, the Russian Federation, India, Türkiye, Norway, Viet Nam and Japan – added a combined total of 1.6 GW during the year.[7]

Global hydropower generation fell 5% in 2023 to 4,185 TWh; the decline was driven mainly by droughts in top hydropower-producing countries such as China, Canada and the United States.[8] Hydropower production in Europe rebounded slightly following the region's worst drought in 500 years in 2022.[9] Production in East and Central Africa also stabilised after record droughts in 2022.[10] The global capacity factor for hydropower – or the amount of energy produced per unit of power installed – was 39% in 2023, down 2% compared to 2022.[11]

i Conventional hydropower capacity and generation figures are used exclusively throughout the section. Pumped storage is excluded where possible, as it serves as energy storage, not as an energy source.

ii The cumulative global hydropower capacity in 2022 has been updated since the release of GSR 2023 and is 1,230 GW.

REGIONAL DEVELOPMENTS

Asia

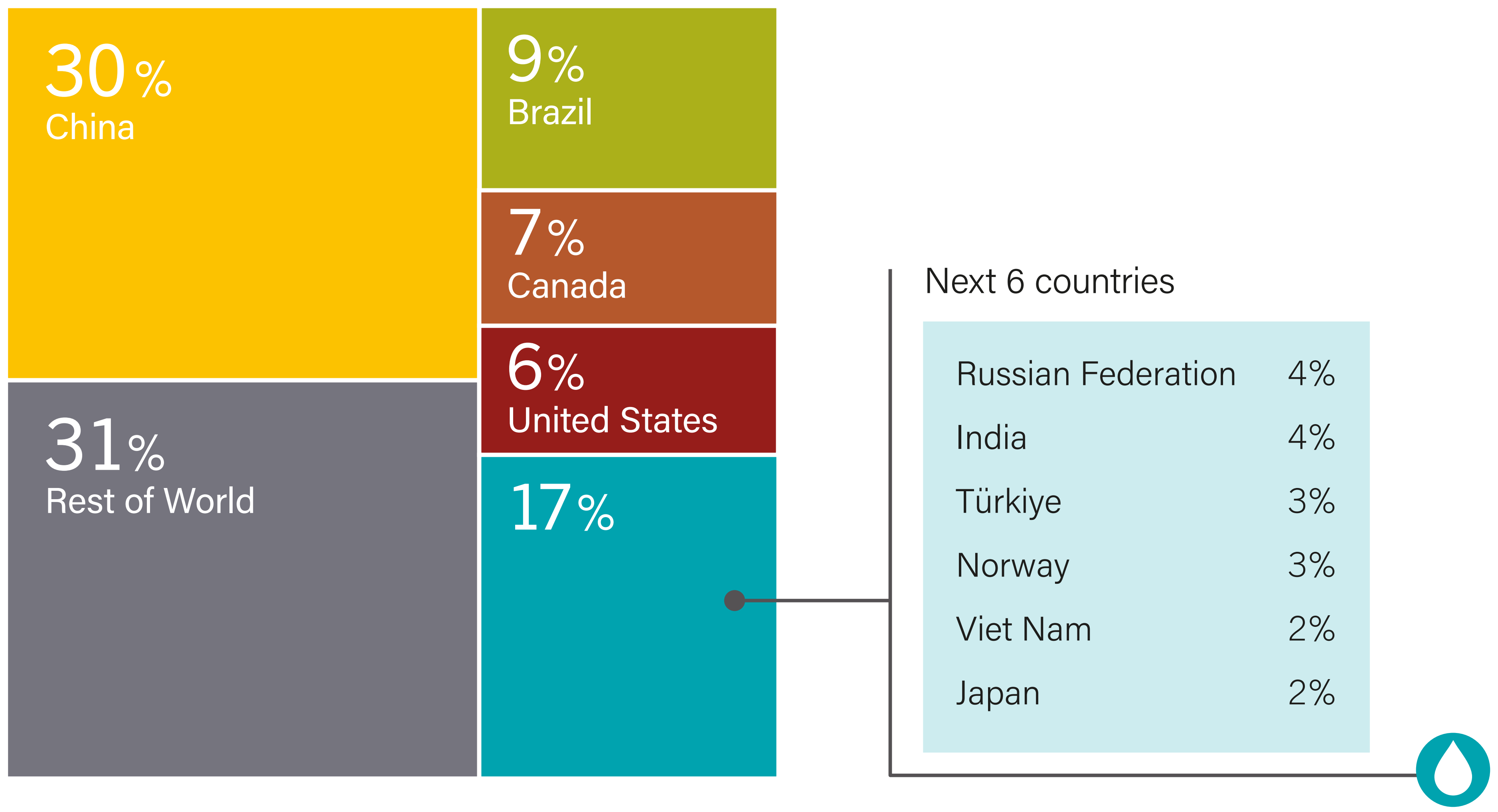
China remained the world leader in cumulative hydropower capacity in 2023, with a 30% global market share and more capacity installed than in 95% of countries.[12] Hydropower capacity growth is cyclical because of the multi-year nature of plant construction. After rapid growth in 2022, China's capacity in 2023 grew by only 530 MW, a 96% decline compared to 2022.[13] The country ended the year with just under 371 GW of total hydropower capacity.[14] In October 2023, the fifth 400 MW unit of the 2 GW Lijiaxia Hydropower Station began operation, representing the country's main capacity added.[15] Hydropower generation in China was down 16% for the year, driven largely by extreme drought conditions in southern provinces during the first half of 2023.[16]

In **Nepal**, due to plentiful hydropower resources, the technology plays a vital role in producing nearly 100% of the country's electricity, and also supports the economy through the export of excess electricity to China and India.[17] Nepal's installed hydropower capacity in 2023 totalled 2.6 GW, with an additional 4.4 GW under construction, nearly double the country's current capacity.[18]

In 2023, **Lao PDR** added 548 MW to its total 9.8 GW of installed capacity.[19] Around 40 dams were still in construction, and the country's Five – Year National Socio-Economic Development Plan (2021-2025) relies greatly on additional hydropower capacities for meeting its renewable energy goals, including the completion of the Luang Prabang 1.46 GW power plant, which is expected to be in operation by 2030.[20]

In **Japan**, where hydropower benefits from a favourable feed-in tariff, the 10.3 MW Komatagawa New Power Plant started operating in Akita Prefecture in January 2023.[21] The plant is part of the Komata River Water System, operating on Moriyoshi Dam, and is the first new hydropower plant in the area in around 70 years.[22] The New Power Plant replaced Komatagawa hydropower plants No. 1 and No. 2, makes up to a net capacity addition of 5.8 MW in 2023 and bringing Japan's total installed capacity to 22.2 GW.[23]

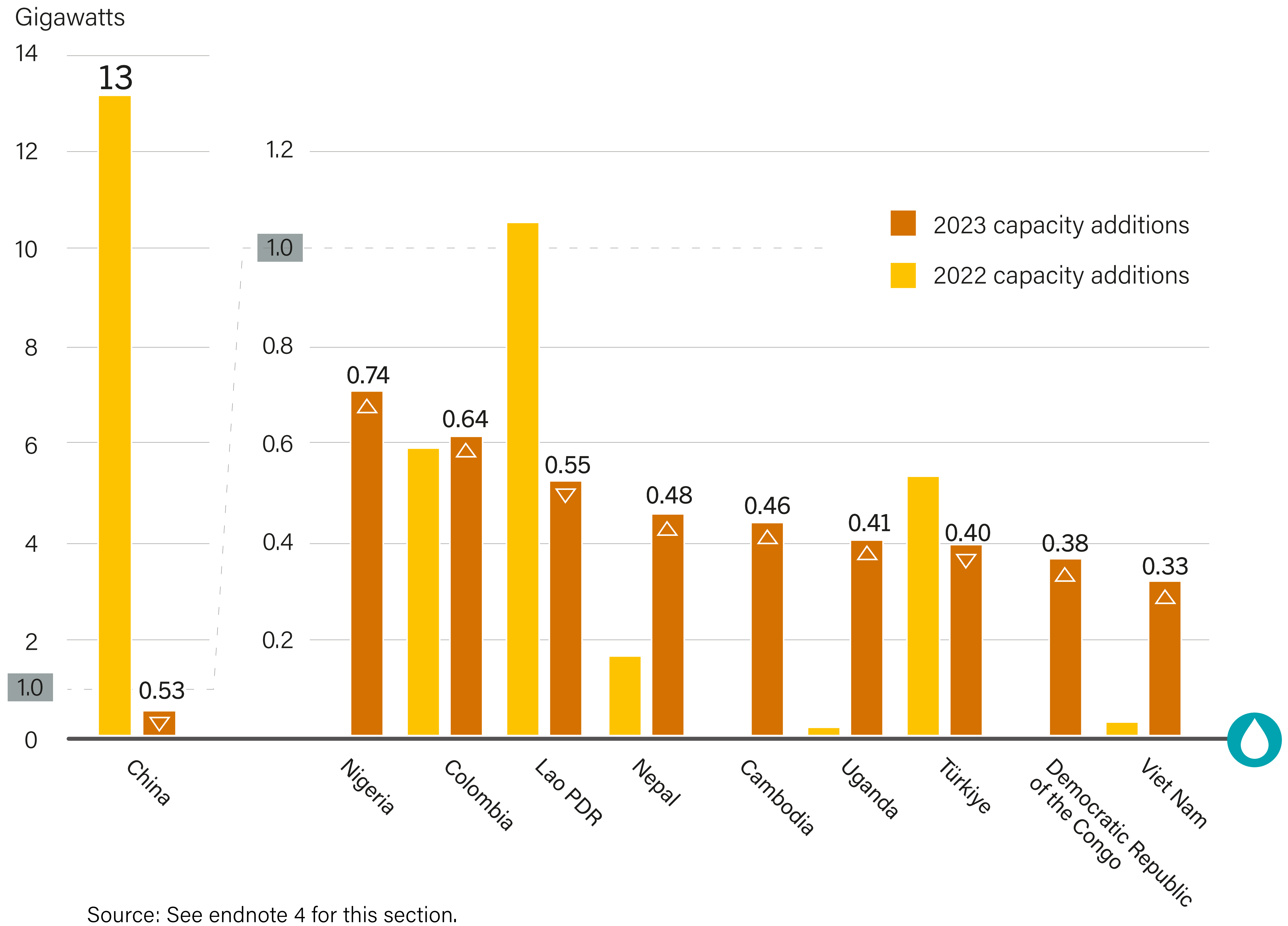
FIGURE 24.
Hydropower Global Capacity, Shares of Top 10 Countries and Rest of World, 2023



Source: See endnote 3 for this section.

Hydropower make up **47%** of all renewable power generation.

FIGURE 25.
Top 10 Countries by Hydropower Capacity Additions in 2023 Compared to 2022 Additions



Source: See endnote 4 for this section.

Africa

Nigeria added the largest amount of hydropower capacity in the world in 2023, due mostly to the commissioning of the 700 MW Zungeru plant, which is expected to provide 10% of the country's electricity needs.[24] The plant is projected to generate around 2.6 TWh annually and is the second largest hydropower plant in the country, after Kainji.[25]

Mozambique announced that it would install its second hydropower plant on the Zambezi River, with the first turbine of the 1.5 GW plant expected to come online by 2031.[26] The existing 2 GW Cahora Bassa Dam on the Zambezi already supplies power to South Africa.[27]

In **Tanzania**, the first turbine of the more than 2 GW Julius Nyerere Hydropower Plant came online in early 2024 and is set to double the country's hydropower capacity when completed.[28] In April 2023, the government of Tanzania signed agreements with several development partners – including the African Development Bank and the French development agency AFD – to finance a second plant, the 87.8 MW Kakono Hydropower Project, in the country's north.[29] The project is targeted to come online in 2026 to displace current diesel generators and to address electricity deficits in the Kagera, Geita and Mwanza regions.[30]

Hydropower generation stabilised in eastern and southern Africa in 2023 after the longest and most severe drought on record in these regions crippled generation in 2022.[31] Overall, the African continent generated 175 TWh of electricity from hydropower, up 16% from 2022.[32]

Americas

In **Canada**, the summer of 2023 was the hottest on record since 1940, and a decline in precipitation led to an 8.4% drop in hydroelectric production, to 359 TWh.[33] Hydropower typically contributes two-thirds of the country's total electricity generation, but in 2023 it was the biggest contributor to the overall decline in electricity supply.[34] In western Canada, the provinces of British Columbia and Manitoba, which rely heavily on hydropower, were forced to import electricity from neighbouring regions.[35] No significant capacity was added in the country during the year.[36]

In late 2022 and early 2023, heavy precipitation along the west coast of the **United States** filled reservoirs and stabilised the country's hydropower production.[37] Although this was a promising start to the year, early snowmelt in the spring combined with continued drought conditions, particularly in the Columbia River Basin, contributed to relatively low production during the rest of 2023.[38] In the states of California, Oregon, and Washington, which together produce half of total US hydropower, production fell 8.1% for the year.[39] Overall, the United States generated 240 TWh from hydropower in 2023, the lowest level since 2001.[40] Only four US projects, totalling 24.4 MW, were brought online by year's end, not enough to replace the 31.3 MW of retired units.[41]

Brazil remained the country with the second largest installed hydropower capacity in 2023, with 118 MW added for a total capacity of 110 GW.[42] Overall, capacity additions and generation remained stable relative to 2022 and 2021 levels.[43] Hydropower generation has stabilised in the country in recent years due to increased rainfall, ending 2023 with 427 TWh and helping to reduce fossil gas imports (with gas-fired generation down 72% since 2021).[44] Hydropower's share of Brazil's total energy mix fell slightly as generation levels remained steady and total energy demand increased in 2023.[45]

Hydropower accounted for well over half of the energy mix in several countries in Central and South America, including Colombia, Costa Rica, Ecuador, Panama and Venezuela.[46] **Colombia** was the second largest contributor to global hydropower capacity additions in 2023 with 643 MW, due to the completion of several turbines of the Hidroituango project.[47] The only other contributors in the region were Chile (230 MW) and Costa Rica (40 MW).[48]

Europe

In **Europe**, hydropower capacity plateaued in 2023, and only six countries added capacity, led by Türkiye (400 MW), Germany (91 MW) and Norway (90 MW).[49] Hydropower contributed 12% of the European electricity mix in 2023; however, it is not expected to contribute greatly to the region's added capacity from renewables. This is because there are few remaining suitable water sources for production, and the European Union (EU) has set no specified growth targets in its REPowerEU plan.[50] In **Austria** and **Latvia**, hydropower continued to contribute a large share (around 60%) of the electricity supply.[51]

Europe's top five hydropower producers in 2023 remained (from largest to smallest) **Norway**, **Sweden**, **Türkiye**, **France** and **Austria**.[52] In 2022, parts of western Europe experienced the worst drought in 500 years, leading to a nearly 20% decline in the continent's hydropower output.[53] Generation rebounded 12.7% in 2023, to 637 TWh, but this was still the third lowest production of the decade.[54] Generation increased in drought-stricken countries such as Italy (up 34%), France (28%) and Portugal (34%).[55]

During 2023 and early 2024, multiple hydropower plants in **Ukraine**, with a cumulative capacity of more than 1 GW, were damaged because of the Russian Federation's ongoing invasion of the country.[56] Bombings in June 2023 damaged the Kakhovka plant (334.8 MW), putting 42,000 people at flood risk.[57] In March 2024, critical infrastructure of the 661 MW Dnipro 2 hydropower plant was bombed and is expected to take years to reconstruct.[58] In May 2024, at least two additional hydropower plants were decommissioned following targeted shelling of the facilities.[59]

In **Türkiye**, renewable energy accounted for 99.5% of the power capacity added in 2023, of which 400 MW was from hydropower.[60] With a total installed capacity of 32 GW, hydropower represented half of the country's renewable energy capacity.[61] Türkiye was responsible for 80% of all hydropower additions in Europe for the year.[62]

MODERNISATION

Nearly half (630 GW) of the world's hydropower facilities are more than 30 years old, and 490 GW (40%) are over 40 years old.[63] Regular maintenance, upgrade and refurbishement of hydropower plants can increase their lifespan to more than 100 years (while also increasing their output, efficiency and resilience) and can help prioritise variable and flexible output.[64]

Two plants of Switzerland's Grande Dixence hydropower scheme, totalling 680 MW, came back online in 2023 after seven years of renovations.[65] Plants slated for modernisation efforts include some of the largest electricity plants in Georgia – the Enguri and Vardnili hydropower plants – which together supply 30% of the country's electricity needs.[66] The Aurland 1 hydropower plant in Norway (840 MW) will optimise three of its 280 MW turbines for greater efficiency by 2027.[67] The African Development Bank granted USD 9.72 million to expand the Africa Hydropower Modernisation Programme, which along with private investment would add 570 MW of available capacity across the continent.[68] Plants slated for upgrades (such as cooling systems and digitalisation) include Nigeria's 760 MW Kainji plant, Sudan's 280 MW Roseires facility, the Democratic Republic of the Congo's 7 MW Lubilanji plant and South Africa's 2.7 MW Sol Plaatje plant.[69]

Following the introduction of the Hydropower Sustainability Standard in 2021, the industry has taken increasingly rigorous steps to ensure the sustainability of hydropower projects.[70] (→ *See Sidebar 3.*) Through multi-stakeholder certification schemes, the standard helps to build trust among diverse stakeholders, while enhancing resilience and integrating good practices in hydropower projects.[71]

SIDEBAR 3. Hydropower Sustainability Standards in Practice

Hydropower is the largest source of renewable electricity, producing around 14.3% of the world's electricity in 2023, and plays a vital role in supplying reliable baseload power. However, hydropower faces significant sustainability challenges, particularly with large-scale projects (exceeding 30 MW). Challenges include ecosystem disruption from dams and reservoirs, methane emissions from decomposing organic material, community displacement and livelihood disruption, as well as the environmental impacts of construction materials such as cement, steel and copper.

To address these issues, sustainability standards for hydropower have been developed in recent years. To enhance resilience and integrate good practices in hydropower projects, the International Hydropower Association – with support from the European Bank for Reconstruction and Development and the World Bank's Korea Green Growth Trust Fund partnership – developed the Hydropower Sector Climate Resilience Guide in 2019. This guide offers a methodological approach to identify, investigate and manage climate risks.

At the World Hydropower Congress in September 2021, a multi-stakeholder consultation process was facilitated to develop the San José Declaration on Sustainable Hydropower[i]. The declaration outlines principles for the sustainable use and planning of hydropower stations and emphasises delivering benefits to communities and ensuring stakeholder collaboration. It provides explicit recommendations for decision makers, such as upgrading existing infrastructure, advancing river restoration and accepting only sustainable hydropower.

Also in 2021, the Hydropower Sustainability Council adopted the Hydropower Sustainability Standard, which evaluates the environmental, social and governance performance of projects based on a rating system covering 12 topics. These include, among others: water quality and sediments, biodiversity, governance and consultations, labour and working conditions, cultural heritage and Indigenous Peoples' rights. The Hydropower Sustainability Alliance, established in 2023, is the multistakeholder body overseeing the governance and implementation of the Hydropower Sustainability Certification System and manages the implementation of the Standard.

In March 2023, Pamir Energy's Sebzor hydropower project in Tajikistan became the world's first project certified under the Hydropower Sustainability Standard, receiving silver certification. Two months later, the Eastmain-1 Development in Quebec, Canada achieved gold certification, and more recently the gold standard also was awarded to Brazil's Jirau project, the largest of the three projects with 3,750 MW of capacity.

The Hydropower Sustainability Standard ensures good practice in project preparation, implementation and operation by driving multi-stakeholder engagement and ensuring transparent processes. Assessments under the Standard use data triangulation, comparing project documents to photos from site visits and interviews with affected communities, ensuring that stakeholder input is effectively integrated in decision making.

i The definition of "sustainable hydropower" under the San José declaration underlines that the preparation, implementation and operation of hydropower should be delivered in accordance with international good practice as defined by the Hydropower Sustainability Standard.

Source: See endnote 70 for this section.

KEY FACTS

OCEAN POWER

- Ocean power has **immense global potential** and is moving towards commercial deployment. A total of 2 MW of ocean power capacity was installed in 2023.
- **Tidal stream and wave power are the key development areas**: since 2010, deployments have totalled 41 MW and 27 MW respectively.
- Public funding for ocean energy deployments in Europe surged to an unprecedented **USD 215 million in 2023**.
- Private investment in ocean energy saw a significant **75% increase** in officially announced deals.

Ocean power technologies[i] represent the smallest share of the renewable energy market, although the global resource is vast. With concerted technology development, dedicated policy support, and growing investment, ocean power has been gradually moving towards commercial-scale deployment. A total of 2 MW of ocean power capacity was installed in 2023, about the same as in 2022.[1] The estimated operating installed capacity in 2023 was 513 MW.[2]

Two tidal range systems account for most of this capacity – the 240 MW La Rance station in France and the 254 MW Sihwa plant in the Republic of Korea.[3] Because suitable locations are limited and large-scale engineering is required, few proposals have been advanced to expand the use of tidal range systems.

Tidal stream and **wave power** devices are the focus of development efforts. Advancements had long been concentrated in Europe, but generous revenue support policies and ambitious research and development (R&D) programmes in other regions have spurred increased activity, particularly in Canada, the United States and China.[4]

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.[5] Developers targeting industrial-scale deployment have converged on horizontal-axis turbines, mounted either on the sea floor or on a floating platform.[6] These devices have demonstrated considerable reliability, and total generation surpassed 90 GWh as of the end of 2023.[7]

Wave power devices are yet to see the same level of design convergence, with a diverse range of operating principles and concepts being developed. Around 27 MW of wave power has been deployed since 2010, with developers generally aiming to tap into utility-scale electricity markets with devices above 100 kW or to fulfil specialised applications with devices below 50 kW.[8] The focus of wave power development has long been on building and assessing full-scale prototypes, but in Europe, the sector is now moving towards larger-scale multi-device deployments.[9]

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 power.

OCEAN POWER INDUSTRY

Most ocean power deployments are pilot projects, with around 60 active teams testing their devices in the open sea.[10] A few developers have now advanced to higher technology readiness levels and are pursuing a pipeline of commercial-scale deployments.

A total of eight **tidal stream** devices were successfully deployed in 2023, with a capacity of 375 kW.[11]

In the **United Kingdom**, Nova Innovation installed two turbines at the Shetland Tidal Array, increasing the project's capacity to 0.6 MW; the original three turbines, deployed in 2016-17, were decommissioned, marking a full life-cycle demonstration.[12] Magallanes Renovables completed the engineering phase for the second generation of its floating tidal platform and secured tariffs for two significant projects: a 3 MW expansion in Wales and a 1.5 MW project in Scotland through the UK Contract for Difference (CfD) auctions.[13] The four 1.5 MW turbines of the MeyGen array in Pentland Firth, Scotland have generated more than 60 GWh of electricity since their installation in 2018, and the next phase of the project aims to add 50 MW of capacity by 2028.[14] Orbital Marine Power secured a 30 MW project in Orkney, Scotland and received 7.2 MW in CfD allocations for two new projects.[15]

In **France**, Scottish company Nova Innovation made its first tidal stream deployment outside of the United Kingdom, a 50 kW full-scale device in the Etel Estuary.[16] French company EEL Energy deployed its turbine in the Rhône River near Lyon, testing an innovative system that uses a plastic membrane that mimics the swimming action of fish.[17]

In the **United States**, Littoral Power trialled a tidal energy device at the Bourne Tidal Test Site in Massachusetts.[18] Ocean Renewable Power Company (ORPC) tested a Modular RivGen hydrokinetic device and a TidGen tidal energy converter in Maine, with plans for further deployment, including in the Lower Mississippi River.[19]

In **China**, the LHD Tidal Current Project marked more than six years of operation, with its Endeavour turbine generating nearly 3 GWh in 20 months.[20] The Zhoushan tidal project (China Three Gorges Corporation) underwent a significant technical upgrade to facilitate grid-connected operations.[21]

Minesto's tidal energy projects in the **Faroe Islands** continued to generate electricity in 2023, and preparations were finalised for installing a larger system.[22] The unique Dragon 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.[23]

In **Canada**, a range of projects advanced, including the 9 MW Uisce Tapa tidal project in Nova Scotia (DP Energy), which plans to use six turbines, and Nova Innovation's 1.5 MW tidal project in Nova Scotia, targeting deployment in 2024.[24] ORPC continued to operate its RivGen Power System (installed in 2022) at the Canadian Hydrokinetic Turbine Test Centre in Manitoba, providing local baseload power to the remote community of Igiugig, Alaska.[25] Canadian company New Energy Corporation expanded its operations to South-East Asia with the delivery of five turbines (25 kW) to Singapore.[26]

For **wave power**, eight additions occurred in 2023, totalling 1.6 MW in capacity.[27] The year marked the highest volume of deployment outside Europe since 2019, with a total of 1 MW.[28]

In **China**, Guangdong Grid Co. and China Southern Power Grid collaborated to develop and deploy the country's inaugural megawatt-class floating wave energy generation device, which has commenced open-sea testing.[29] Characterised by a novel triangular structure, the Nankun has demonstrated robust typhoon resistance.[30] Two 500 kW devices have been deployed as part of the Wanshan wave energy project, expected to enter into operation shortly, and the Penghu platform continued to demonstrate the effective integration of wave power with aquaculture.[31]

In the **United States**, Oscilla Power deployed a prototype of its community-scale (100 kW) device in Maine and prepared for connection of its 1 MW utility-scale device off Hawaii, towing it from the harbour to the grid connection point where in-water tests were being conducted.[32] Ocean Power Technologies successfully tested the next generation of its wave energy converter

1.6 MW
of wave power was deployed in 2023.

Small arrays of tidal turbines are **reliably delivering** power to the grid.

buoy in New Jersey.[33] The new design allows for the integration of wind and solar energy generation and is fully sealed to eliminate all external moving parts, increasing reliability and lowering maintenance costs.

In the **United Kingdom**, Mocean's BlueX wave energy prototype operated for 10 months and showcased the integration of solar panels; the company received USD 4 million (GBP 3.2 million) for developing a new 250 kW device.[34] AWS Ocean Energy tested a 16 kW Waveswing wave energy converter at the European Marine Energy Centre (EMEC) in Orkney, Scotland and is seeking partners for a 2 MW prototype.[35] OceanEnergy is also set to demonstrate its 1 MW floating wave energy converter at the EMEC.[36] The device floats on the water's surface and allows waves to flow in, causing a water column within the device to rise and fall, which pressurises air to drive a turbine.

In **Portugal**, CorPower Ocean successful installed its inaugural commercial-scale wave energy device, C4, in Aguçadora, showcasing durability against storms.[37] The company aims to redeploy the unit in 2024 for performance evaluation and to launch three full-scale devices by 2025.[38]

In **Spain**, Wavepiston completed the installation of a full-scale prototype at the PLOCAN test site in Gran Canaria for power production and desalination, with commissioning planned for early 2024.[39] The Mutriku Wave Power Plant surpassed 3 GWh of energy generated since its commissioning in July 2011, with 266 MWh produced within the year.[40] Carnegie Clean Energy and IDOM both secured approvals for deployments at the Biscay Marine Energy Platform (BiMEP) in 2025.[41] Rotary Wave tested its low-power full-scale device (20 kW) in La Marina de Valencia, producing 30,000 kWh from March to November of 2023.[42]

In **Canada**, Oneka Technologies scaled up its wave-powered desalination technology, securing significant funding and partnerships for deployments in Chile and California, focusing on utility-scale solutions and emergency freshwater supply.[43]

The development of other ocean power technologies, such as **ocean thermal energy conversion** (OTEC), has remained slow, with only a handful of pilot projects launched.[44] In 2023, **China** successfully tested a 20 kW device and finalised construction of a 50 kW device integrated into an experimental test platform.[45] Global awareness and expertise around OTEC remain limited, and there is a lack of financial support to move beyond small demonstration plants towards pre-commercial prototypes.[46] The scarcity of cost data has hindered understanding of OTEC's economic feasibility for full-scale operations, and a consortium of countries has launched a collaboration to tackle key economic challenges facing the technology.[47]

INVESTMENT

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.[48] Dedicated revenue support is essential to achieve predictable returns and to attract private investors until the industry reaches greater maturity.[49]

Public funding for ocean energy deployments in Europe surged to an unprecedented USD 215 million (EUR 195 million) in 2023.[50] The European Union's (EU) Horizon Europe project allocated USD 44 million (EUR 40 million) for the development of two new tidal farms, and the EU Innovation Fund provided USD 71 million (EUR 65 million) for the demonstration of two wave energy projects.[51] The EuropeWave programme, supported by the Scottish and Basque governments and the European Commission, granted USD 14.8 million (EUR 13.4 million) to three wave technology developers for at-sea testing by 2025.[52]

At the national level, the **United Kingdom** allocated USD 38 million (GBP 30 million) annually for tidal stream projects over 15 years through its CfD auction, with 11 projects adding 53 MW to the 40 MW already contracted.[53] **France** provided a financial package – including at least USD 72 million (EUR 65 million) in funding and a feed-in tariff – for the 17.5 MW FloWatt project by HydroQuest.[54] It also announced commercial tenders for tidal stream projects as part of its national energy strategy revision.[55] In **Spain**, the Renmarinas Demos Program awarded USD 265 million (EUR 240 million) for testing infrastructure and marine renewable technologies, including USD 13.5 million (EUR 12.2 million) for wave energy demonstration projects. In the **United States**, the government allocated a record USD 120 million to the Water Power Technology Office's Marine Energy Program, bringing total US R&D funding since 2019 to USD 520 million.[56]

Private investment in ocean energy saw a significant 75% increase in officially announced deals in 2023.[57] Minesto (Sweden) secured USD 11.8 million (EUR 10.7 million) through a rights issue of shares, and Oneka Technologies (Canada) obtained USD 9.6 million (EUR 8.7 million) through an equity round to support its desalination solution development.[58] Mocean Energy (Scotland) secured USD 2.9 (EUR 2.6 million) in new equity for advancing its Blue Star technology.[59] Havkraft (Norway) raised USD 1.4 million (EUR 1.3 million) through a capital raise campaign, and HydroQuest (France) collected USD 1.6 million (EUR 1.5 million) via a crowdfunding campaign.[60] Additionally, Wavepiston (Denmark) secured USD 1.5 million (EUR 1.4 million) from crowdfunding and private investors.[61]

Public investment in ocean energy totalled USD 710 million in 2023.

POLICY

Diverse policies have been deployed to foster the development of the ocean power sector, including support programmes, streamlined regulations and financial backing for research. Policies aim to foster innovation, mitigate risks and enhance the sector's competitiveness. There is also a focus on establishing test sites, which are critical for innovating and testing new technologies. These efforts are increasingly complemented by marine spatial planning initiatives that seek to balance development and ecosystem conservation. International collaboration and knowledge sharing are crucial for advancing ocean power.[62]

Deploying ocean power at scale requires streamlined consenting processes.[63] 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.[64] Current scientific knowledge suggests that the deployment of a single device poses little risk to the marine environment; however, the impacts of multi-device arrays are not well understood. This calls for an adaptive approach that responds to new information over time, supported by more long-term data and greater knowledge sharing across projects.[65]

In 2023, the International Energy Agency's Ocean Energy Systems programme (IEA-OES) launched an International Vision for Ocean Energy, which provides a roadmap to develop 300 GW of ocean power by 2050.[66] The document offers a detailed plan for addressing challenges and opportunities for tidal stream and wave power, emphasising the synergy between R&D and the need for co-ordinated efforts and clear strategies. The key policy recommendations focus on market support, accelerated innovation, infrastructure development (including opportunities for collaboration with the offshore wind sector) and building a robust and efficient regulatory framework.

KEY FACTS

SOLAR PHOTOVOLTAICS (PV)

- At least 407 GW_{DC} of solar PV capacity came online worldwide in 2023, bringing the **total installed capacity to 1.6 TW**; this was a record increase driven by low manufacturing costs, increased consumer demand and policy-driven incentives.
- **China installed at least 235 GW of solar PV in 2023**, 58% of the global total, followed by the United States and India.
- **Centralised solar PV** made up at least 55% of the total additions, while distributed solar PV comprised the remaining 180 GW.

At least 407 GW of solar PV capacity came online worldwide in 2023.[i,1] This record-breaking addition represented a 73% increase in cumulative capacity from the previous year and was the largest percentage increase since 2011.[2] More solar PV capacity was installed in 2023 alone than the entire global cumulative capacity of 2017.[3] Total solar PV capacity in operation by year's end reached an estimated 1.6 terawatts (TW), up from 1.2 TW in 2022.[4] (→ *See Figure 26.*)

The top solar PV markets were again China, the United States, India, Japan, and Germany (→ *see Figure 27*) with India overtaking Japan to take third place compared to the 2022 rankings.[5] The next five countries were Spain, Brazil, Australia, Italy, and the Republic of Korea, with Brazil jumping from 10th to 7th place, Spain climbing from 7th to 6th, Australia dropping from 6th to 8th, Italy dropping from 8th to 9th and the Republic of Korea dropping from 9th to 10th.[6] Leading drivers of solar PV deployment in the global market included low manufacturing costs, increased consumer demand and policy-driven incentives.[7]

Solar PV generation totalled around 5.4% of global electricity demand, up from 4.6% in 2022.[8] Generation from solar PV grew more than any other source of electricity, and twice as much as coal.[9] In at least 17 countries, solar PV produced more than 10% of overall electricity in 2023.[10] The countries with the highest shares of solar PV in the electricity mix were Chile (19.9%), Greece (19.0%), Hungary (18.4%), the Netherlands (17.3%), Australia (17.0%) and Spain (16.7%).[11]

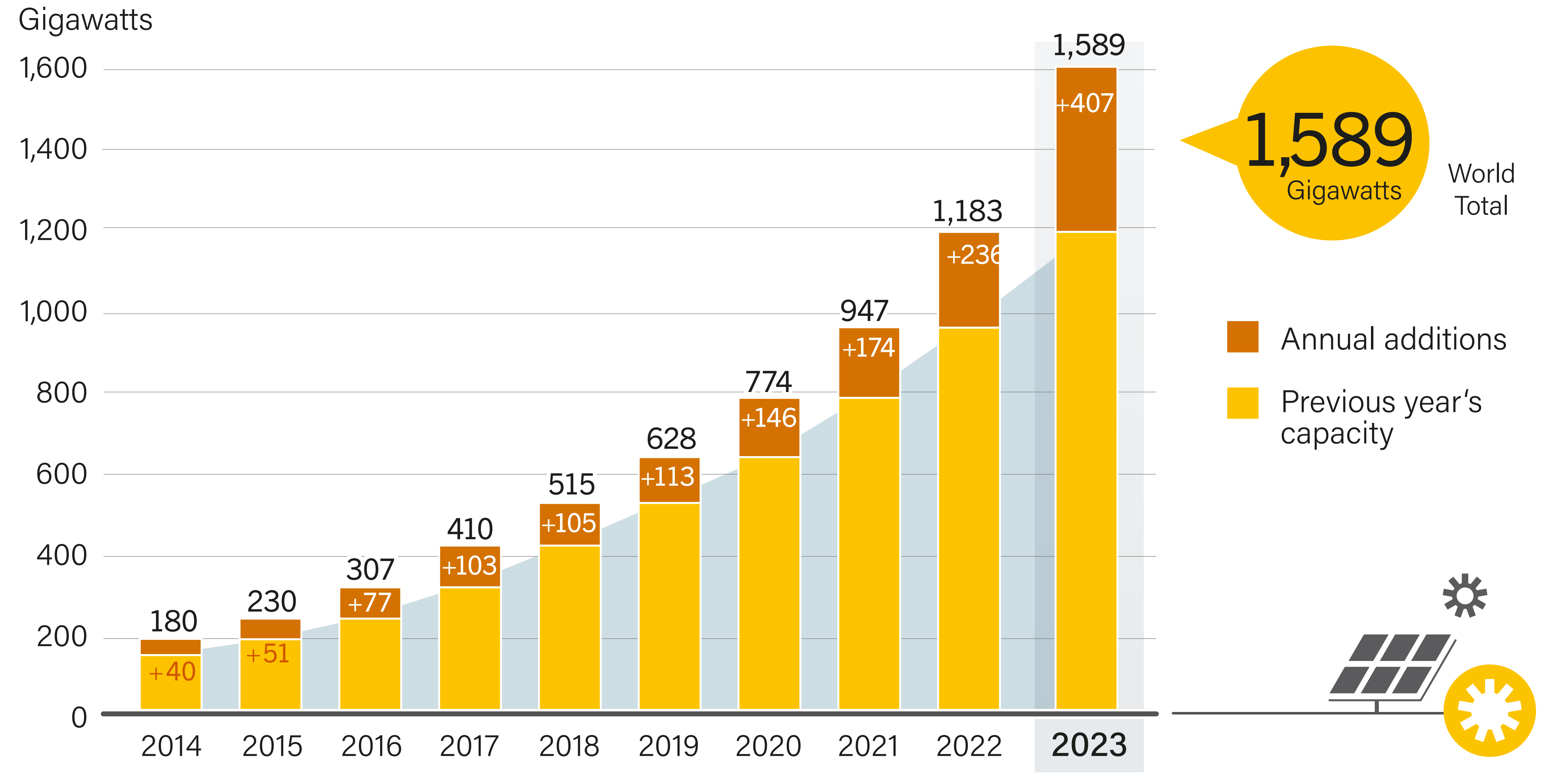
i Figures in this section are in direct current (DC), unless otherwise stated. China's National Energy Administration provides installed capacity in alternating current (AC), and the International Energy's Photovoltaic Power Systems Programme applies a AC-to-DC conversion range to account for uncertainty. Figures in this report assume the most conservative figure.

Global capacity additions of **utility-scale solar PV** – large-scale centralised systems connected to the grid – increased around 80% to reach a total of 226 GW, while distributed solar[i] rose 56% to reach 180 GW.[12] **Distributed solar PV** represented 44% of the PV capacity added in 2023, driven by decreasing costs that made the technology more accessible for residential and commercial investors.[13] Installation of distributed solar PV occurred mainly in China, the United States, Germany, Brazil and Poland.[14] (→ *See Figure 28.*)

In the European Union (EU), **rooftop solar PV** accounted for the largest share of solar PV installations in 2023, with the residential segment representing 33% of the total installed capacity (up 32% from 2022) and the commercial and industry segment another 33% (up 29% from 2022).[15] Solar PV was installed on 600,000 roofs In France and 200,000 rooftops in the United Kingdom, in response to hikes in electricity rates.[16] The Republic of Korea and Japan have shifted from encouraging rooftop solar PV to mandating distributed generators on new residential and commercial construction.[17] In Lebanon, distributed solar PV jumped 360% in 2022 and 13% in 2023 due to economic and political uncertainty that kept the central grid unreliable.[18]

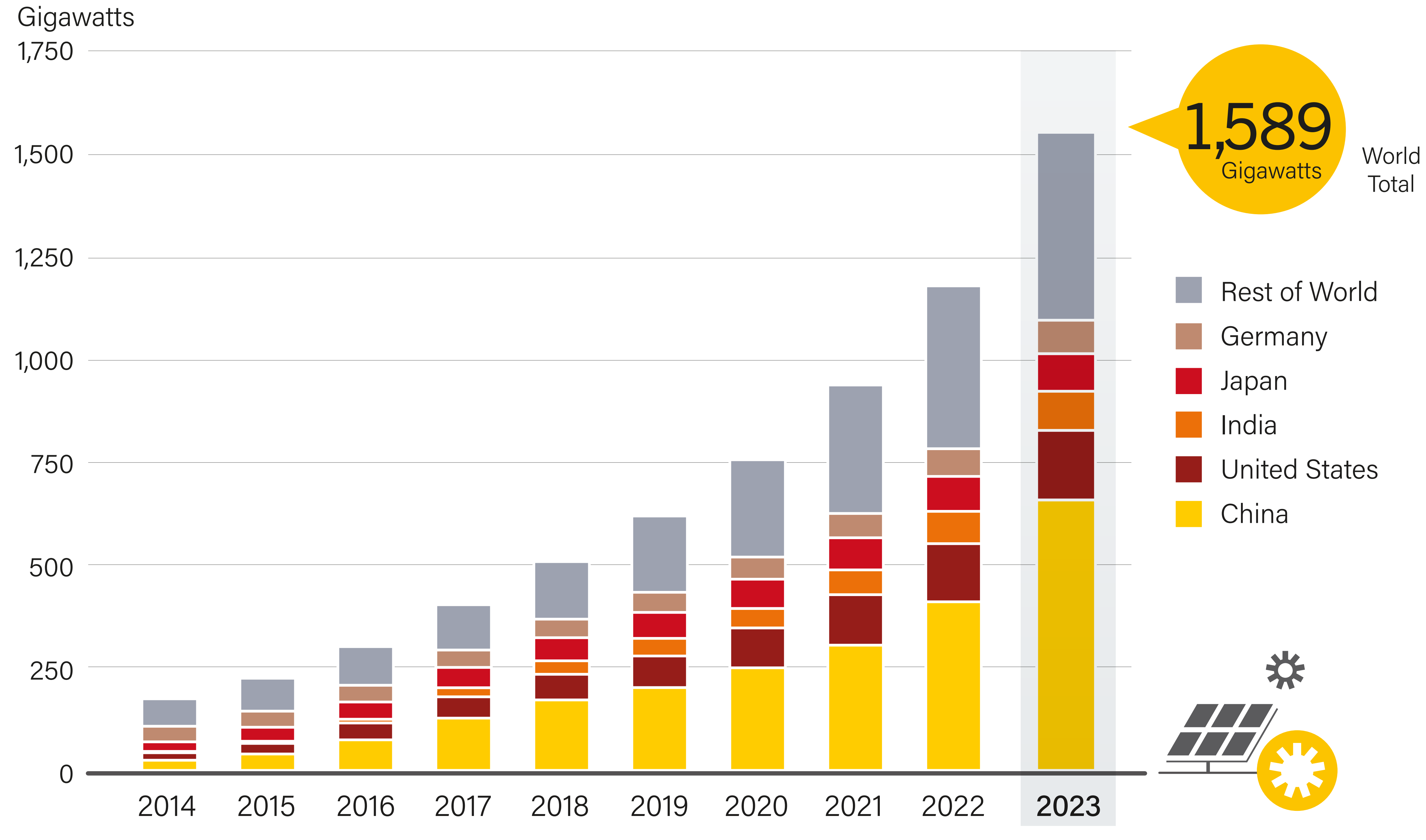
i Distributed generation refers to systems that provide power to grid-connected consumers, or directly to the grid, but on distribution networks rather than on bulk transmission or off-grid systems. In this section, distributed generation refers to rooftop and ground-mounted PV for residential, commercial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

FIGURE 26.
Solar PV Global Capacity and Annual Additions, 2014-2023



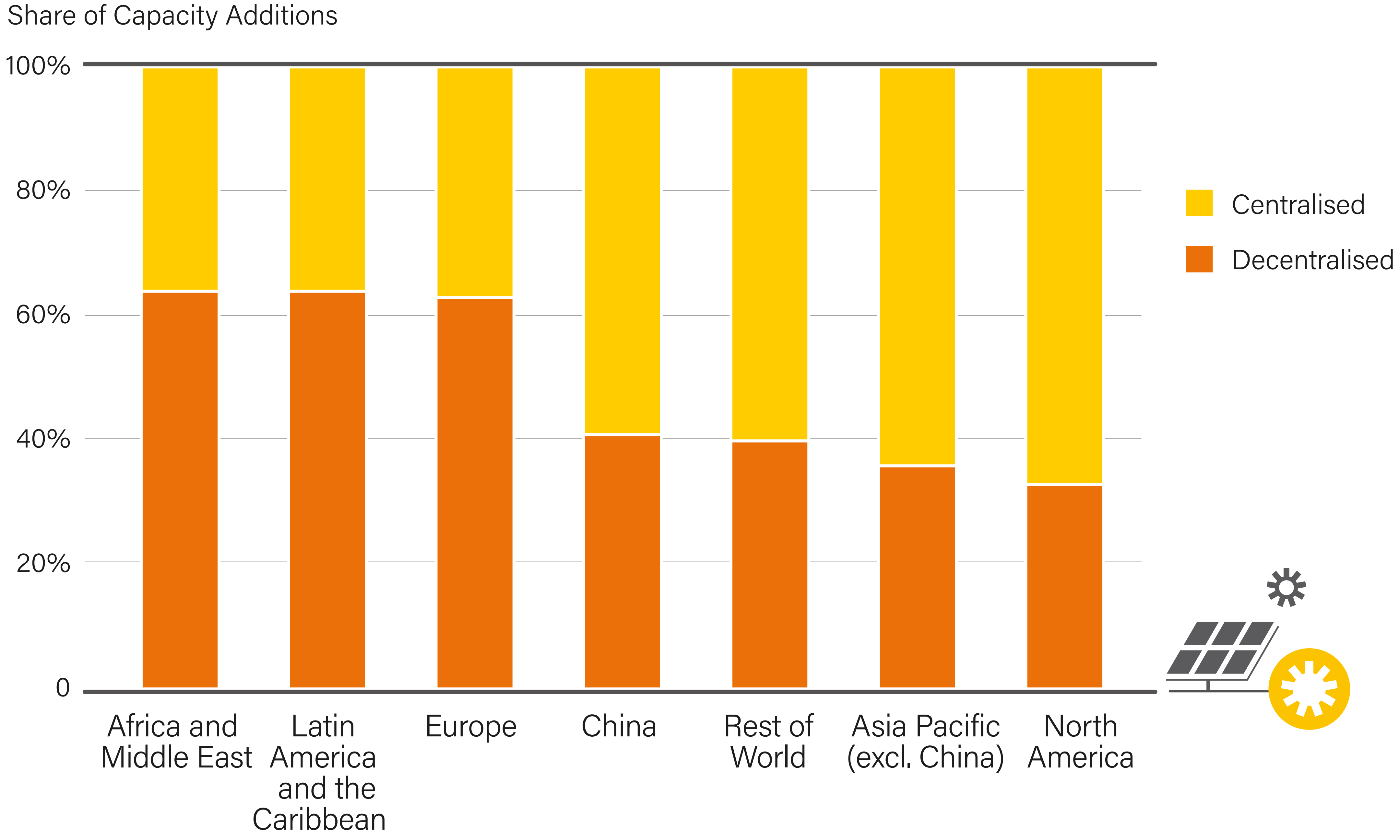
Source: See endnote 4 for this section.

FIGURE 27.
Solar PV Global Capacity, Top 5 Countries and Rest of World, 2014-2023



Source: See endnote 5 for this section.

FIGURE 28.
Share of Solar PV Capacity Additions, by Installation Type and Country/Region, 2023



Source: See endnote 14 for this section.

TOP MARKETS

The top five countries in **net additions** of solar PV capacity in 2023 were (from largest to smallest) China, the United States, India, Germany and Brazil.[19] (→ *See Figure 29*.) The top three countries for capacity additions remained the same as in 2022; however, Germany replaced Spain for the fourth position, and Brazil dropped to fifth, together comprising around 76% of the newly installed capacity (up from 66% in 2022).[20]

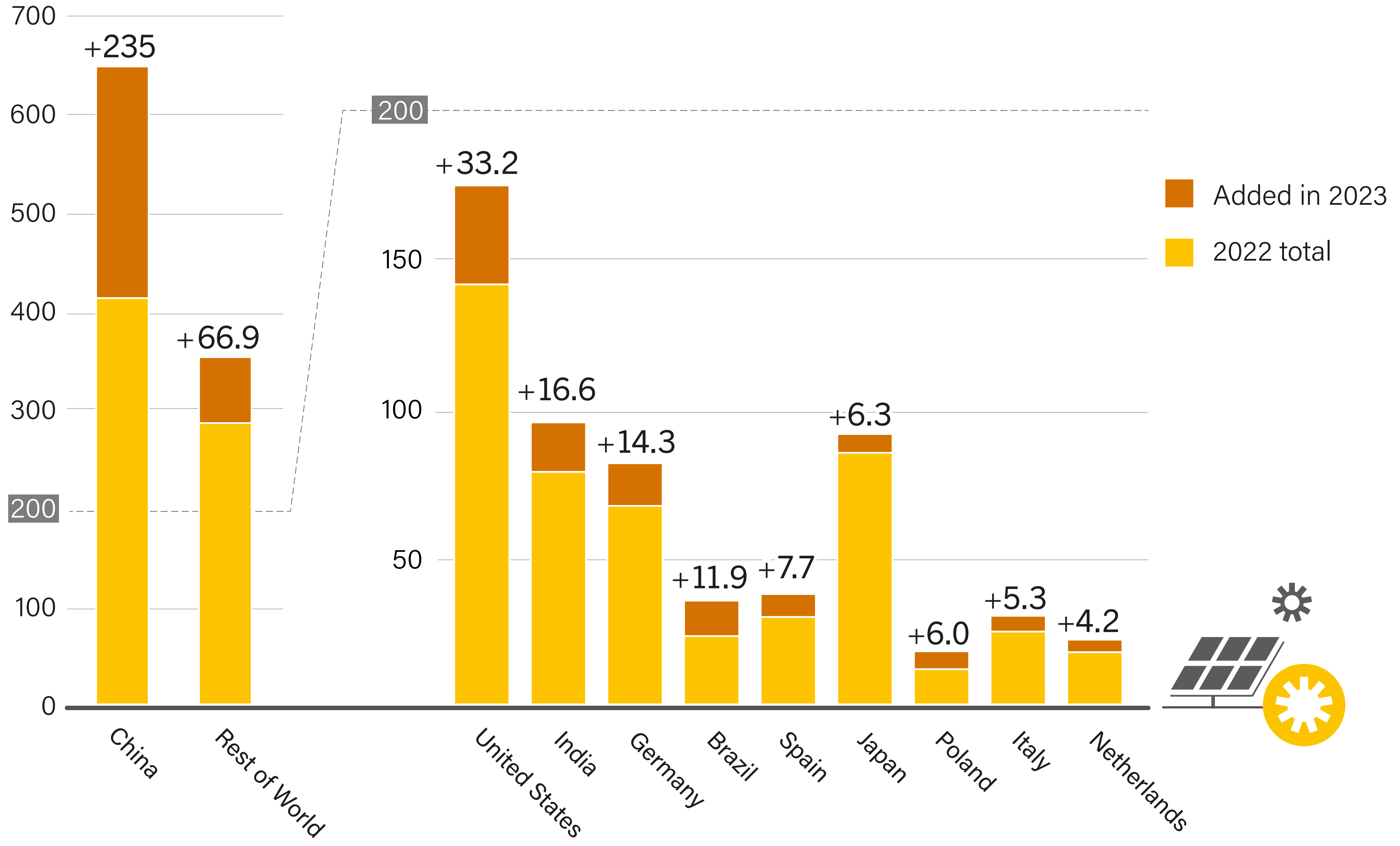
The next five solar PV markets were Spain, Japan, Poland, Italy and the Netherlands.[21] The annual market size required to rank among the top 10 countries in 2023 was 4.2 GW, up from 3.9 GW in 2022.[22] The leading markets for installed capacity per capita continued to be Australia, the Netherlands, Germany, Belgium and Spain.[23] By region, Asia again dominated in new solar PV installations, followed by the Americas, which again surpassed Europe.[24]

China's solar PV capacity increased at least 235 GW in 2023, representing 58% of global additions (→ *see Figure 30*) and bringing the country's cumulative capacity to at least 662 GW (42% of the global total).[25] China's installed PV capacity increased a record-breaking 60% in 2023, more than doubling the previous five-year average (26%).[26]

Most new PV installations in China were centralised systems, accounting for 59% (139 GW) of the country's total installed capacity, outpacing rooftop solar PV for the first time since 2020.[27] China's ambitious 2020 commitment to become carbon neutral by 2060 and to push for large-scale growth of renewables in inland deserts has driven growth in centralised PV.[28] Distributed solar PV systems made up the remaining 96 GW.[29] Despite the record deployment of solar power and other renewables, fossil fuel use in China increased slightly in 2023, with coal representing more than half (55%) of total energy consumption.[30]

Distributed solar PV represented **44%** of total solar PV capacity additions in 2023.

FIGURE 29.
Solar PV Global Capacity Additions, Top 10 Countries and Rest of World, 2023



Source: See endnote 19 for this section.

In 2023, China added
58%
of the global solar PV capacity additions.

In the **United States**, 33.2 GW of solar PV came online in 2023, a 57% increase over 2022, for a total of 177 GW.[31] The explosive increase in solar PV capacity was due largely to the 2022 Inflation Reduction Act, which created financial incentives for small- to large-scale renewable energy projects.[32] Generation from both distribution and centralised solar PV totalled 235 GWh, representing 5.6% of the overall US energy mix.[33] Utility-scale solar PV comprised two-thirds (22 GW) of the capacity added and 69% of the total PV energy generation.[34] The remaining one-third (11 GW) of capacity was from small-scale generators (less than 1 MW, in size).[35] Distributed solar PV generation totalled 73.6 TWh, led by the residential sector, with 68% of output.[36] Bottlenecks to even greater solar PV growth included local opposition, high interest rates and inflated project costs.[37]

India started operation of the first 551 MW of solar PV at the Khavada Renewable Energy Park, a 30 GW solar PV and wind power hybrid mega-project in the western state of Gujarat.[38] Additionally, 38 GW of solar PV projects were approved in 2023 under a scheme where states identify land for solar development, and the country's Ministry of New and Renewable Energy provides infrastructural support.[39] A total of 12.5 GW of projects had already been fully or partially completed under the scheme.[40] By year's end, India had 95 GW of installed solar PV capacity, a 17 GW increase from 2022.[41] Centralised solar PV represented 77% of the total installed capacity.[42]

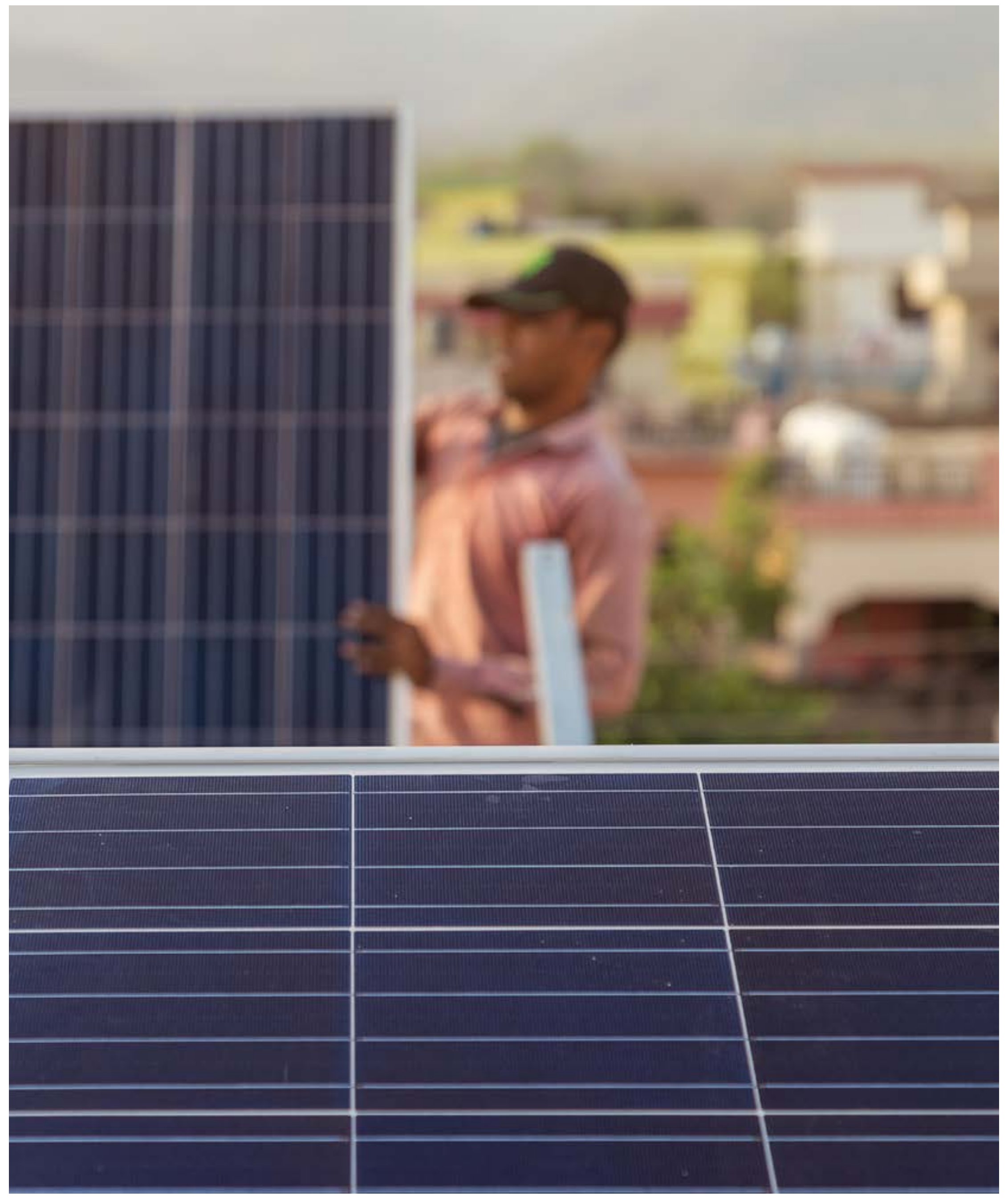
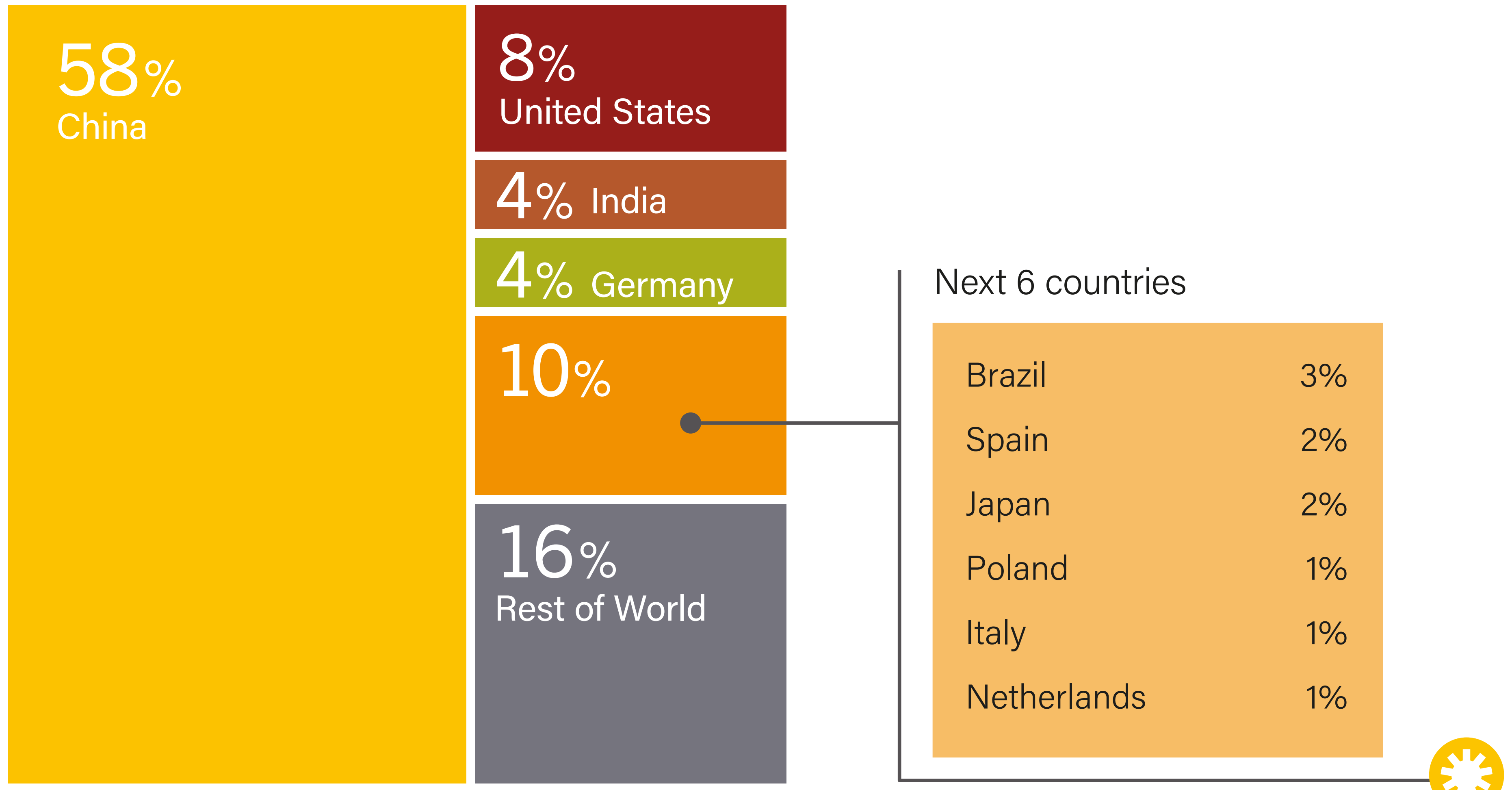


FIGURE 30.
Solar PV Global Capacity Additions, Shares of Top 10 Countries and Rest of World, 2023

Solar PV Global Additions 2023: **407.3 GW**



Source: See endnote 25 for this section.

The **European Union** brought online 50 GW of solar PV capacity in 2023, 25% more than in 2022, to bring the region's cumulative capacity to 257 GW.[43] **Germany** added more solar PV to its grid in 2023 than in 2021 and 2022 combined, with 14 GW.[44] As an early adopter of PV, Germany represented 32% of the total European market, with a total of 82 GW of capacity installed by the end of 2023.[45] **Spain** was Europe's second biggest market with 38 GW of installed capacity by year's end; however, net additions fell from 8.4 GW in 2022 to 7.6 GW in 2023.[46]

Italy remained the third biggest market in Europe, with 30 GW of installed capacity in 2023; it added 5.2 GW, or more than double the capacity added in 2022.[47] **France** remained the fourth largest market, adding 3.9 GW in 2023 (31% more than it added in 2022), bringing the country's total installed capacity to 23 GW.[48] The **Netherlands**, the fifth biggest market in Europe, added 4.2 GW (8% more than in 2022), bringing its cumulative capacity to 22.5 GW.[49] **Poland's** solar PV market continued to expand rapidly, adding 6 GW in 2023 (a 22% increase) and bringing the total installed capacity to 18.5 GW.[50] In the **United Kingdom**, annual additions in the last two years did not exceed 1 GW, and the total installed capacity was 16 GW at the end of 2023.[51]

Solar PV generation in **Brazil** has rapidly outpaced other electricity technologies, producing 50 TWh in 2023, or roughly a 17-times increase in added capacity compared to 2018 levels.[52] In 2023 alone, PV generation increased 70%, with 12 GW of capacity brought online.[53] Net metering legislation, rising electricity tariffs and low PV equipment prices have pushed solar PV to become the second largest energy producer in the country after hydropower.[54] Brazil ended the year with 35 GW of total installed capacity.[55] Other notable capacity additions in Latin America were in Chile (1.3 GW), Colombia (695 MW) and Mexico (680 MW).[56]

Japan was the third largest solar PV market in Asia after China and India, with a cumulative installed capacity of 91 GW; the country added 6.3 GW in 2023 (5% less than in 2022).[57] The **Republic of Korea** was the fourth biggest market with a total installed capacity of 27.7 GW; the country added 3.3 GW in 2023 (1% more than 2022).[58] Viet Nam, the fifth largest solar PV market in Asia, witnessed explosive growth prior to 2021 after the introduction of a generous feed-in-tariff (FIT), reaching 18.4 GW of total installed capacity in 2021.[59] However, the FIT was suspended due to weak grid planning , the market stalled and the country added less than 100 MW in the subsequent two years.[60] (→ *See Snapshot: Viet Nam.*)

SNAPSHOT VIET NAM

ADVANCING SOLAR PV POLICIES TO ENSURE ENERGY SECURITY AND GRID STABILITY

Viet Nam has emerged as one of the leading players in the South-East Asian solar energy market, owing to its exceptional solar resources as well as supportive policies and feed-in tariffs in recent years. The country's solar PV capacity reached 18.6 GW in 2023, making up around 1.2% of the global total cumulative capacity.

Yet, Viet Nam still relies heavily on fossil fuels to meet its electricity demand. In 2021, coal accounted for 45% of electricity generation, and fossil gas for 10%. Among renewables, hydropower supplied 31% of electricity, solar PV accounted for 11%, and the remaining capacity was covered by wind power and bioenergy, with a combined 2.3% of the total.

Several Vietnamese renewable energy projects have ceased to be economically viable as the grid is strained by rising electricity demand. Related transmission and distribution issues as well as market and regulatory constraints have led to a curtailment of solar power capacity after two years of multi-GW installations in 2019 and 2020. In 2020, Viet Nam was among the top 10 global solar PV markets and its solar power contribution to electricity supply reached 24%, ranking among the highest globally. After the country's feed-in tariff system (FiT 2) came to an end in late 2020, solar PV capacity additions plummeted from 10 GW to 2 GW. In 2023, just 100 MW of solar PV capacity was added.

To tackle the policy vacuum in the sector and revive the Vietnamese solar power market, the government launched a National Power Development Plan VIII (PDP8) in 2023. The plan outlines renewable energy deployment targets until 2030 and a long-term vision for the electricity system until 2050, aiming to enhance the country's energy security and promote sustainable development. Supported by a USD 135 billion funding plan and a direct power purchasing agreement framework, Viet Nam aims to cover at least 31% of its energy demand with renewable energy sources by 2030.

PDP8 particularly encourages rooftop solar PV development by granting household and construction projects unlimited PV capacity, provided that the systems are cost-effective and efficiently utilise existing grid connections. By 2030, 50% of office buildings and residential houses are set to be equipped with rooftop solar PV panels for on-site electricity consumption. Battery storage is further highlighted as a crucial aspect of power development, with a targeted capacity of 300 MW by 2030. Yet, the expansion of rooftop solar PV capacity by 2030 is capped at 2,600 MW to prevent grid overload.

Given PDP8's attention to both grid-connected rooftop solar PV and grid deficiencies, net metering has become a contentious issue in Viet Nam. A draft decree on rooftop solar PV was released by the Ministry of Industry and Trade (MOIT) in early 2024, suggesting to rule out the possibility of electricity trading. MOIT instead proposed to deploy solar PV power for self-consumption only and to feed surplus electricity back into the grid on a free-of-charge basis. The primary rationale behind this was, again, the risk that surplus electricity poses to the safety of the national grid.

Taking MOIT's concerns into account, the PDP8 Implementation Plan was adopted in April 2024, focusing on the capacity development of rooftop solar power on a self-consumption basis and on the reinforcement of the country's transmission system. Viet Nam aims to ultimately connect its grid with neighbouring countries and to emerge as a power exporter by the decade's end, targeting electricity exports ranging from 5 GW to 10 GW. Moreover, Viet Nam's solar PV aspirations offer a chance to both decarbonise the energy system and boost the country's local solar PV manufacturing.

Source: See endnote 60 for this section.

Emerging Markets

Africa added at least 3.7 GW of solar PV capacity in 2023, bringing the continent's total capacity to 16.3 GW, not accounting for residential installations[i],[61] South Africa drove most of the increase in added capacity, followed by Burkina Faso and Mauritania.[62]

South Africa comprised 47% of Africa's total installed solar PV in 2023, adding 3 GW for a total of 7.8 GW by year's end, excluding residential installations.[63] Unlike most countries, solar PV growth in South Africa has been driven by the commercial and industrial sector, following the launch of the national Renewable Independent Power Producer Programme (REIPPP) in 2011.[64] Around 75% of non-residential solar PV capacity in the country is from commercial and industrial installations.[65]

Seychelles and **Namibia** surpassed South Africa in per capita installed solar PV capacity, with 185 watts peak and 115 watts peak respectively.[66] The **Central African Republic** installed its first solar PV plants with the additions of the 15 MW Sakaï plant and the 25 MW Danzi plant.[67]

Large, centralised installations single-handedly bolstered the solar PV capacity in the **Middle East** in 2023.[68] The 2 GW Al Dhafra mega-project in the United Arab Emirates came online during the year, the only significant source of PV added capacity in the country.[69] In Saudi Arabia, the 1.5 GW Sudair solar park became fully operational.[70]

Solar PV Industry

Solar PV is the largest driver of job growth among renewable energy technologies.[71] In 2022, an estimated 3.9 million jobs were created in the sector – mostly in construction and manufacturing – as a result of the global deployment boom.[72] The renewable energy sector employs a higher share of women than the fossil fuel industry, and in 2022 women workers represented 40% of global solar PV employment.[73]

Early investment in **PV cell manufacturing** since 2011 has enabled China to become the dominant actor in the solar PV supply chain, exporting 80% of all panels and components.[74] In 2023, China exported 219 GW worth of PV modules to the rest of the world, up 34% from 2022.[75] Nearly half of the exports went to Europe, and 85 GW of these modules were still mothballed in European warehouses as of February 2024.[76] Despite stalled installations, European countries, especially the Netherlands, bought a surplus of Chinese panels due to low prices, leading domestic manufacturers to declare unfair trade practices against China.[77]

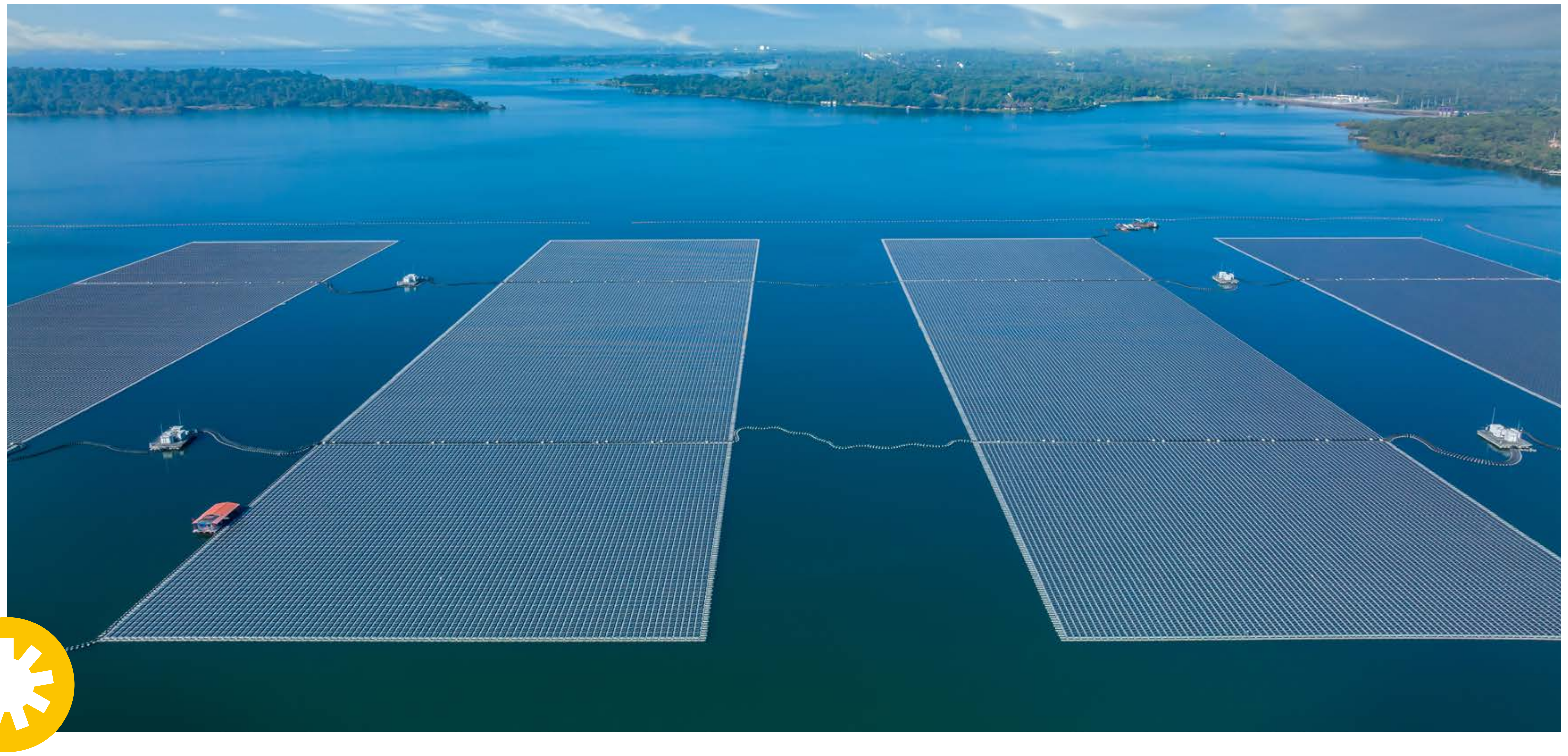
Issues with both alleged and documented forced labour in Chinese manufacturing have led some countries to stop purchasing modules from supply chains that lack transparency.[78] Meanwhile, circular solutions for the re-use, recovery and recycling of solar PV panels have gained momentum.[79] (→ *See Snapshot: France.*)

In 2023, most solar PV modules were based on crystalline (c-Si) **cell technology**, comprising 95% of the global PV market.[80] The remaining 5% of modules in commercial operation used thin-film technology, namely cadmium-telluride (CdTe) solar cells.[81] During the year, Japanese researchers were able to achieve similar efficiencies to polysilicon cells with cells made with perovskite – an emerging low-cost, mineral-created material – although no commercial applications had yet surfaced.[82]

Niche Solar PV Markets

Large-scale **floating solar PV** installations became more commonplace in 2023. Centralised floating PV plants that came online during the year included 192 MW of a 500 MW plant in Indonesia, part of a 75 MW floating solar facility in Brazil, and part of Albania's first large-scale floating PV facility.[83] Globally, at least 5.6 GW of floating solar PV was operational by the end of 2022.[84] In Taiwan, an extension of the Changbin floating solar project (originally started in 2020) began operation in February 2024 as one of the world's largest floating PV installations, at 440 MW.[85]

Interest in solar **agrivoltaics** has grown based on calls for dual land use.[86] Reporting remains subjective in many markets, but agrivoltaic projects typically contain some degree of animal grazing, introduction of pollinators or native flora on the project site, or growing and harvesting crops between or under solar arrays.[87] At least 14 GW of operating agrivoltaics was documented in 2021, including nearly 6 GW of operating agrivoltaic capacity in the United States alone.[88]



i Refined data from the Africa Solar Industry Association show an additional 1 GW of capacity in 2023 due to gaps in knowledge of operational solar PV installations from previous years. Here, the 1 GW of capacity is applied only to total cumulative capacity, not capacity added in 2023.

SNAPSHOT FRANCE

A UNIQUE APPROACH TO RE-USE AND RECYCLE SOLAR PV PANELS

There is increasing recognition of the benefits of circular supply chains in the solar PV industry. While 94% of a solar panel's components are recyclable, the complexities of the specialised processes make them still expensive, and the lack of standardisation for guaranteeing the performance and safety of second-hand panels and components constrains the development of such market streams.

Aligned with the extended producer responsibility (EPR) regulation of the European Union, France has been pro-active in addressing solar PV waste. The EPR regulation holds manufacturers and producers accountable for the entire life cycle of certain products – including PV panels – from collection to treatment, re-use and recycling. The EPR concept ensures that the producers of the PV panels also bear the costs associated with managing their waste.

In France, SOREN, a non-profit recovery system ("éco-organisation") founded in 2014, is accredited by the government to manage both collection and recycling by operating private tendering procedures. In 2023, SOREN recovered 5,207 tonnes of solar modules (35% more than in 2022), of which 3,631 tonnes were processed, managing to recycle up to 90% of them.

SOREN collects used PV panels at no cost to the owners, regardless of the technology, brand or year of marketing. The process is financed through the "eco-participation" system, which applies also to sectors. In the case of the solar PV sector, companies pay a contribution to SOREN for each product put into the market. The contribution is determined by a set of criteria such as the weight of the panel and the technology.

SOREN has also partnered with ENVIE 2E, a social enterprise specialised in recycling and re-use, to develop a market stream for second-hand solar panels. This includes guaranteeing safety, performance and a minimum lifespan, enabling a second life for the PV panels and therefore saving precious resources. As the adoption of solar energy continues to expand, it becomes crucial to implement circularity in the PV industry, extending the lifetime of panels and recovering valuable components from used panels, which can then be reprocessed into new materials or products.

Source: See endnote 79 for this section.

KEY FACTS

SOLAR THERMAL HEATING

- The global market for solar thermal collectors contracted 7.2% in 2023, to reach a newly installed capacity of **21 GW_{th}**.
- Small-scale systems have lost market share in several regions, but demand for **large-scale projects** has risen in recent years.
- Globally, **337 large-scale solar thermal district heating systems**, with total capacity exceeding 1.9 GW_{th}, were operating by the end of 2023.
- In 2023, **116 solar industrial heat plants** (SHIP) began operation, bringing the global total to at least 1,209 installations supplying process heat.
- Solar thermal heating technologies continued to face market competition due to a **lack of awareness** and an imbalance in incentives.

Solar thermal collectors absorb radiation from the sun and transform it into useful thermal energy for various heat[i] applications, ranging from domestic water and space heating to high-temperature heat and steam for industrial processes. In 2023, the global solar heat market contracted 7.2% to reach a newly installed capacity of an estimated 21 gigawatts-thermal (GW_{th})[ii], continuing the downward slide since 2013 (excepting 2021).[1] Sales grew strongly in several markets including the United Kingdom (up 65%), Mozambique (40%), India (27%), South Africa (12.4%), Lebanon (11.2%) and Greece (10%).[2] However, sales declined in several traditionally strong markets, such as China and much of Europe[iii].[3]

By year's end, millions of residential, commercial and industrial clients in at least 134 countries were benefiting from solar thermal heating systems.[4] Cumulative global capacity in operation increased 3% in 2023, reaching an estimated 560 GW_{th} (800 million square metres, m^2, of collector area[iv]).[5] (→ *See Figure 31.*) The total global capacity of solar water collectors in operation was enough to provide around 456 terawatt-hours of heat annually, equivalent to the energy content of 268 million barrels of oil.[6]

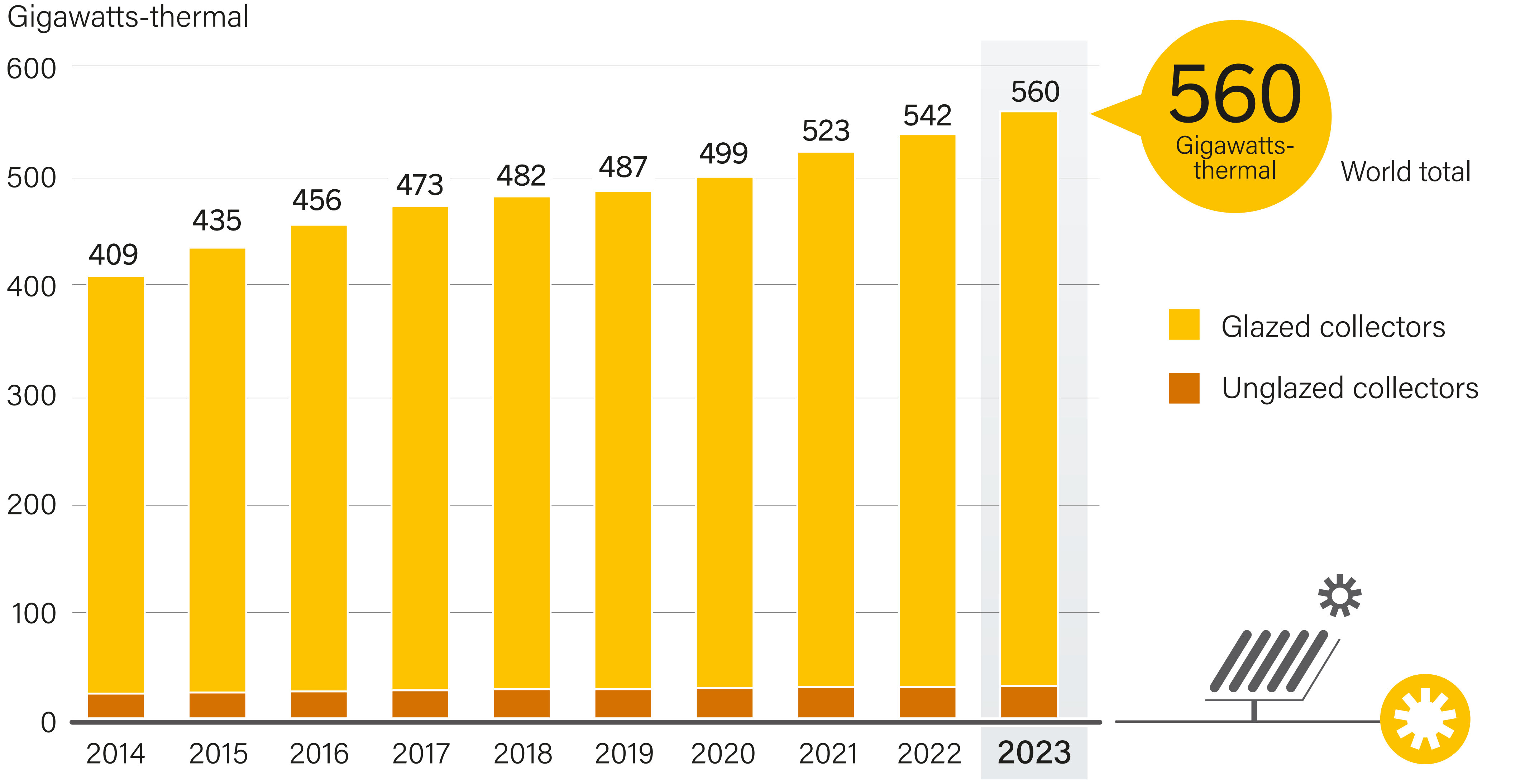
i Solar thermal energy also can be used for cooling and chilling purposes, but this remains a niche market.

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

iii Traditionally strong markets that experienced declines in 2023 included Germany (-46%), Poland (-38%), Italy (-33%), the United States (-32.7%), Spain (-26%), Austria (-21.6%), Portugal (-15%), Denmark (-12%), Cyprus (-9.7%), China (-8.5%), Australia (-8.4%) and Türkiye (-2.6%). See endnote 3 for this section.

iv Conversion from square metres (m^2) to capacity uses a factor of 0.7 kilowatts-thermal (kW_{th}) per m^2 based on the agreement of international solar thermal experts in Gleisdorf, Austria in 2004.

FIGURE 31.
Solar Water Heating Collectors Global Capacity, by Type, 2014-2023



Note: Data are rounded to nearest GW_{th}. Data are for glazed and unglazed solar water collectors and do not include concentrating, air or hybrid collectors.

Source: See endnote 5 for this section.

The top markets in 2023 were **China, India, Brazil, Türkiye and the United States.**

Despite energy price volatility in recent years, solar thermal continued to face fierce market competition due to a lack of awareness of solar thermal options and an imbalance in policies and utility incentives in many countries.[7] The competition was mainly from solar photovoltaics (PV) but also from heat pumps and (less so) from biomass boilers, both of which offer stand-alone solutions for hot water and/or space heating.[8] As a result, small-scale solar thermal systems have lost market share across much of Europe, the United States and China.[9] Meanwhile, demand for large-scale projects has risen, with several multi-megawatt plants under construction for commercial and industrial clients.[10]

TOP COUNTRY MARKETS

China remained the largest market for solar thermal systems of all types and accounted for around 65% of annual sales of solar water collectors in 2023, followed by India, Brazil, Türkiye and the United States; Greece, Australia, Mexico, Germany and Italy rounded out the top 10.[11] (→ *See Figure 32.*) At year's end, China accounted for 73% of cumulative world solar thermal capacity, followed distantly by Türkiye, the United States, Brazil, Germany and India.[12] For total capacity per capita, the top countries in 2022 were Barbados, Cyprus, Israel, Austria and Greece.[13]

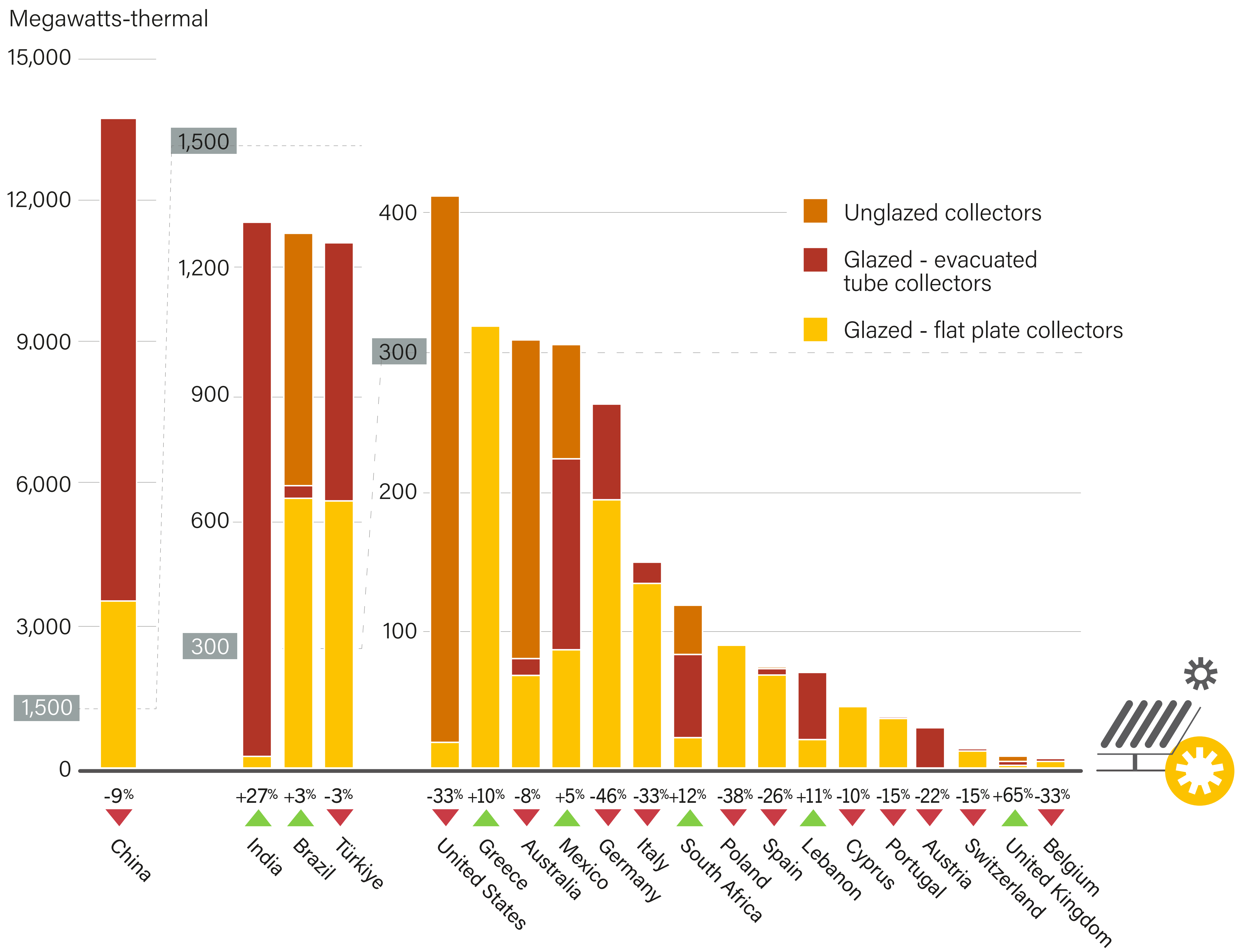
China's solar thermal sales continued the decline that began in 2014 (except for a slight rise in 2021), falling 8.5% in 2023.[14] An estimated 13.7 GW_{th} began operation for a year-end total of 410.1 GW_{th}.[15] The drop was attributed to the country's real estate crisis and economic slowdown.[16] By 2023, China's energy savings from the use of solar thermal technologies exceeded an estimated 1.1 billion tonnes of standard coal.[17]

Sales of vacuum tube collectors in China fell 8.5% to 10.2 GW_{th}, accounting for three-quarters of total sales, while flat plate sales declined 11.8% to 3.6 GW_{th}.[18] The engineered market[i] (76.3%) continued to dominate, although its share was down from 83% in 2022, and the retail market accounted for the rest.[19] Water heating remained the primary use for solar thermal systems in China, although the market for space heating continued to expand (up 11%).[20]

Following a significant (21%) decline in 2022, **India**'s solar thermal market grew 27% in 2023, moving the country into second place globally for new installations.[21] India's increase was due largely to an easing of the financial system after the COVID-19 pandemic, although falling solar PV prices and India's net metering system have continued to make rooftop-generated electricity more desirable than solar heat generation on roofs.[22] The country added 1.3 GW_{th} for an estimated total of 14.8 GW_{th}.[23] Sales of vacuum tube collectors rose 24% after a decline in 2022, whereas flat plate collector sales rose 79%, in a positive note for a stressed domestic manufacturing industry.[24]

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.

FIGURE 32.
Solar Water Heating Collector Additions, Top 20 Countries for Capacity Added, 2023



Note: Additions represent gross capacity added. Growth rates of annual market are rounded to the nearest whole number.

Source: See endnote 11 for this section.

Closely behind India, **Brazil** added a record 1.28 GW_{th} (1.83 million m^2) of solar thermal systems in 2023, with unglazed collectors for swimming pools accounting for 47% of the newly installed collector area.[25] The market for collectors expanded 2.8% in 2023, following a 2.1% decline in 2022.[26] The smaller-than-expected increase was due to economic uncertainties and a lack of financing and public incentives.[27] By region, Brazil's south-east accounted for 65% of sales, and the largest market nationally remained the residential sector (84%).[28] Brazil's total operating capacity grew 8% in 2023, to 16.8 GW_{th} (24 million m^2).[29]

Most solar thermal systems in **Türkiye** are residential water heaters; however, systems also have been installed in hotels, hospitals, and other facilities, ranking the country second after China for the number of large systems in operation.[30] 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.[31] In 2023, Türkiye added 1.26 GW_{th} (1.8 million m^2) for a cumulative capacity of 19.4 GW_{th}.[32] A 2.6% market decline was due mainly[i] to high inflation and to damage from the February earthquake, which affected more than 10 south-eastern cities.[33]

The **United States** ranked fifth for solar thermal sales in 2023 (adding 417 megawatts-thermal, MW_{th}), bringing the total installed capacity to 18.2 GW_{th}.[34] New installations fell 32.7% relative to 2022.[35] Despite federal and state incentives, the US market has declined steadily over several years for glazed systems used for residential and commercial heating due to a focus on heat pumps, electrification of heat and solar PV.[36] An exception is Hawaii, which dominates the glazed collector market and where one-in-four homeowners use solar systems to heat water.[37] In 2023, 95% of the US market was for unglazed collectors (396 MW_{th}), putting the country second after Brazil for new solar pool heating systems.[38]

Australia followed for installation of unglazed collectors, ranking third, and placed seventh globally for total solar thermal additions in 2023, despite a 8.4% decline.[39] Australia installed 312.5 MW_{th} (446,421 m^2), with unglazed collectors representing nearly 74% of additions.[40] The state of Victoria accounted for around 40% of the national market due to a mandate for solar thermal systems on new homes.[41] At year's end, Australia had an estimated 6.6 GW_{th} (9.5 million m^2) in operation.[42]

Mexico placed eighth among the top 10 markets of 2023. The country installed 309 MW_{th} (441,590 m^2), up 5.1%, for a total of 4.5 GW_{th}.[43] Mexico also has a large unglazed collector market, accounting for nearly 27% of 2023 additions.[44]

India's market grew 27% in 2023, moving the country into second place for new installations.

i Subsidies for fossil gas (zero-cost up to 25 cubic metres), provided to every household monthly through much of the year, also probably affected sales, although the impact is difficult to measure. See endnote 33 for this section.

The remaining top 10 solar thermal countries were all in Europe. Unlike in many other large markets (including Türkiye, Brazil and India), where solar water heaters are cost-effective compared to electricity-driven solutions, in most European countries (and much of the United States) financial incentives are still needed to reduce upfront investment costs, due to higher equipment and labour costs and in some cases lower solar resources.[45] In 2023, market strength varied considerably across Europe, with improvements in countries with balanced policies and incentives but substantial contractions in countries supporting solar PV and heat pumps.[46] Falling fossil gas prices towards the end of the year also affected markets for most heating technologies.[47]

Greece passed Germany to rank sixth globally and to lead in Europe for new installations.[48] The country added a record 323 MW_{th} (460,300 m^2), bringing the total to 4 GW_{th} (5.7 million m^2).[49] Annual installations were up 10%, following a 17% increase in 2022.[50] The Greek market has been driven largely by high electricity prices and a desire to shift away from fossil fuels.[51]

In Europe's other top markets, annual installations declined in 2023. In Germany, which placed second in Europe and ninth globally, annual sales were down sharply (46%), following three years of stability or growth.[52] An estimated 51,000 solar thermal systems were added, totalling 266 MW_{th} (380,000 m^2).[53] While the energy crisis of 2022 brought increased interest in solar thermal for space and water heating, this interest dropped off in 2023.[54] Slower demand combined with the dismantling of old systems meant that total operating capacity barely rose, reaching an estimated 15.8 GW_{th} (22.6 million m^2).[55] Germany's heat production from solar thermal collectors fell around 6%, due largely to a decline in average solar radiation.[56]

After two years of explosive growth (43% in 2022 and 83% in 2021), following a decade of decline, **Italy**'s solar thermal market again contracted.[57] Sales fell 33% in 2023 to 151.4 MW_{th} (216,288 m^2), for a total of 3.9 GW_{th} (5.6 million m^2) in operation.[58] The large drop was due to a change in the Superbonus subsidy scheme, delays in Italy's economic recovery plan and a general decline in heating installations.[59] Other traditionally strong markets in Europe, including Poland (-38%) and Spain (-26%), also witnessed substantial market contractions in 2023, as solar hot water systems struggled to compete with alternatives.[60]

DISTRICT HEATING

Although most solar thermal capacity installed globally continued to provide water heating in individual buildings, the use of **solar thermal technology in district heating** continued to expand. Under favourable conditions, solar thermal energy is a cost-effective[i] option for decarbonising urban district heat systems.[61] In 2023, China was the leading market for newly installed collector area, followed by Germany, Austria and Denmark.[62] By year's end, a documented 337 large-scale[ii] solar thermal district heating systems were operating worldwide, with a total capacity exceeding 1.9 GW_{th} (2.73 million m^2); many of these systems include storage capacity to address seasonal variability.[63]

China reported commissioning five systems for district heating in 2023, with a combined collector area of 147,206 m^2 (103 MW_{th}).[64] Four of the projects, completed in Tibet, are among the 20 largest solar district heating systems in the world and have a combined capacity of 102 MW_{th}.[65] By the end of 2023, China had 72 solar district heating systems in operation, for a total capacity of 503 MW_{th} (718,670 m^2).[66]

i Solar thermal can provide costs in the range of USD 22-55.2 (EUR 20-50) per MWh under favourable conditions, well below the prices customers pay for district heating. See endnote 61 for this section.

ii Solar district heating systems are considered to be large-scale if they are more than 350 kilowatts-thermal (500 m^2). Globally, 600 large-scale solar thermal systems were in operation at the end of 2023, with a total installed capacity of 2,370 MW_{th} (3.4 million m^2), including systems for heating large residential, commercial and public buildings. See endnote 63 for this section.

Across **Europe**, 266 of the around 6,000 cities and towns with district heating systems were feeding solar heat into their grids as of mid-2023.[67] The largest number of systems at year's end was in Denmark (124), followed by Germany (55), Sweden (23) and Austria (20).[68]

Germany's district heating market continued to build on the 30% growth in collector area that occurred in 2022.[69] In 2023, seven large-scale plants were completed with a combined collector area of 22,794 m^2 (16 MW_{th}), mostly for district heat systems in small towns and municipalities.[70] As of early 2024, Germany had 55 plants (112 MW_{th}) in operation, 9 systems (79 MW_{th}) in the realisation phase and 70 systems (277 MW_{th}) in preparation.[71] The market for solar thermal in district heating has been driven by the technology's potential to achieve climate protection goals while stabilising prices and improving energy security.[72] Local energy co-operatives have initiated a growing number of projects[i,73]

In 2023 and early 2024, Germany began construction on plants in Bad Rappenau (20 MW_{th}) and Leipzig (45.5 MW_{th}), the latter of which will generate more than triple the output of the country's largest operating system[ii].[74] Increasingly, suppliers of large turnkey solar thermal plants in Germany are guaranteeing minimum yields to reduce investor risk.[75]

Austria ranked third globally for new installations in 2023, thanks to two extensions to existing projects.[76] A total of 2,173 m^2 of collector area (1.5 MW_{th}) was added to solar district heating systems in St. Ruprecht/Raab and in the city of Mürzzuschlag.[77] The plants fall under a subsidy scheme granted by Austria's Climate and Energy fund for large solar collector fields.[78]

Denmark added only one solar thermal district heating system (2,000 m^2) in 2023, following the addition of one system in 2022, for a year-end total exceeding 1.1 GW_{th} (1.6 million m^2).[79] Long the leader in annual installations, Denmark's market collapsed in 2020 after significant changes in policy and funding conditions, and as of 2023 the country had fallen to fourth globally for newly installed large-scale plants.[80]

Although most solar district heating systems are installed in Europe and China, systems also are operating in Canada, Japan, the Kyrgyz Republic, the Russian Federation, Saudi Arabia, South Africa and the United States.[81] Solar thermal is more efficient at meeting low-temperature heat needs than a heat pump or solar PV system used for the same purpose.[82] Despite its potential, solar thermal in district heating faces obstacles including a lack of awareness about its benefits; challenges finding suitable sites near heat demand; and lengthy and costly permitting processes, which have caused bottlenecks across Europe.[83]

INDUSTRIAL HEAT

Industrial heat accounts for almost 20% of global energy consumption and relies heavily on fossil fuels, but there is growing interest in solar thermal energy, particularly for industries that are difficult to decarbonise.[84] Around the world, companies are turning to renewable heat solutions, including solar heat technologies, to meet social and environmental goals and to achieve energy price stability[iii].[85]

Across industries, supply chains require direct heat or steam for a range of processes[iv].[86] Solar thermal technologies provide emission-free low-temperature (below 150 degrees Celsius, °C) or medium-temperature (150-400°C) heat in the form of hot water, air flow or steam[v].[87]

In 2023, 116 **solar industrial heat plants** (SHIPs) began operation; although the number of projects remained the same as in 2022, the capacity installed in 2023 (94 MW_{th}) more than tripled[vi].[88] By year's end, at least 1,209 SHIP installations, totalling 951 MW_{th}, were supplying process heat to factories worldwide.[89] Food and beverage industries had the largest number of systems (199), and the mining sector had the largest share (47%) of total operating capacity.[90]

116
SHIP systems
were added for a total of at least 1,209 operating worldwide.

i In September 2023, 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 73 for this section.
ii The largest German system in operation at the end of 2023 was in Greifswald, at 13.1 MW_{th} (18,732 m^2).
iii 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 85 for this section.
iv 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).
v Solar thermal collectors and sorption chillers also can provide cold energy, down to -40C, for process refrigeration, although this is still a niche market. See endnote 87 for this section.
vi More capacity was added during 2017 and 2019 because of very large installations during those years in Oman and China.

Individual SHIP projects have gotten larger, and the share of systems with temperatures above 100°C has grown rapidly.[91] The type of collectors is determined in part by required temperatures, with air collectors, flat plate and evacuated tube collectors[i] providing temperatures up to 100°C, and concentrating collectors providing temperatures up to 400°C.[92] In 2023, at least eight different technology types[ii] were installed; the share of concentrating collectors in newly added capacity increased to 43% of collector area (up from 21% in 2022 and 22% in 2021).[93]

The top countries for newly commissioned SHIP projects were unchanged, although shifts occurred in the rankings[iii]: the Netherlands remained well in the lead with 43 new systems added, followed by Mexico, Germany, China and France.[94] Spain installed by far the greatest amount of capacity (49.2 MW_{th}), followed by France and China (11.1 MW_{th} each), the Netherlands (6.8 MW_{th}) and Belgium (3.9 MW_{th}).[95] The top European countries have implemented support systems, whereas Mexico and China have long been top markets without direct subsidies thanks to very cost-effective systems.[96]

Among significant projects that began operations in 2023 were Europe's largest SHIP plant, a 30 MW_{th} (plus 68 megawatt-hours of storage) concentrating system in Seville, Spain, which is expected to reduce fossil gas consumption by more than 60% at Heineken España's facility; a 13 MW_{th} (with 3,000 m^2 of storage) system at a whey production facility for a global dairy manufacturer (Lactalis) in France; and the world's largest solar concentrating dish unit – to replace biomass briquettes for production of steam for cooking, sterilisation and laundry – at a hospital in Gujarat, India.[97]

SHIP remains a challenging sector because awareness of the options remains low, clients typically want short payback periods, and projects require significant lead time[iv].[98] **Heat purchase agreements**, which minimise the market risk for investors, are increasingly common, particularly for large-scale plants using concentrating collectors.[99] Heat purchase agreements have moved SHIP into new markets.[100] In 2023, for example, such agreements were signed for large SHIP plants (totalling 154 MW_{th}) for Chile's copper mining sector.[101]

As of early 2023, there were 68 **SHIP suppliers** from 25 countries.[102] Relative to 2022, 10 companies shifted their portfolios or closed down, and 7 companies were added.[103] Although the potential for growth is significant, it is challenging to build a sustainable market with the long sales cycle for industrial clients, rising interest rates, competition from solar PV and heat pumps, and low fossil gas prices in many countries.[104] In Mexico, for example, the highly competitive SHIP market has traditionally been strong, but it suffered in 2023 from falling gas prices.[105]

GlassPoint (United States), which restarted operations in 2022 following liquidation in 2020, has deployed more than half of all solar steam systems for industry and helped accelerate use of the energy-as-a-service model.[106] In 2023, the company announced a partnership with Saudi Arabia to build a manufacturing facility for projects across the country and for export, and broke ground on the Ma'aden project[v], which is expected to be five times larger than any existing solar heat facility.[107]

Numerous start-ups, including Heliovis (Austria) and SolarSteam (Canada), also are innovating in this sector, scaling up production capabilities and initiating commercial projects.[108]

i In addition, stationary collectors with vacuum as insolation can achieve temperatures higher than 100°C. See endnote 92 for this section.

ii These included parabolic trough (38% of collector area, up from 12% in 2022), vacuum tube (26%), air collectors (17%), flat plate (12%, down from 39% in 2022), linear Fresnel (4%), PVT (1%), high-temperature flat plate (1%) and concentrating dish (0.6%). See endnote 93 for this section.

iii The Netherlands led in 2022 for number of systems added, followed by China, France, Mexico and Germany. See endnote 94 for this section.

iv 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 98 for this section.

v The plant will replace fossil gas in the refining of bauxite into alumina, and is expected to reduce the company's carbon footprint by an estimated 50%, with the aim of helping to decarbonise the aluminium supply chain in Saudi Arabia. See endnote 107 for this section.

As in other sectors, there is a growing interest in combining SHIP systems with thermal energy storage.[109] More than 30 companies (mostly start-ups), based in at least 12 countries, are providing **high-temperature thermal storage** to meet rapidly expanding demand.[110] A wide range of technologies[i] can store heat from a few hours to several days, making it possible for concentrating solar thermal systems to provide 24-hour heat, or to store surplus electricity from the grid using power-to-heat solutions for industrial clients.[111] Several companies put commercial storage into operation in 2023, while others announced that their first commercial plants were under construction.[112]

PV-THERMAL TECHNOLOGIES

PV-Thermal[ii] (PVT) technologies convert solar energy into both electricity and thermal energy for applications spanning from single households to industry, with temperatures ranging from around – 20°C to 150°C.[113] The heat can be used directly or via secondary systems, such as heat pumps.[114]

There is rising interest in PVT, particularly across Europe, with steady market growth from 2017 through 2021.[115] However, following a slump (down 52%) in 2022 – due to discontinued subsidies, inflation and the war in Ukraine – the market contracted further in 2023.[116] Systems completed in 2023 included those for a swimming pool club in Barcelona, Spain, apartments in Switzerland, an industrial customer in the Netherlands and a nursing home in Germany (the latter two systems are combined with heat pumps).[117] Worldwide, an estimated 56,967 m^2 (29.5 MW_{th}, 14.5 MW_{peak}) was added in 2023, bringing the global capacity in operation to nearly 1.6 million m^2 (822 MW_{th}, 292 MW_{peak}), up from just over 1 million m^2 in 2017.[118] The majority of this capacity was in Europe (led by France), followed by Asia.[119]

To meet anticipated future demand, Abora Solar (Spain) commissioned an assembly line in 2023 to increase PVT production.[120] As of early 2024, Sunmaxx PVT (Germany) was constructing a new production plant, and other established manufacturers had announced significant new production capacities.[121]

More than **30** companies are providing high-temperature thermal storage for SHIP systems.

i The technologies used depend on required temperatures, with some solutions able to store at temperatures up to around 2,000°C. For temperatures above 565°C, systems use solid materials such as sand, graphite, concrete blocks, granite or even steel rods. See endnote 111 for this section.

ii PVT systems perform like flat plate solar thermal collectors but with slightly lower thermal performance because PV cells absorb some of sunlight; the cooling effect on solar PV cells offsets any output losses due to front glass. See endnote 113 for this section.

KEY FACTS

WIND POWER

- A record **117 GW** of wind power capacity was added to the world's grids in 2023, **increasing the total in operation more than 12.8%** to an estimated 1,021 GW.
- The top markets for newly installed grid-connected capacity in 2023 were **China**, followed distantly by the **United States, Brazil, Germany and India**.
- Despite the cost-competitiveness of wind energy and ambitious targets in countries around the world, **numerous obstacles** continued to impede the wind industry.
- The industry continued to innovate, particularly in the **offshore sector**.
- The European Union took steps to **accelerate installations** and strengthen the competitiveness of the region's **turbine manufacturing industry**.

Wind power had a record year in 2023 with around 117 GW of capacity (106.1 GW onshore, 10.9 GW offshore) added to the world's grids; this increased the total capacity in operation more than 12.8% to surpass the 1 terawatt mark (1,021 GW).[i,1] (→ *See Figure 33.*) Annual additions rose more than 50% over 2022, with markets up in all regions except North America and Europe.[2] Outside of China, however, installations rose only 3.4%; China dominated the global market, accounting for nearly two-thirds of total additions.[3] Record highs also were set for turbine orders and for investment in offshore projects.[4]

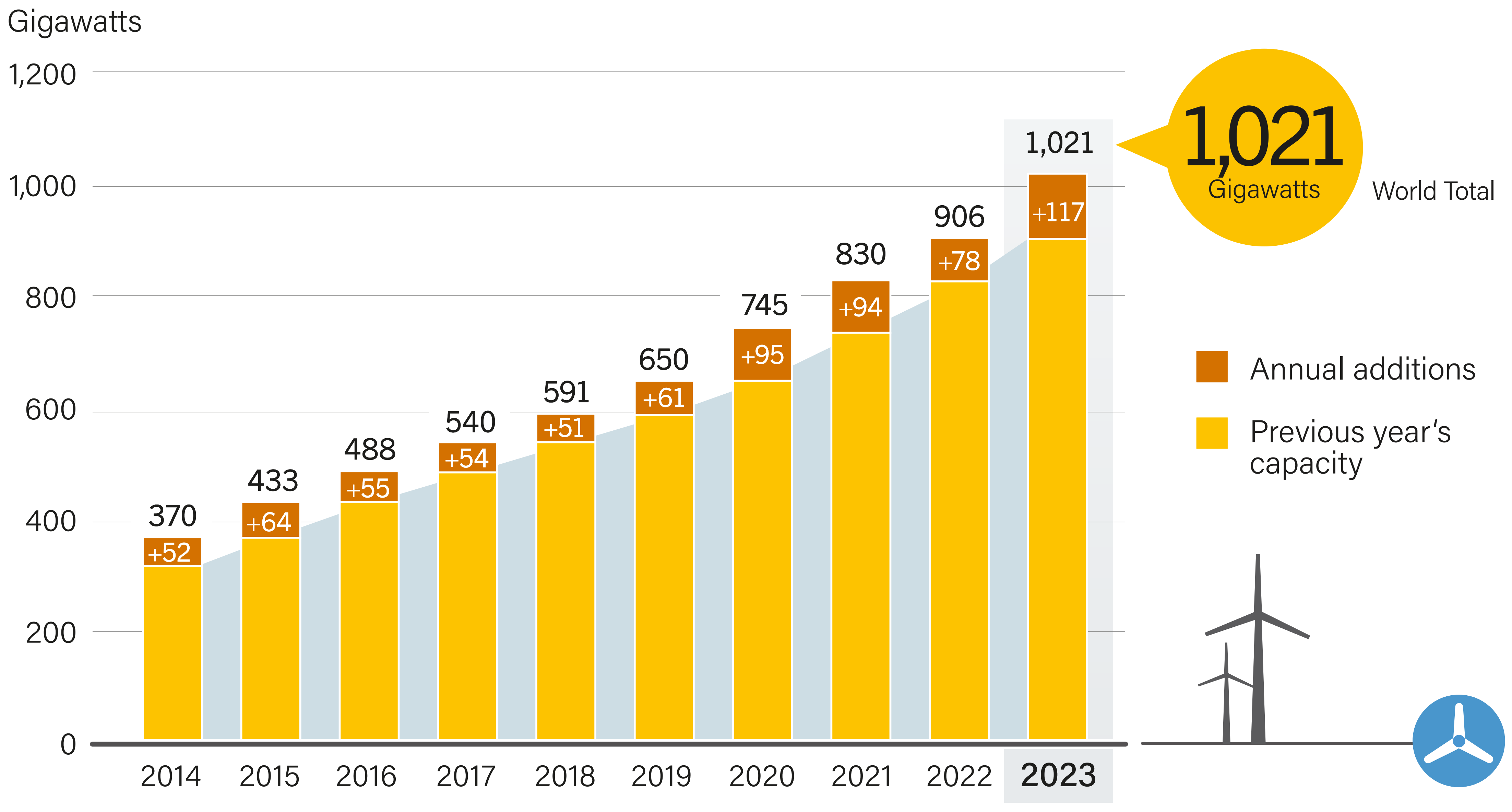
Several countries – including at least eight countries in Europe plus Uruguay – generated at least one-quarter of their electricity with wind in 2023.[5] Wind power continued to advance in new countries: Djibouti, Mauritania and the United Arab Emirates all installed their first (commercial-scale) projects.[6]

The top policy mechanisms supporting installations remained "grid parity" in China, tax credits in the United States, and auctions elsewhere, with feed-in tariffs (FITs) also playing a role.[7] In addition to an agreement by more than 130 countries to triple renewable energy capacity by 2030, countries around the world increased wind power targets, driven by climate change, energy security and economic growth goals, as well as the cost-competitiveness[ii] of wind energy.[8] Private sector power purchase agreements (PPAs) also continued to drive demand for new capacity in several countries.[9]

i The data in this section reflect wind power capacity that was grid-connected by the end of 2023. Including capacity that was mechanically installed in China, but not necessarily grid-connected, global wind power additions in 2023 were closer to 120 GW, with the year-end global total as high as 1,051 GW. "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 1 for this section.

ii Despite cost increases in recent years, wind power remains among the cheapest forms of electricity generation worldwide. Wind energy also can provide additional benefits. For example, a US government study found that the health and climate benefits of wind energy in the United States, plus the associated grid system value, far exceeded the levelised costs of wind energy in that country. See endnote 8 for this section.

FIGURE 33.
Wind Power Global Capacity and Annual Additions, 2014-2023



Note: Capacity is rounded to nearest GW and totals may not add up due to rounding. Data reflect grid-connected capacity, and additions are gross.

Source: See endnote 1 for this section.

Numerous **obstacles** continued to impede investments in supply chains and installations.

Despite the competitiveness of wind energy and ambitious targets, numerous obstacles continued to affect installations, the health of the wind industry and its ability to scale production to meet future demand.[10] These included ongoing subsidies for fossil fuels, which increased following the Russian Federation's invasion of Ukraine, and market frameworks that reward investment in fossil fuels.[11] The stop-start nature of many government auctions, a focus on price as the only determining factor, and failure to adapt bidding prices to the new macroeconomic environment in many cases have led to thin or negative margins for the wind industry.[12] Delayed permitting for new projects (due in part to local opposition, as well as cumbersome permitting processes) also has constrained deployment, as have protracted, complex and expensive grid planning and long grid-connection queues.[13] Such factors increase the variability of demand, inhibiting investment in supply chains and installations.[14]

For western companies, supply chain pressures, high commodity prices and shipping rates, as well as inflation further pushed up turbine prices and project costs[i,15] These challenges were compounded in 2023 by higher interest rates, long a barrier to renewables in low-income countries.[16] Because most investment occurs up front, higher borrowing costs put a brake on new wind power installations in Europe and the United States.[17]

Challenges were felt particularly in the offshore sector, where the supply chain is strongly concentrated, and where building turbines and related infrastructure far from shore requires significant time and money.[18] Stuck with supply contracts at prices that no longer covered their costs, developers cancelled contracts or projects for several gigawatts of capacity in US and European waters; in Asia, surging costs led Japanese developers to withdraw from projects in Taiwan.[19]

Developers' struggles, in turn, affected turbine manufacturers.[20] Even so, western manufacturers saw improvements in 2023, with GE Vernova (United States) and Siemens Gamesa (Germany) narrowing their losses, Nordex (Germany) breaking even, and Vestas (Denmark) returning to profitability thanks to record orders, higher turbine pricing and growth in the service sector.[21]

In China, by contrast, turbine prices reached new lows in 2023, despite record orders, due to the fiercely competitive domestic environment.[22] The country has developed a complete wind power supply chain to reduce costs and enable scaling of turbines, and thus is less affected by bottlenecks than other regions.[23] China's offshore industry has driven down wind power prices to match coal, even as prices in Europe and North America have risen.[24] However, the impact on China's largest turbine manufacturers has been shrinking profits: Goldwind, for example, saw profits fall 98% in the first nine months of 2023.[25]

i According to one estimate, wind project costs in Europe have increased 30-35% since before the COVID-19 pandemic. See endnote 15 for this section.

The industry notes that political ambition alone is insufficient to ramp up supply chain investment in order to build production facilities and grid and other necessary infrastructure, and to develop the workforce and advance innovation as required to deliver on global wind energy goals.[26] Governments have begun recognising the challenges and taking actions to speed permitting, provide grid access and keep investment flowing.[27] To address rising opposition, often due to mis- or dis-information as well as to valid local concerns, an increasing number of jurisdictions has enacted laws requiring wind farm investors to engage local communities[i,28]

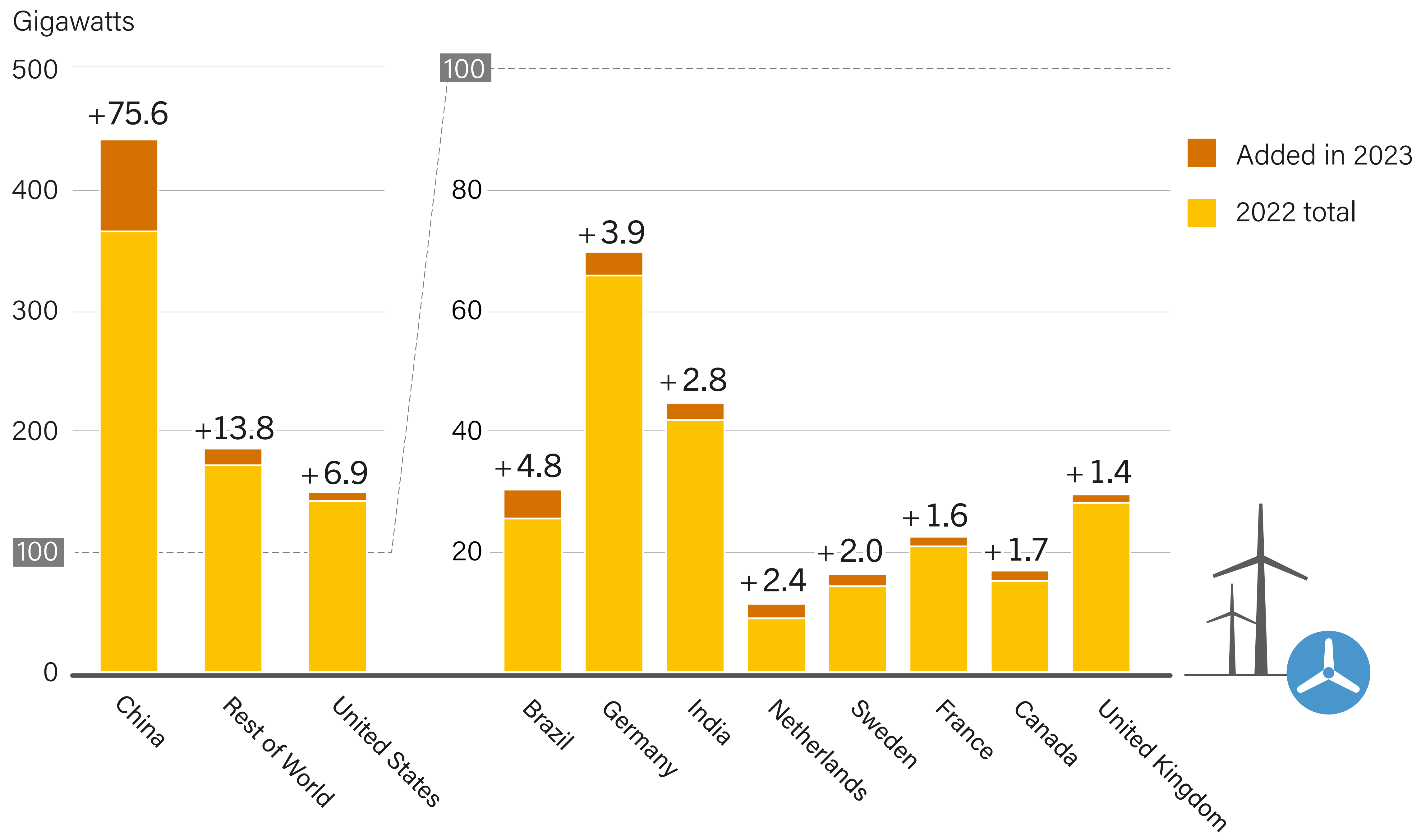
TOP MARKETS

New wind farms reached full commercial operation in at least 55 countries in 2023 (up from 45 in 2022).[29] For the 16th consecutive year, Asia was the largest regional market, representing nearly 70.3% of new grid-connected capacity (up from 55% in 2022).[30] Most of the remaining installations were in Europe (15.2%), North America (7.3%, down nearly 5 percentage points) and Latin America and the Caribbean (5.4%)[ii,31] The top five countries – China, the United States, Brazil, Germany and India – together accounted for more than 80% of annual installations.[32] Rounding out the top 10[iii] for additions were the Netherlands, Sweden, France, Canada and the United Kingdom.[33] (→ *See Figure 34.*) The list of the 10[iv] leading countries for cumulative capacity remained the same as in 2022.[34]

Two years after completing a shift from a national FIT to "grid parity"[v], **China**'s annual grid-tied installations doubled in 2023 to exceed 75.6 GW[vi] (69.3 MW onshore, 6.3 MW offshore).[35] China alone accounted for 65% of the global wind power market, up from 48.5% in 2022.[36] China's strong growth was thanks in part to the end of pandemic-era restrictions and a push to add renewables in deserts and interior regions.[37] The world's largest land-based wind farm (3 GW) began operating in Inner Mongolia.[38]

At year's end, China's total grid-connected wind power capacity was nearly 441.1 GW (403.3 GW onshore, 37.8 GW offshore), easily surpassing a government target of 430 GW set in late 2022.[39] Wind generation accounted for 9.5% of Chinese electricity production by the end of 2023 (up from 8.8% for all of 2022).[40]

FIGURE 34.
Wind Power Capacity and Additions, Top 10 Countries and Rest of World, 2023



Note: Data reflect grid-connected capacity only. Numbers above bars are gross additions, but bar heights reflect year-end totals. Net additions were lower for the United States (6.6 GW), Germany (3.4 GW) and France (1.5 GW) due to decommissioning. Totals may not add up due to rounding.

Source: See endnote 33 for this section.

i Some jurisdictions are engaging local communities through, for example, the offer of partial ownership in wind power projects, payments associated with wind power projects, or reduced electricity prices.

ii The regions of the Pacific and of Africa and the Middle East each accounted for less than 1% of global 2023 additions.

iii The top 10 markets changed relative to 2022, when they were China, the United States, Brazil, Germany, Finland, France, Sweden, India, the United Kingdom and Spain. To rank among the top 10 in 2023, annual installations of nearly 1.4 GW were required, about level with 1.4 GW in 2021, but down from 1.6 GW in 2022. See endnote 33 for this section.

iv The top 10 countries for cumulative capacity at the end of 2021, 2022 and 2023 were China, the United States, Germany, India, Spain, the United Kingdom, Brazil, France, Canada and Sweden.

v China's national FIT expired at the end of 2021. Under the "grid parity" scheme, all new wind projects receive the regulated price for coal-fired generation in each province.

vi The Chinese Wind Energy Association reported that 79.4 GW (72.2 GW onshore and 7.2 GW offshore) was mechanically installed during 2023, up from 50 GW in 2022, for a year-end total of 474.6 GW (of which 436.9 GW was onshore and 37.7 GW was offshore). See endnote 35 for this section.

China continued to dominate wind turbine manufacturing as well as the world's supply chain for critical components and raw materials.[41] Across the global supply chain (mining to transport to installation), China held 64% of the total value generated as of 2023.[42] Although most Chinese-made turbines (97%) were installed domestically in 2023, fierce competition at home has pushed manufacturers to turn elsewhere, and the competitive pricing and technological improvements of Chinese turbines have attracted increasing international interest[i].[43] Ten of the world's top 15 turbine producers were based in China, with Goldwind and Envision placing first and second globally; the remaining five were Vestas, which ranked third, followed by Siemens Gamesa, GE, Nordex and Enercon (Germany).[44]

The **United States** continued to rank second for wind power additions and cumulative capacity, adding 6.9 GW (6.6 GW net[ii]) for a total of 150.9 GW (almost all onshore).[45] However, US installations fell more than 25%, to their lowest level since 2014 and well below the 2020 peak of 16.9 GW.[46] The slower pace in 2023 was due to several factors, including inflation, higher borrowing costs, supply chain challenges, policy uncertainty, market saturation in some areas, long waits in interconnection queues[iii] and permitting delays.[47] Rising local opposition to renewable projects, including bans and moratoria, also slowed deployment.[48]

US wind power generation also declined in 2023 (from almost 10.3% in 2022 to just below 10.2%) for the first time since the 1990s, due to slower-than-normal wind speeds[iv].[49] Despite the lower share nationally, wind energy was the largest source of electricity in 4 US states and accounted for more than 20% of generation in 12 states.[50]

At year's end, US capacity under construction approached 17.6 GW (mostly onshore), and capacity in advanced development neared 28.7 GW (64% offshore).[51] A surge in turbine orders during the year provided a sign that the federal Inflation Reduction Act (IRA) could accelerate installations.[52]

For the fourth consecutive year, **Brazil** ranked third for new capacity. Wind represented almost 48% of the country's new power capacity, with record installations exceeding 4.8 GW (up 18.5% relative to 2022), for a total surpassing 30.4 GW.[53] Brazil accounted for more than three-fourths of the total additions in Latin America and the Caribbean.[54] The country's strong growth was driven primarily by the free market through private PPAs.[55]

Wind energy was Brazil's second largest source of electricity after hydropower in 2023, accounting for 14.2% of generation.[56] Most of this electricity is produced in the country's north-east, far from population centres and hydropower resources.[57] To link these regions and increase wind (and solar) energy penetration, Brazil is investing heavily in new transmission infrastructure, with auctions held in late 2023 and early 2024.[58]

India rose three spots in 2023 to place fifth for additions, after Germany.[59] Following a 26.6% increase in 2022, India's wind market rose 52% to 2.8 GW, bringing cumulative capacity to 44.7 GW (all onshore).[60] This was the strongest year for additions since India shifted from a FIT system to reverse auctions in 2017, although the policy focus on minimising price has continued to strain investors and the domestic supply chain.[61] Wind energy's share of generation for the year was around 4.8%.[62]

During 2023, 21 GW of wind power capacity was publicly tendered in India.[63] The year also saw increased interest in PPAs among industrial and commercial consumers.[64]

i Chinese turbine manufacturers installed 2.3 GW of turbines outside of China in 2023, with 63% of that in Asia; 97% of installations by Chinese companies were installed domestically, as in 2022. China's turbine prices are about 20% below those of European and US companies' machines. See endnote 43 for this section.

ii This figure is net of the 325 MW of onshore wind power capacity that was decommissioned in 2023. In addition, eight onshore projects were partially repowered (286 MW) during the year, and four projects completed full repowering (417 MW). By one estimate, repowering of US projects that are 12 years or older can bring about capacity factor gains of 10-20%. See endnote 45 for this section.

iii Wind power accounted for 366 GW of capacity actively waiting in US interconnection queues at the end of 2023. See endnote 47 for this section.

iv The slower winds (following a year of stronger than normal winds) were reportedly due to El Niño, which weakened winds across much of the United States and particularly in the Midwest, where a large portion of US wind turbines is operating. As a result, the average US capacity factor in 2023 was 33.5%, down from a high of 35.9% in 2022. See endnote 49 for this section.

An average of 15 GW per year will be needed to achieve the national wind power target (140 GW) for 2030.[65]

By region, **Europe** placed second and accounted for all of the remaining top 10 countries, with the exception of Canada.[66] Europe added nearly 17.8 GW (net 17 GW[i]), most of which was installed onshore (78.6%), for a total of 260 GW (225.8 GW onshore, 34.2 GW offshore).[67] Additions were slightly (0.5%) below the record installations in 2022 but, excluding Germany, Europe's annual gross additions fell more than 8%.[68] Seven European countries installed more than 1 GW, while 16 (including 7 European Union (EU) Member States) did not add any capacity in 2023.[69]

The region's top markets – Germany, the Netherlands, Sweden, France and the United Kingdom – together accounted for 63% of Europe's 2023 installations.[70] Additions increased significantly in Germany and the Netherlands, but declined in the other three countries.[71]

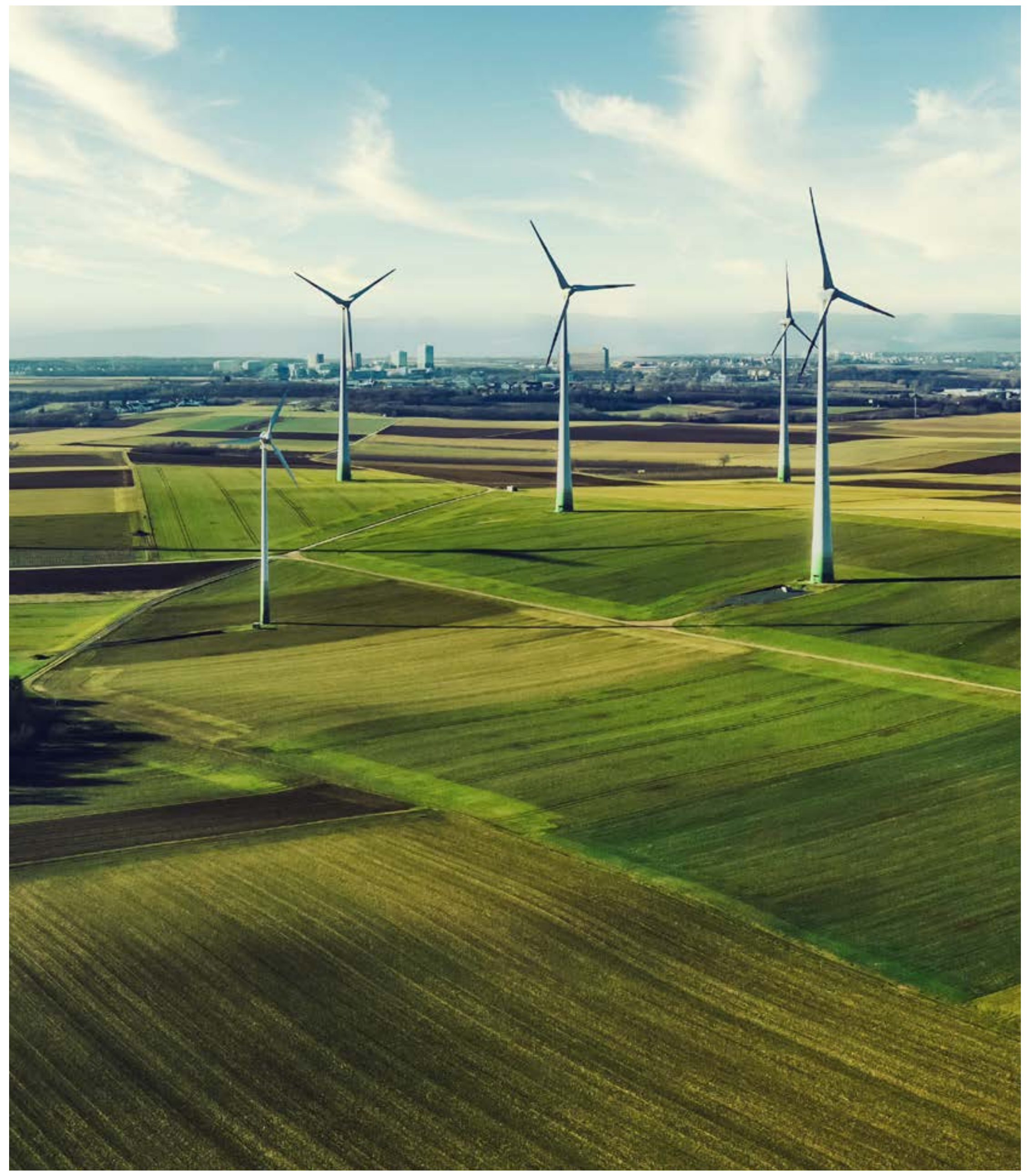
The EU added a record 16 GW (13.1 GW onshore, 2.9 GW offshore; net 15.3 GW) to total 220.1 GW (200.7 GW onshore, 19.4 GW offshore).[72] Although annual installations remained well below what is needed to achieve EU targets[ii] for 2030, investments in new wind projects more than doubled relative to 2022, when investment fell to its lowest level since 2009.[73]

Several actions in 2023 and early 2024 improved the situation for EU wind power markets and industry moving forward. Many more permits than ever before were approved for onshore projects, thanks to new regional permitting rules, with both Germany and Spain seeing 70% increases over 2022.[74] In October, the European Commission unveiled a plan[iii] to accelerate installations and strengthen the competitiveness of the region's turbine manufacturing industry to create quality jobs and enhance energy security.[75] Two months later, 26 EU Member States (not Hungary) committed to implementing several actions[iv] including: streamlined permitting rules; auction prices indexed to reflect cost increases; long-term visibility of auction schedules; and steps to unlock investments in wind energy's value chain and necessary infrastructure.[76] However, auctions continued to exclude smaller locally based investors, including local co-operatives; some experts argue that their inclusion could counter local protests and help speed permitting.[77] In early 2024, final agreement was reached on the Net Zero Industry Act, which, among others, targets 36 GW of turbine manufacturing in Europe annually and includes non-price award criteria (such as sustainability and supply chain resilience) in selection of winning bids at auction.[78]

Nonetheless, challenges continued during 2023, with new threats arising. Hundreds of gigawatts of wind power capacity were awaiting grid connection, and as of October the EU had four times more capacity awaiting permits than under construction.[79] The year also saw numerous acts of sabotage, leading governments and companies to begin monitoring and securing wind farms and related infrastructure, particularly offshore.[80]

Germany again claimed Europe's top spot for additions in 2023 and ranked fourth globally after Brazil.[81] The country installed 3.9 GW (3.6 MW onshore, 0.3 GW offshore; 3.4 GW net) for a year-end total nearing 69.7 GW (more than 61.1 GW onshore, 8.5 GW offshore).[82] Onshore installations, up 48% over 2022, were the highest in a single year since 2017, just before Germany's FIT system expired; however, additions remained well below the 2017 peak (6.1 GW).[83] Further increases in annual installations will be needed to achieve new federal wind power targets of 115 GW onshore and 30 GW offshore by 2030.[84]

Improvements in Germany's market have followed the adoption (since 2021) of several laws to end reliance on Russian fossil fuels and to accelerate renewable energy deployment; these included ambitious annual installation goals, adjusted prices in auctions to account for rising costs, and measures to reduce permitting challenges.[85] Although EU legislation on energy communities had not been implemented at the federal level by the end of 2023, several German states had adopted (or were considering) community energy legislation.[86]



i The difference is due to decommissioning.

ii The REPowerEU strategy calls for 420 GW of wind power capacity by 2030. See endnote 73 for this section.

iii The European Wind Power Action Plan aims to address several challenges facing the region's wind industry, including "insufficient and uncertain demand, slow and complex permitting, lack of access to raw materials, high inflation and commodity prices, unsupportive design of national tenders, increased pressure from international competitors and risks on availability of a skilled workforce." See endnote 75 for this section.

iv The commitments were made under the European Wind Charter. See endnote 76 for this section.

Following Germany for new wind power capacity was the **Netherlands**, which installed a record 2.4 GW to rank sixth worldwide.[87] With around 0.5 GW added onshore and 1.9 GW added offshore, the country increased its total capacity 26%, to nearly 11.5 GW.[88] Having surpassed a 4.5 GW offshore target by the end of 2023, the Netherlands aims to reach 21 GW by the end of 2032.[89]

Annual installations in **Sweden** fell slightly, with nearly 2 GW added (all onshore) for a total of 16.4 GW.[90] The country ranked third in Europe and seventh globally for new capacity.[91] Sweden does not use auctions to deploy wind power capacity, but the domestic industry is supported by a strong PPA market.[92] Additional capacity made up for less favourable wind conditions during the year, increasing total wind generation by 4.5% (34.5 TWh).[93]

France had its second strongest year, ranking eighth worldwide for installations.[94] Additions of 1.6 GW (1.2 GW onshore, nearly 0.4 GW offshore) brought total capacity to 22.6 GW (mostly onshore).[95] France's first national renewable energy law came into force in early 2023, improving auction conditions in order to accelerate wind (and solar) installations.[96] The country was second in Europe, after Germany, for awarded capacity (4.2 GW) via auctions in 2023.[97] Wind energy generated a record 50.7 TWh and met an estimated 10.2% of France's electricity demand during the year.[98]

Despite a 17.5% decline in additions relative to 2022 (following a 36.4% decline in 2022), the **United Kingdom** continued to rank among the top countries in Europe (fifth) and the world (tenth), with 1.4 GW added.[99] Onshore additions, almost entirely in Scotland, remained constant (0.5 GW), while offshore installations fell to 0.8 GW.[100] In the final quarter of 2023, wind energy generated more electricity than gas and provided more than half (51.5%) of UK generation.[101]

Over the past two decades, the EU has seen a consistent increase[i] in wind energy's output and share of electricity demand.[102] Despite relatively poor wind conditions in 2023, wind generation rose 3% to a new record and met 19% of EU electricity demand[ii] (16.8% onshore, 2.2% offshore).[103] Across all Europe, Denmark (56%) and Ireland (36%) had the highest wind shares in their electricity mix, and wind energy met or exceeded 20% of electricity demand in the United Kingdom (28.7%); Germany, the Netherlands and Spain (all 27%); Sweden and Portugal (both 26%); Lithuania (21%); and Greece (20%).[104] At year's end, Germany continued to lead in Europe for total wind power capacity, with 69.7 GW, followed by Spain (30.6 GW), the United Kingdom (29.6 GW), France (22.6 GW) and Sweden (16.4 GW).[105]

Canada rejoined the global top 10 for the first time since 2018, placing ninth after France.[106] More than 1.7 GW of utility-scale wind capacity came online in 2023, up 71% over 2022 and the most since 2014, although this was short of the estimated annual installations required to achieve Canada's net zero targets.[107] Most new capacity was installed in Alberta, with small amounts in the Yukon, the Northwest Territories and New Brunswick; other provinces had no additions due to the lack of centralised procurement policies and of corporate PPA options.[108] At year's end, Canada had a total of 17 GW of wind power capacity.[109] Wind energy generated 6.4% of Canada's electricity in 2023 (up from 6.1% in 2022).[110]

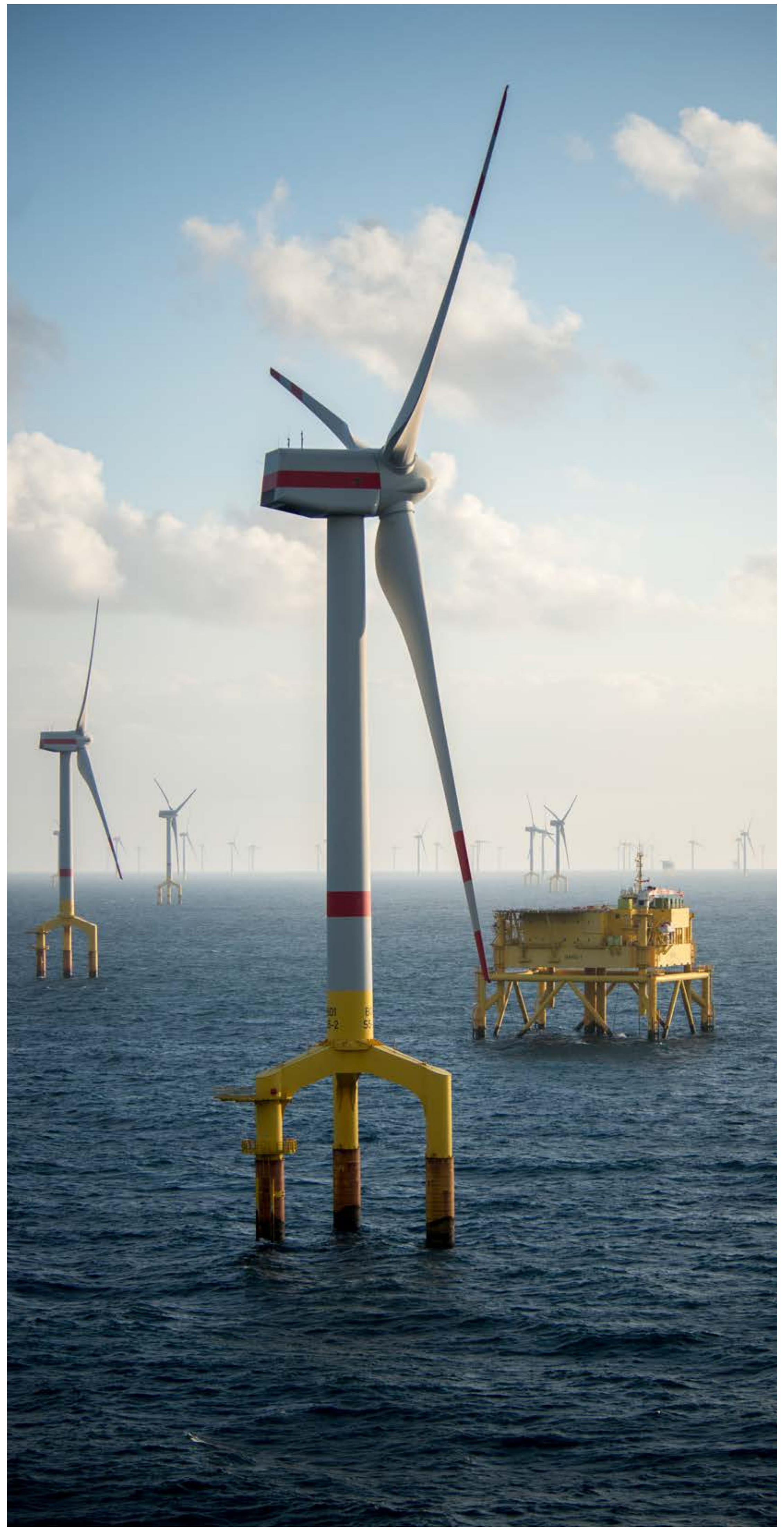
The Netherlands increased its total installed wind power capacity by

26%

in 2023.

i The year 2021 was an exception, with wind energy's output down relative to 2020 due to poor wind conditions.

ii EU electricity demand was down 4% relative to 2022. See endnote 103 for this section.



OFFSHORE WIND

Offshore, seven countries in Europe and four in Asia added 10.9 GW of wind power capacity in 2023, for a global total of 75.2 GW.[111] Turbines operating offshore accounted for over 9% of new grid-connected wind power capacity in 2023 and represented nearly 7.4% of the total at year's end.[112]

China led the sector for the sixth consecutive year, adding 6.3 GW to end 2023 with 37.8 GW, overtaking all of Europe.[113] China's 25% market increase followed a dramatic 2022 decline that was due mostly to a slowdown after a rush to commission projects before the national FIT expired (end-2021), as well as to pandemic-related restrictions.[114]

Elsewhere in Asia, Taiwan ranked second for new capacity, adding 0.7 GW for a total of 2.1 GW.[115] Japan and the Republic of Korea also added capacity in 2023.[116] On the first day of 2024, Japan completed its largest commercial offshore project (112 MW), paired with battery storage capacity.[117] Also in 2023, India unveiled a strategy to award leases for up to 37 GW by 2030, and the Philippines signed contracts for development rights for two offshore wind farms totalling 440 MW.[118]

Following a significant decline in 2022, **Europe** had a record year for offshore wind installations, with 3.8 GW of new capacity connected to the grid.[119] The Netherlands (1.9 GW) accounted for half of Europe's additions and ended the year with the world's largest operating offshore wind farm (1.5 GW).[120] Others to add capacity were the United Kingdom (833 MW), France (360 MW), Denmark (344 MW), Germany (329 MW), and Norway (35 MW), which completed the world's largest floating offshore project (95 MW).[121]

In Europe, a record USD 33.1 billion (EUR 30 billion) was invested in offshore wind, following a low of USD 0.44 billion (EUR 0.4 billion) in 2022, in a sign that delayed projects were moving ahead.[122] However, the news was not all good: developers paused or scrapped projects in the United Kingdom in response to grid infrastructure challenges and soaring costs; Iberdrola cancelled its flagship floating pilot in Spain; and Equinor postponed indefinitely a floating project in Norway due to technology availability challenges and rising costs.[123] After receiving no bids in its offshore auction, the UK government raised the ceiling price for the next auction to account for inflation and higher input prices.[124]

At year's end, Europe's offshore wind power capacity totalled 34.2 GW across 13 countries.[125] The region's floating wind power capacity rose 37 MW to 208 MW, accounting for 88% of global installations.[126] European countries targeted a combined 120 GW of offshore wind capacity in northern sea areas by 2030, and the EU targeted more than 215 GW by 2040.[127] To reach offshore wind targets for 2030, Europe will need to build far more capacity than the existing supply chain can manufacture each year (around 7 GW annually).[128]

The initial turbines of the **United States'** first two commercial-scale offshore wind farms[i] began feeding electricity to the grid in December 2023 and early January 2024.[129] Also in 2023, the US state of Louisiana signed agreements for the first projects in the Gulf of Mexico, and California enacted a law paving the way for its first offshore wind farm and joined the Global Offshore Wind Alliance[ii], adopting a state target of 25 GW by 2045.[130] At year's end, 11 US states had combined procurement targets totalling 84 GW; more than 4 GW of capacity was newly procured in 2023, but cancellations drove down the net total.[131]

i The South Fork Wind project (132 MW) off the coast of New York became the first commercial-scale US wind farm with its completion in March 2024. Two additional projects were under construction in 2023: Vineyard Wind (806 MW) in Massachusetts, and Revolution Wind (704 MW), which will supply electricity to Connecticut and Rhode Island. See endnote 129 for this section.

ii The Global Offshore Wind Alliance was launched in 2022 and has 13 member countries (Australia, Belgium, Colombia, Denmark, Germany, Ireland, Japan, Netherlands, Norway, Portugal, Spain, the United Kingdom, the United States). It aims to contribute to achieving total global offshore wind power capacity of at least 380 GW by 2030. See endnote 130 for this section.

Overall, it was a turbulent year for US offshore wind, with more than 12 GW of contracts (half the country's offshore pipeline) cancelled or targeted for renegotiation, due to soaring costs, high interest rates, and supply chain delays, with developers forced to write down billions of dollars of investments.[132]

The lack of a US supply chain exposes developers to global market pressures, while the year's challenges[i] slowed investment in the supply chain's progress.[133] In an effort to get the sector back on course, several eastern US states[ii] and federal agencies agreed to co-ordinate their project procurement and supply chain development.[134]

Several governments around the world added or increased targets for future offshore wind power capacity in 2023.[135] A record 39.4 GW of offshore capacity was awarded during the year, including 18.2 GW in China under the "grid parity" mechanism, and the remaining 21.2 GW through auctions in Europe (15.5 GW), the United States (4 GW) and Japan (1.4 GW).[136] The global pipeline for floating wind power capacity rose 32%, from 185 GW in late 2022 to 244 GW in late 2023, with most development in Europe.[137]

By the end of 2023, as in 2022, 19 countries (13 in Europe, 5 in Asia and 1 in North America) had at least some offshore wind capacity in operation.[138] China led in total capacity (37.8 GW), followed distantly by the United Kingdom (14.8 GW), Germany (8.5 GW), the Netherlands (4.7 GW) and Denmark (2.7 GW).[139] Asia (mostly China) was home to nearly 55% of the total.[140]

TECHNOLOGY AND INNOVATION

Innovation in the wind power industry is constantly progressing, particularly in the offshore sector, where turbines are moving farther from shore and are exposed to extreme weather.[141] Companies are testing new manufacturing approaches and materials, and new commercial structures, to meet demand and operate in an ever-more competitive environment.[142] Advances are driven mainly by firms in Asia and Europe, largely in response to price pressure, with activity focused on logistical capacities, floating foundations and green hydrogen production.[143]

The upward trend in turbine sizes continued, as a means to optimise cost and performance[iii], with the average turbine delivered to market in 2023 exceeding 5 MW, up 22% over 2022.[144] The industry continued to push turbine sizes ever larger in order to increase per unit output, achieve ambitious government targets and thrive in an increasingly competitive market.[145] For onshore use, several Chinese manufacturers announced new turbines with capacities in the 10-12 MW range, and SANY launched a 15 MW machine.[146] Newer turbine models for offshore use were in the 14 to 18 MW range, with plans unveiled for turbines rated up to 22 MW, including a model that would stand taller than the Eiffel Tower.[147]

Rapid innovation and up-scaling of turbines as manufacturers seek to outdo one another, often without sufficient research and development, has led to problems ranging from operational inefficiencies, to an undermining of business profitability, to turbine failures.[148] In 2023, quality issues arose with rotor blades and bearings for two of Siemens Gamesa's onshore turbine platforms because they were not sufficiently tested; fixing them was expected to cost the company USD 1.8 billion (EUR 1.6 billion).[149] Vessel builders, logistics planners and others are increasingly challenged to adapt as turbine sizes grow ever larger and become more specialised.[150]

Some western manufacturers have begun shifting their focus from up-scaling turbines to standardising supply chains and product lines in order to optimise technology and support a resilient and sustainable path of development.[151] In 2023, Vestas and Siemens Gamesa[iv] partnered to increase standardisation – starting with equipment for tower transport – to reduce costs and speed shipping.[152] In early 2024, GE Vernova cancelled plans for its 18 MW machine to focus on a smaller platform while upgrading its turbines and improving efficiency.[153]

Manufacturers aim to balance the quest for ever-greater economies of scale with quality and speed of manufacturing.

i Additional challenges that hampered the industry included uncertainty regarding rules related to federal tax credits and the lack of installation vessels, for which some developers face multi-year delays. See endnote 133 for this section.

ii In early 2024, some US states offered opportunities for developers to rebid at auction and adopted inflation-adjustment mechanisms, and by late February the industry was on track to replace the contracts that faltered in 2023, amounting to up to 15.5 GW. However, in April, GE Vernova's decision to abandon its 18 MW turbine led New York State to cancel power contracts for three offshore projects that had planned to use the machines; the anticipated project costs and environmental impacts were based on deploying this turbine. See endnote 134 for this section.

iii 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 (at least in theory) faster project development, reduced risk, lower costs of grid-connection and of operation and maintenance, and overall greater yield and lower levelised cost of energy, all important for the offshore sector in particular. See endnote 144 for this section.

iv While acknowledging that slowing new product introduction might help the industry overall and that there is a rethink underway about whether bigger is really better, as of early 2024, Siemens Gamesa was planning to install a 21 MW prototype (awarded through the European Commission Innovation Funds) during the year, reflecting the unrelenting pressure to rapidly innovate and scale up machines while attempting to balance the quest for ever-greater economies of scale with turbine quality and speed of manufacturing. See endnote 152 for this section.

CHALLENGES & OPPORTUNITIES

CHALLENGES

Renewables are not being deployed at a fast enough rate to meet climate targets and international pledges.

- In most economies, renewables are competing with **heavily subsidised fossil fuels**. Additionally, across most regions, fossil fuel prices are lower than electricity prices, hindering the energy transition.
- Deployment of renewables is delayed by **slow permitting and expensive grid planning**.
- Renewable energy companies are facing new challenges such as **high interest rates, inflation, supply chain disruptions and shrinking profits**.
- Renewable heat and fuel resources and technologies still **lack the awareness required to scale up** and are not receiving comprehensive and integrated policy support.
- Renewables development is **not happening at the same rate** across regions, technologies and carriers.

OPPORTUNITIES

- Renewable energy can mitigate **climate change, improve energy security, create jobs and boost local and national economies**.
- The wide range of renewable energy resources can meet the demand of a variety of applications even in **energy-intensive industry and transport**.
- Regional interconnections, grid planning, improved storage solutions and sector coupling can help integrate a **higher share of renewables** into the energy system.
- **Thirty countries have more than a 50% renewable energy share** in their electricity mix, and 12 countries have more than a 30% solar PV and wind power share in their electricity mix.
- Countries are taking concrete steps to improve **local supply chains** for renewables to **maximise the economic and social value from renewable energy**.
- At COP 28 in Dubai, more than **130 countries committed to triple renewable energy generation capacity** and to double the rate of energy efficiency improvements by 2030.
- In 2023, the renewable power sector saw **record capacity additions** with 536 GW newly installed.

TECHNOLOGY-SPECIFIC **CHALLENGES**

- The **lack of consistent and predictable regulations** along with harmonised standards among geographies are hindering the growth of investments in the bioenergy sector.
- **High exploration and development risk**, along with limited availability of rich and accessible resources, has limited geothermal technology to relatively few and highly localised regions worldwide.
- **Droughts** in top hydropower generating countries led to a 5% decrease in production in 2023 and a global net capacity factor of 39%.
- Although policy makers in many countries are focusing increasingly on the heating sector, policies tend to support the electrification of heating (and cooling) and to **overlook the enormous potential of the direct use of solar thermal energy**.
- For western companies, supply chain pressures and inflation helped push up wind turbine prices and project costs, while higher interest rates also slowed new installations. **Fierce competition** among turbine manufacturers drove prices to new lows but is also leading to **shrinking profits** among the largest manufacturers.

TECHNOLOGY-SPECIFIC **OPPORTUNITIES**

- **The availability of diverse biomass feedstocks**, including agricultural residues, forestry by-products, energy crops, and organic waste, makes bioenergy adaptable to various markets and regions.
- With continued progress, both enhanced geothermal systems (EGS) and closed-loop systems **could expand vastly** the regions of the world where deep geothermal energy can be harnessed economically for thermal applications and power.
- Heat pumps **hold large potential for demand response initiatives** and are expected to play a crucial role in a smarter, digitised and more electrified energy system. While still in the early stages of development, industrial heat pumps represent a promising and emerging technology in the field.
- The rooftop solar PV market has increased steadily since 2018 and experienced a **record 180 GW of additions in 2023** as the market became more attractive for both residential and commercial customers.
- Around the world, countries have **increased their targets for wind power capacity and generation**, driven by climate change, energy security and economic growth goals, as well as the **cost-competitiveness** of wind energy.

ENDNOTES | MODULE OVERVIEW

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ENDNOTES | SOLAR PV

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ENDNOTES | SOLAR THERMAL HEATING

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9 W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide; F. Stier, "Producers Point to Forced Electrification and Cheap Natural Gas as Barriers for Solar Thermal in the US", Solar Thermal World, 30 August 2023, https://solarthermalworld.org/news/producers-point-to-forced-electrification-and-cheap-natural-gas-as-barriers-for-solar-thermal-in-the-us; see also B. Epp, "'Large-scale Plants Are a New League That Solar Companies Alone Cannot Handle'", Solar Thermal World, 23 April 2024, https://solarthermalworld.org/news/large-scale-plants-are-a-new-league-that-solar-companies-alone-cannot-handle.

10 B. Epp, solrico, personal communication with REN21, 10 May 2023. See, for example, the following: B. Epp, "Welcome to a New Year and Another Chance for Solar Heat to Get Big", Solar Thermal World, 17 January 2023, https://solarthermalworld.org/news/welcome-to-a-new-year-and-another-chance-for-solar-heat-to-get-big; F. Stier, "Feasibility Studies for Large Solar Heat Plants Totalling Almost 1 Million M2 Underway", Solar Thermal World, 6 April 2023, https://solarthermalworld.org/news/feasibility-studies-for-large-solar-heat-plants-totalling-almost-1-million-m2-underway; B. Epp, "Big Solar Heat Deal in the Chilean Copper Sector

Made Possible by Two People", Solar Thermal World, 23 February 2024, https://solarthermalworld.org/news/big-solar-heat-deal-in-the-chilean-copper-sector-made-possible-by-two-people; B. Epp, "Construction Imminent on 77 MW Solar Heat Plant for Leisure Resort", Solar Thermal World, 30 April 2022, https://solarthermalworld.org/news/construction-imminent-on-77-mw-solar-heat-plant-for-leisure-resort; B. Epp, "37 MW Solar District Heating Plant in the Netherlands with Outstanding Features", Solar Thermal World, 11 November 2022, https://solarthermalworld.org/news/37-mw-solar-district-heating-plant-in-the-netherlands-with-outstanding-features.

11 Top countries in 2023, China's share (65.2%) and **Figure 32** based on data from W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide, and from M. Spörk-Dür, AEE – Institute for Sustainable Technologies, personal communication with REN21, March–May 2024, as well as on data from country contributors provided in endnote 3, and on data for Brazil from D. Johann, Associação Brasileira de Energia Solar Térmica (ABRASOL), personal communication with REN21, 2 April 2024, and from ABRASOL, "Solar Heating Systems Production and Sales 2024 (Database 2023)", May 2024, https://abrasol.org.br/wp-content/uploads/2024/05/Solar-Heating-Systems-Production-and-Sales-2024.pdf. Data for top 20 countries are based on the latest market data available for gross additions of glazed and unglazed water collectors (not including concentrating, PV-thermal and air collectors), at the time of publication, for countries that together represent around 95% of the world total. In 2022, the top countries for new installations were China, Türkiye, Brazil, India and the United States, from Weiss and Spörk-Dür, op. cit. this note.

12 Share (73.2%) of cumulative capacity in China based on Chinese Solar Thermal Industry Federation, "2023 China Solar Thermal Industry Operation Status Report", 8 December 2023, https://mp.weixin.qq.com/s/sfgpH30oJEJGEcnkFhPfww (using Google Translate), and on totals for China and the world from W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide, and from M. Spörk-Dür, AEE – Institute for Sustainable Technologies, personal communication with REN21, March–May 2024; top five countries and ranking based on data from Weiss and Spörk-Dür, op. cit. this note, from Spörk-Dür, op. cit. this note, and on additions and cumulative data for top 20 countries from sources cited throughout this section.

13 W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2022, Detailed Market Figures 2021, 2023 Edition", International Energy Agency Solar Heating and Cooling Programme, May 2023, p. 9, https://www.iea-shc.org/solar-heat-worldwide.

14 W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide; M. Spörk-Dür, AEE – Institute for Sustainable Technologies, personal communication with REN21, March–May 2024; Chinese Solar Thermal Industry Federation, "2023 China Solar Thermal Industry Operation Status Report", 8 December 2023, https://mp.weixin.qq.com/s/sfgpH30oJEJGEcnkFhPfww (using Google Translate).

15 China added 13,727.3 MW_{th} (including 3,554.6 MW_{th} flat plate and 10,172.7 MW_{th} of vacuum tubes) in 2023 for a year-end total of 410.1 GW_{th}, from W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide, from M. Spörk-Dür, AEE – Institute for Sustainable Technologies, personal communication with REN21, March–May 2024, and based on data from Chinese Solar Thermal Industry Federation (CSTIF), "2023 China Solar Thermal Industry Operation Status Report", 8 December 2023, https://mp.weixin.qq.com/s/sfgpH30oJEJGEcnkFhPfww (using Google Translate). China added 21.898 million m^2 of collector area (15.3 GW_{th}) in 2023 for a year-end total of 628 million m^2 (628 GW_{th}), from CSTIF, idem. Note that CSTIF data include vacuum tube collectors that were exported; Weiss and Spörk-Dür assume that all vacuum tube collectors in the world market were from China, with the exception of those from three companies producing vacuum tubes in Türkiye; they also assume 15-year lifespans for collectors in China, from Spörk-Dür, op. cit. this note.

16 Chinese Solar Thermal Industry Federation, "2023 China Solar Thermal Industry Operation Status Report", 8 December 2023, https://mp.weixin.qq.com/s/sfgpH30oJEJGEcnkFhPfww (using Google Translate).

17 Figure of 1.1 billion based on 1.096 billion tonnes (and 30,484 GWh of electricity), from Chinese Solar Thermal Industry Federation, "2023 China Solar Thermal Industry Operation Status Report", 8 December 2023, https://mp.weixin.qq.com/s/sfgpH30oJEJGEcnkFhPfww (using Google Translate).

18 W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide; M. Spörk-Dür, AEE – Institute for Sustainable Technologies, personal communication with REN21, March–May 2024; Chinese Solar Thermal Industry Federation (CSTIF), "2023 China Solar Thermal Industry Operation Status Report", 8 December 2023, https://mp.weixin.qq.com/s/sfgpH30oJEJGEcnkFhPfww (using Google Translate). Sales of vacuum tubes accounted for 76.8% (16.82 million m^2, 11.8 GW_{th}) and flat plate sales fell 11.8% relative to 2022 and accounted for 23.2% (5.078 million m^2, 3.6 GW_{th}), from CSTIF, idem.

19 Figure of 76.3% in the engineered market (and 23.7% in the retail market) in 2023 from Chinese Solar Thermal Industry Federation, "2023 China Solar Thermal Industry Operation Status Report", 8 December 2023, https://mp.weixin.qq.com/s/sfgpH30oJEJGEcnkFhPfww (using Google Translate); 83% in 2022 from Sun Realm Think Tank, "'2022 China Solar Thermal Industry Operation Status Report' officially released", 16 March 2023, https://mp.weixin.qq.com/s/1jXYS-8iMpstP2-3ddSerw (using Google Translate). The 2022 shares are based on a sample survey of enterprises in several provinces and key regions of China, from Sun Realm Think Tank, idem.

20 Chinese Solar Thermal Industry Federation, "2023 China Solar Thermal Industry Operation Status Report", 8 December 2023, https://mp.weixin.qq.com/s/sfgpH30oJEJGEcnkFhPfww (using Google Translate).

21 Decline in 2022 based on data from J. Malaviya, Malaviya Solar Energy Consultancy, personal communication with REN21, March 2023; increase in 2023 based on data from J. Malaviya, Malaviya Solar Energy Consultancy, cited in B. Epp, "Signs of Growth in India Solar Thermal Market", Solar Thermal World, 3 April 2024, https://solarthermalworld.org/news/signs-of-growth-in-indian-solar-thermal-market, from W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide, and from M. Spörk-Dür, AEE – Institute for Sustainable Technologies, personal communication with REN21, March–May 2024.

22 Based on data from J. Malaviya, cited in B. Epp, "Signs of Growth in India Solar Thermal Market", Solar Thermal World, 3 April 2024, https://solarthermalworld.org/news/signs-of-growth-in-indian-solar-thermal-market.

23 Additions and year-end total (water collectors only) from W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide, and from M. Spörk-Dür, AEE – Institute for Sustainable Technologies, personal communication with REN21, March–May 2024. India ended 2023 with 21,181,710 m^2 of collector area (4,304,426 m^2 of flat plate and 16,877,284 m^2 of vacuum tube) in operation, equivalent to 14.8 GW_{th}, from both sources in this note.

24 Based on data from J. Malaviya, cited in B. Epp, "Signs of Growth in India Solar Thermal Market", Solar Thermal World, 3 April 2024, https://solarthermalworld.org/news/signs-of-growth-in-indian-solar-thermal-market.

25 Based on data from D. Johann, Associação Brasileira de Energia Solar Térmica (ABRASOL), personal communication with REN21, 2 April 2024, and from ABRASOL, "Solar Heating Systems Production and Sales 2024 (Database 2023)", May 2024, https://abrasol.org.br/wp-content/uploads/2024/05/Solar-Heating-Systems-Production-and-Sales-2024.pdf; record additions based on installations in 2021 and 2023, from ABRASOL, idem, and on 2021 installations then being a record high, from ABRASOL, "Produção de aquecedor solar de água cresce 28% em 2021", Boletim 24, February 2022, https://abrasol.org.br/boletim-i-fevereiro-i-no24-2022-2 (using Google Translate). In 2023, Brazil added 925,065 m^2 of glazed collector area, 862,311 m^2 of unglazed collectors and 43,080 m^2 of vacuum tube collectors (bringing total additions to 1,830,456 m^2), from ABRASOL, "Solar Heating Systems...", op. cit. this note.

26 Based on data from Associação Brasileira de Energia Solar Térmica (ABRASOL), "Solar Heating Systems Production and Sales 2024 (Database 2023)", May 2024, https://abrasol.org.br/wp-content/uploads/2024/05/Solar-Heating-Systems-Production-and-Sales-2024.pdf.

27 Based on data from Associação Brasileria de Energia Solar Térmica (ABRASOL), "Solar Heating Systems Production and Sales 2024 (Database 2023)", May 2024, https://abrasol.org.br/wp-content/uploads/2024/05/Solar-Heating-Systems-Production-and-Sales-2024.pdf. The industry had expected a 16% increase in 2023, from ABRASOL, "Produção e Vendas de Sistemas de Aquecimento Solar 2023, Base 2022", 2023, p. 6, https://abrasol.org.br/pesquisa-de-producao-e-vendas.

28 Associação Brasileria de Energia Solar Térmica (ABRASOL), "Solar Heating Systems Production and Sales 2024 (Database 2023)", May 2024, https://abrasol.org.br/wp-content/uploads/2024/05/Solar-Heating-Systems-Production-and-Sales-2024.pdf. By region, the portion of sales in the south-east continued to increase, to 65% in 2023, followed by the south (20%), central-west (7%), north-east (5%) and north (3%); the residential sector was followed by the commercial/services (12%), industrial (3%) and social (1%) sectors, all from idem.

29 Figure of 8% based on a total of 22,796,314 m^2 of collector area in operation at the end of 2022 and 24,626,770 m^2 (17.2 GW_{th}) at the end of 2023, from Associação Brasileria de Energia Solar Térmica (ABRASOL), "Solar Heating Systems Production and Sales 2024 (Database 2023)", May 2024, https://abrasol.org.br/wp-content/uploads/2024/05/Solar-Heating-Systems-Production-and-Sales-2024.pdf; cumulative capacity at end-2023 based on 24,022,177 m^2 of collector area (including 10,103,248 m^2 unglazed, 13,606,133 m^2 flat plate, and 312,796 m^2 of vacuum tube), equivalent to 16.8 GW_{th}, from W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide, and from M. Spörk-Dür, AEE – Institute for Sustainable Technologies, personal communication with REN21, March–May 2024.

30 Importance of small-scale (residential) from Y. Akay, Solimpeks Solar Corp, personal communication with B. Epp, solrico, February 2022; second after China for large systems from W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide. Türkiye had 18 large-scale systems (>350 kW_{th}; 500 m^2) with a total installed capacity of 14.2 MW_{th}, from idem.

31 Y. Akay, Solimpeks Solar Corp, personal communication with B. Epp, solrico, February 2022.

32 Additions in 2023 from K. Ülke, Bural Heating, Kayseri, Türkiye, personal communication with REN21, 2-3 May 2024. Newly installed flat plate collector area was 916,000 m^2 (641.2 MW_{th}) and newly installed vacuum tube collector area was 882,000 m^2 (617.4 MW_{th}), from idem. Year-end total from W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide, and from M. Spörk-Dür, AEE – Institute for Sustainable Technologies, personal communication with REN21, March–May 2024.

33 Figure of 2.6% based on 2023 data from K. Ülke, Bural Solar, Kayseri, Türkiye, personal communication with REN21, 2-3 May 2024; 2022 data from W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide, Table 11; reasons for decline and fossil gas from Ülke, op. cit. this note.

34 Additions based on data from B. Heavner, CALSSA, Sacramento, California, United States, provided by M. Spörk-Dür, AEE – Institute for Sustainable Technologies, personal communication with REN21, 30 April 2024 (US new additions of vacuum tube collectors and thermosiphon systems were not available); ranking and estimated total year-end capacity of 25,958,118 m^2 of collector area (including 22,786,415 m^2 of unglazed, 2,994,975 m^2 of flat plate, and 176,728 m^2 of vacuum tubes), equivalent to 18.2 GW_{th}, from W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide, and from Spörk-Dür, op. cit. this note, March–May 2024.

35 Based on data for 2022 from W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide, Table 11, and from B. Heavner, CALSSA, Sacramento, California, United States, provided by M. Spörk-Dür, AEE – Institute for Sustainable Technologies, personal communication with REN21, 30 April 2024.

36 F. Stier, "Producers Point to Forced Electrification and Cheap Natural Gas as Barriers for Solar Thermal in the US", Solar Thermal World, 30 August 2023, https://solarthermalworld.org/news/producers-point-to-forced-electrification-and-cheap-natural-gas-as-barriers-for-solar-thermal-in-the-us.

37 Hawaiian Electric, "Renewable Energy Sources – Solar Water Heating", accessed 10 March 2024, https://www.hawaiianelectric.com/clean-energy-hawaii/our-clean-energy-portfolio/renewable-energy-sources/solar. An estimated 90,000 residential solar water heating systems in Hawaiian Electric Company's service territories from idem. Hawaii's market is strong for several reasons, including good solar resources and a solar mandate. See, for example, B. Epp, "Use Mandates to Boost Established Markets, But Not to Build Up New Ones", Solar Thermal World, 23 October 2020, https://solarthermalworld.org/news/use-mandates-boost-established-markets-not-build-new-once. Importance of Hawaii also from B. Heavner, CALSSA, Sacramento, California, United States, provided by M. Spörk-Dür, AEE – Institute for Sustainable Technologies, personal communication with REN21, 30 April 2024.

38 US unglazed based on 565,889 m^2 of collector area installed in 2023, accounting for nearly 95% of the year's additions, based on data from B. Heavner, CALSSA, Sacramento, California, United States, provided by M. Spörk-Dür, AEE – Institute for Sustainable Technologies, personal communication with REN21, 30 April 2024; Brazil from information and sources in this section.

39 Rankings and decline relative to 2022 based on data from D. Ferrari, Exemplary Energy, provided by M. Spörk-Dür, AEE – Institute for Sustainable Technologies, personal communication with REN21, March–May 2024, and from W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide.

40 Australia based on an estimated 330,000 m^2 of unglazed collector area installed in 2023, and total annual installations of 446,421 m^2, from D. Ferrari, Exemplary Energy, provided by M. Spörk-Dür, AEE – Institute for Sustainable Technologies, personal communication with REN21, March–May 2024. Australia added 312.5 MW_{th} (including 69.3 MW_{th} of glazed flat plate collectors, 12.2 MW_{th} of vacuum tube collectors, and 231 MW_{th} of unglazed collectors), from W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide, and from Spörk-Dür, op. cit. this note.

41 Victoria mandate from D. Ferrari, Exemplary Energy, provided by M. Spörk-Dür, AEE – Institute for Sustainable Technologies, personal communication with REN21, March–May 2024; year-end total from Spörk-Dür, idem. Note that changes to Victoria's regulations in 2023 permit heat pumps, which could affect the future market for solar thermal systems, from Ferrari, op. cit. this note.

42 Based on a year-end 2023 total of 9,480,832 m^2 of collector area (including 5,939,832 m^2 of unglazed, 3,269,000 m^2 of flat plate, and 272,000 m^2 of vacuum tubes), equivalent to 6.6 GW_{th}, from W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide, and from M. Spörk-Dür, AEE – Institute for Sustainable Technologies, personal communication with REN21, March–May 2024.

43 Mexico added 309 MW_{th} (441,590 m^2) in 2023, of which 82.7 MW_{th} were unglazed (26.8% of newly installed in 2023), from W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide, and from M. Spörk-Dür, AEE – Institute for Sustainable Technologies, personal communication with REN21, March–May 2024; increase relative to 2022 and 2023 total from Spörk-Dür, idem.

44 Based on data from W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide; M. Spörk-Dür, AEE – Institute for Sustainable Technologies, personal communication with REN21, March–May 2024.

45 B. Epp, solrico, personal communication with REN21, April 2022 and May 2023. For Italy, see, for example, R. Battisti, "Conto Termico: Good Incentive But with Room for Improvement", Solar Thermal World, 25 April 2023, https://solarthermalworld.org/news/conto-termico-good-incentive-but-with-room-for-improvement.

46 L. Mico, Solar Heat Europe, personal communication with REN21, 15 May 2024.

47 L. Mico, Solar Heat Europe, personal communication with REN21, 15 May 2024.

48 Ranking based on data from W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide, and from M. Spörk-Dür, AEE – Institute for Sustainable Technologies, personal communication with REN21, March–May 2024.

49 Based on 460,000 m^2 of flat plate and 300 m^2 of vacuum tube collector area installed during 2023, for a total glazed water collector area of 5,742,000 m^2, from C. Travasaros, Greek Solar Industry Association (EBHE), provided by M. Spörk-Dür, AEE – Institute for Sustainable Technologies, personal communication with REN21, March–May 2024; record additions based on increase in 2023 (from idem) and on record additions in 2022, from C. Travasaros, EBHE, personal communication with REN21, 29 January 2023.

50 Based on additions in 2023 from C. Travasaros, Greek Solar Industry Association (EBHE), provided by M. Spörk-Dür, AEE – Institute for Sustainable Technologies, personal communication with REN21, March–May 2024, and record additions in 2022 of 293 MW_{th} (419,000 m^2) for an end-2022 total of 3.8 GW_{th} (5.4 million m^2), from C. Travasaros, EBHE, personal communication with REN21, 29 January 2023. The Greek market expanded 12% relative to 2022, from L. Mico, Solar Heat Europe, personal communication with REN21, 15 May 2024.

51 C. Travasaros, Greek Solar Industry Association (EBHE), personal communication with REN21, 11 April 2023.

52 Rankings and decline of 46% based on data from W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide, and from M. Spörk-Dür, AEE – Institute for Sustainable Technologies, personal communication with REN21, March–May 2024; three years of stability or growth based on data from German industry associations BSW Solar and BDH, cited in J.P. Meyer, "The German Solar Thermal Market Only Grew Slightly in the Energy Crisis Year 2022", Solar Thermal World, 14 February 2023, https://solarthermalworld.org/news/the-german-solar-thermal-market-only-grew-slightly-in-the-energy-crisis-year-2022. Germany's annual market held even in 2021 relative to 2020, in which the market expanded 26% over 2019, from Meyer, idem. Germany's market declined 47% in 2023, from L. Mico, Solar Heat Europe, personal communication with REN21, 15 May 2024.

53 BSW Solar, "Statistische Zahlen der deutschen Solarwärmebranche (Solarthermie)", February 2024, https://www.solarwirtschaft.de/datawall/uploads/2024/02/2024_01_BSW_Solar_Faktenblatt_Solarwaerme.pdf. This compares with an estimated 91,000 systems installed in 2022, totalling 496 MW_{th} (709,000 m^2) in 2022, from German industry associations BSW Solar and BDH, cited in J.P. Meyer, "The German Solar Thermal Market Only Grew Slightly in the Energy Crisis Year 2022", Solar Thermal World, 14 February 2023, https://solarthermalworld.org/news/the-german-solar-thermal-market-only-grew-slightly-in-the-energy-crisis-year-2022, and from A. Liesen, BSW Solar, personal communication with REN21, 28 February and 2 March 2023. The 2022 additions were up from 448 MW_{th} in 2021, from Meyer, op. cit. this note.

54 Geschäftsstelle der Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat) am Umweltbundesamt, "Erneuerbare Energien in Deutschland: Daten zur Entwicklung im Jahr 2023", Dessau-Roßlau, March 2024, p. 12, https://www.umweltbundesamt.de/publikationen/erneuerbare-energien-in-deutschland-2023.

55 Solar demand and total barely rose, from AGEE-Stat am Umweltbundesamt, "Erneuerbare Energien in Deutschland: Daten zur Entwicklung im Jahr 2023", Dessau-Roßlau, March 2024, p. 12, https://www.umweltbundesamt.de/publikationen/erneuerbare-energien-in-deutschland-2023; year-end capacity of 22,581,092 m^2 of collector area (including 392,640 m^2 of unglazed, 19,520,910 m^2 of flat plate, and 2,667,542 m^2 of vacuum tubes), equivalent to 15.8 GW_{th}, from W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide, and from M. Spörk-Dür, AEE – Institute for Sustainable Technologies, personal communication with REN21, March–May 2024. Note that year-end capacity was 22.15 million m^2 (14.4 GW_{th}), from BSW Solar, "Statistische Zahlen der deutschen Solarwärmebranche (Solarthermie)", February 2024, https://www.solarwirtschaft.de/datawall/uploads/2024/02/2024_01_BSW_Solar_Faktenblatt_Solarwaerme.pdf. This capacity (in 2.6 million systems) was up from 22.07 million m^2 and 2.58 million systems at the end of 2022, and 21.6 million m^2 and 2.52 million systems at the end 2021; 2023 output accounted for 0.8% of Germany's total heat consumption, from BSW Solar, op. cit. this note. Strong incentives for heat pumps in Germany also played a role in the decline in Germany's solar thermal system installations during 2023, from L. Mico, Solar Heat Europe, personal communication with REN21, 15 May 2024.

56 AGEE-Stat am Umweltbundesamt, "Erneuerbare Energien in Deutschland: Daten zur Entwicklung im Jahr 2023", Dessau-Roßlau, March 2024, pp. 12, 26, https://www.umweltbundesamt.de/publikationen/erneuerbare-energien-in-deutschland-2023; total heat energy output from solar thermal systems was 9,733 GWh in 2022 and 9,126 GWh in 2023, from idem, p. 21; Germany's systems produced 9.3 TWh-thermal of solar heat in 2023, from BSW Solar, "Statistische Zahlen der deutschen Solarwärmebranche (Solarthermie)", February 2024, https://www.solarwirtschaft.de/datawall/uploads/2024/02/2024_01_BSW_Solar_Faktenblatt_Solarwaerme.pdf.

57 Figure of 43% in 2022 and decade of decline from W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2022, Detailed Market Figures 2021, 2023 Edition", International Energy Agency Solar Heating and Cooling Programme, 2023, pp. 6, 58, 60, https://www.iea-shc.org/solar-heat-worldwide, and from M. Spörk-Dür, AEE – Institute for Sustainable Technologies, personal communication with REN21, May 2023; up 83% in 2021 from R. Battisti, "Superbonus Has Pushed Solar Heat in Italy", Solar Thermal World, 9 March 2022, https://solarthermalworld.org/news/superbonus-has-pushed-solar-heat-in-italy.

58 Figure of 33% based on installations in 2022, from the following sources: W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2022, Detailed Market Figures 2021, 2023 Edition", International Energy Agency Solar Heating and Cooling Programme (IEA SHC), 2023, pp. 6, 58, 60, https://www.iea-shc.org/solar-heat-worldwide; M. Spörk-Dür, AEE – Institute for Sustainable Technologies, personal communication with REN21, May 2023; R. Battisti, "Superbonus Has Pushed Solar Heat in Italy", Solar Thermal World, 9 March 2022, https://solarthermalworld.org/news/superbonus-has-pushed-solar-heat-in-italy. Also based on 2023 installations of 151.4 MW_{th} (including 136 MW_{th} of flat plate, and 15.4 MW_{th} of vacuum tube), and year-end total based on 5,561,908 m^2 of collector area (including 43,800 m^2 of unglazed, 4,786,330 m^2 of flat plate, and 731,778 m^2 of vacuum tubes), equivalent to 3.9 GW_{th}, all from W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", IEA SHC, 2024, https://www.iea-shc.org/solar-heat-worldwide, and from Spörk-Dür, op. cit. this note, March–May 2024.

59 Solar Heat Europe, provided by M. Spörk-Dür, AEE – Institute for Sustainable Technologies, personal communication with REN21, March–May 2024; Italy's market contracted 31.4% in 2023, and the country is pushing strongly for solar PV plus heat pumps, which is affecting solar thermal heating demand, from L. Mico, Solar Heat Europe, personal communication with REN21, 15 May 2024.

60 Poland ranked fourth in Europe and its market contracted 38% in 2023 based on additions in 2022 of 210,000 m^2 (147 MW_{th}), from W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2022, Detailed Market Figures 2021, 2023 Edition", International Energy Agency Solar Heating and Cooling Programme (IEA SHC), 2023, pp. 6, 58, 60, https://www.iea-shc.org/solar-heat-worldwide, and on additions in 2023 of 130,800 m^2 (91.6 MW_{th}), from W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", IEA SHC, 2024, https://www.iea-shc.org/solar-heat-worldwide, and from M. Spörk-Dür, AEE – Institute for Sustainable Technologies, personal communication with REN21, March–May 2024. This followed increases in 2021 (17%) and 2022 (11%) from E. Engelniederhammer, "Polish Heating Device Market with Interesting Ups and Downs", Solar Thermal World, 28 July 2023, https://solarthermalworld.org/news/31237. Poland's market declined 37.7% in 2023, due in large part to the end of general incentives, from L. Mico, Solar Heat Europe, personal communication with REN21, 15 May 2024; Spain ranked fifth in Europe and its market contracted 26%, based on data (including additions in 2023 of an estimated 75.5 MW_{th}) from Weiss and Spörk-Dür, "Solar Heat Worldwide", 2023, op. cit. this note, and from Spörk-Dür, op. cit. this note. The decline in Spain was despite recent subsidies (up to 40% of system costs) to support renewable heat in buildings, public infrastructure, industry and elsewhere, with applications due by the end of 2023, from A.D. Rosell, "Spain's Solar Thermal

Market Impacted by Various New Policies", Solar Thermal World, 23 June 2023, https://solarthermalworld.org/news/spains-solar-thermal-market-impacted-by-various-new-policies. The change was to Royal Decree 477, approved in 2021 and modified in 2022, from Rosell, idem. Struggle to compete based on, for example: challenged in Poland by strong policy emphasis on heat pumps and electrification, from Engelniederhammer, op. cit. this note, and on struggling in Spain to compete with solar PV and increasingly with heat pumps for hot water, despite being economically competitive, from Rosell, op. cit. this note.

61 W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide.

62 W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide.

63 W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide. Large-scale systems also are being used for residential, commercial and public buildings, with many installed on hospitals, hotels and sports centres. At the end of 2023, 263 such systems were in operation, totalling 457 MW_{th} (652,216 m^2), mostly in China (155 systems, 355 MW_{th}). Türkiye followed distantly with 18 systems (14.2 MW_{th}), from idem. Year-end total installations of concentrating collector technologies (linear Fresnel, parabolic trough and dish) were reported by aperture area and converted into solar thermal capacity using the internationally accepted convention for stationary collectors, 1 million m^2 = 0.7 GW_{th}.

64 W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide. China also installed 17 additional large-scale systems (totalling 147,794 m^2) in the buildings sector, from idem.

65 Planenergi, Solarthermalworld.org, B. Epp and China Academy of Building Research, all cited in W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide, Table 1. These Tibetan projects were a 32 MW_{th} (45,036 m^2) project in Longzi, a 26 MW_{th} (36,700 m^2) project in Lazi, a 24 MW_{th} (34,250 m^2) project in Dingri, and a 20 MW_{th} (28,356 m^2 project in Seni, all from idem.

66 W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide.

67 B. Epp, "Solar District Heating Info Package for Cities and Towns", Solar Thermal World, 22 June 2023, https://solarthermalworld.org/news/solar-district-heating-info-package-for-cities-and-towns.

68 Denmark, Sweden and Austria from W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide, Figure 9; 55 systems in Germany from B. Epp, "District Heating Has Never Had Such a High Significance in Germany", Solar Thermal World, 28 April 2024, https://solarthermalworld.org/news/district-heating-has-never-had-such-a-high-significance-in-germany.

69 W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide.

70 W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide.

71 B. Epp, "District Heating Has Never Had Such a High Significance in Germany", Solar Thermal World, 28 April 2024, https://solarthermalworld.org/news/district-heating-has-never-had-such-a-high-significance-in-germany. At year's end, 51 systems, some with seasonal storage, were in operation across Germany; in addition, nine systems, totalling 19.6 MW_{th} (28,000 m^2) were under construction or in advanced planning, with another 66 systems totalling 318 MW_{th} (454,550 m^2) under concrete discussion, from W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide.

72 H. Huther, AGFW, cited in Solar Wärme Netze, "2022 Rekordjahr für solare Wärmenetze in Deutschland", 28 March 2023, https://www.solare-waermenetze.de/2023/03/28/solare-waermenetze-in-betrieb-2023 (using Google Translate).

73 F. Stier, "Successful Operator Models for Solar District Heating in Germany", Solar Thermal World, 5 January 2023, https://solarthermalworld.org/news/operator-models-for-solar-district-heating; F. Stier, "From LECs to TECs – Citizen Energy in Focus", Solar Thermal World, 28 May 2022, https://solarthermalworld.org/news/from-lecs-to-tecs-citizen-energy-in-focus.

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75 J.P. Meyer, "Guaranteed Yields Are Standard for New Solar District Heating Plants in Germany", Solar Thermal World, 19 October 2023, https://solarthermalworld.org/news/guaranteed-yields-are-standard-for-new-solar-district-heating-plants-in-germany.

76 W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide.

77 W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide.

78 B. Epp, solrico, personal communication with REN21, 6 May 2024. Austria also has a government campaign to encourage homeowners to renovate buildings and shift away from fossil boilers that, along with high energy prices, has led to a renewed interest in solar thermal for buildings not connected to district heat systems, from idem and from F. Stier, "Feasibility Studies for Large Solar Heat Plants Totalling Almost 1 Million m^2 Underway", Solar Thermal World, 6 April 2023, https://solarthermalworld.org/news/feasibility-studies-for-large-solar-heat-plants-totalling-almost-1-million-m2-underway.

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80 W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide.

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82 C. Travasaros, Prime Laser Tec. and Solar Heat Europe, cited in F. Stier, "European Council Speeds Up Permission Procedures But Only for Solar Systems on Buildings", Solar Thermal World, 2 February 2023, https://solarthermalworld.org/news/european-council-speeds-up-permission-procedures-but-only-for-solar-systems-on-buildings. Solar

thermal provides an estimated 3 times the energy yield per area of solar PV and 33 times that of biomass for heat, from International Energy Agency Solar Heating and Cooling Programme, cited in Euroheat & Power and Solar Heat Europe, "The Rise of Solar District Heating", webinar, 28 March 2023, p. 20, https://www.euroheat.org/data-insights/reports/the-rise-of-solar-district-heating-webinar. Another study estimates that solar thermal provides up to 43 times the energy yield per area of biomass and ethanol used for heat, from Fraunhofer ISE, PlanEnergi, and Chalmers University, cited in "Solar Thermal Shows Highest Energy Yield per Square Metre", Solar Thermal World, 31 July 2017, https://solarthermalworld.org/news/solar-thermal-shows-highest-energy-yield-square-metre. Another source says up to four times solar PV and 50 times biomass, from E. Augsten, "Will Smart District Heating Bring Solar Thermal Back into Focus in Germany?" Solar Thermal World, 11 October 2022, https://solarthermalworld.org/news/will-smart-district-heating-bring-solar-thermal-back-into-focus-in-germany.

83 Lack of awareness from F. Stier, "Feasibility Studies for Large Solar Heat Plants Totalling Almost 1 Million m² Underway", Solar Thermal World, 6 April 2023, https://solarthermalworld.org/news/feasibility-studies-for-large-solar-heat-plants-totalling-almost-1-million-m2-underway, and from B. Epp, "Solar District Heating Solutions Providing Higher Temperatures", Solar Thermal World, 4 December 2022, https://solarthermalworld.org/news/solar-district-heating-solutions-providing-higher-temperatures; suitable sites and permitting from F. Stier, "Access to Land Is One of the Key Bottlenecks for Rolling Out Renewables", Solar Thermal World, 22 November 2022, https://solarthermalworld.org/news/access-to-land-is-one-of-the-key-bottlenecks-for-rolling-out-renewables, and from C. Travasaros, Prime Laser Tec. and Solar Heat Europe, cited in F. Stier, "European Council Speeds Up Permission Procedures But Only for Solar Systems on Buildings", Solar Thermal World, 2 February 2023, https://solarthermalworld.org/news/european-council-speeds-up-permission-procedures-but-only-for-solar-systems-on-buildings. One dilemma of solar thermal for district heating systems is that it must be located close to end-users, but there are challenges of finding available land in or near to urban centres; further, permitting is a serious bottleneck and burden in terms of time and money, all from C. Tavasaros, cited in Stier, "European Council Speeds…", op. cit. this note; bottlenecks also from M. Berberich, Solites, cited in Epp, "Solar District Heating Solutions…", op. cit. this note. Additional challenges, at least in Germany, include the research and development required for large-scale seasonal storage for really large networks, and the fact that some district heat networks operate at temperatures above 100°C, from B. Epp, "District Heating Has Never Had Such a High Significance in Germany", Solar Thermal World, 28 April 2024, https://solarthermalworld.org/news/district-heating-has-never-had-such-a-high-significance-in-germany.

84 Figure of 20% (heat accounts for two-thirds of total industrial energy demand) and heavy reliance on fossil fuels from E. Bellevrat and K. West, "Clean and Efficient Heat for Industry", International Energy Agency, 23 January 2018, https://www.iea.org/commentaries/clean-and-efficient-heat-for-industry; growing interest in solar thermal from M. Lehnis, "Sunshine, Mirrors and Steam: Meet the Company Quickly Decarbonizing the $444 Billion Industrial Heat Market", Forbes, 14 December 2023, https://www.forbes.com/sites/mariannelehnis/2023/12/14/sunshine-mirrors-and-steam-meet-the-company-quickly-decarbonizing-the-444-billion-industrial-heat-market; heavy reliance on fossil fuels also from M. de Kempenaer et al., "Net-Zero Heat: Is It Too Hot to Handle?" McKinsey, 22 July 2022, https://www.mckinsey.com/capabilities/sustainability/our-insights/sustainability-blog/net-zero-heat-is-it-too-hot-to-handle.

85 J. Byström, Absolicon Solar Collector, personal communication with B. Epp, solrico, February 2022; energy price stability and volatility from S. Papa, Solar Heat Europe, personal communication with REN21, 2 May 2023. See also, for example, the following: B. Epp, "Concentrating Solar Heat Capacity Quadruples in 2022", Solar Thermal World, 29 August 2022, https://solarthermalworld.org/news/concentrating-solar-heat-capacity-quadruples-in-2022 (updated November 2022); B. Epp, "Big Solar Heat Deal in the Chilean Copper Sector Made Possible by Two People", Solar Thermal World, 23 February 2024, https://solarthermalworld.org/news/big-solar-heat-deal-in-the-chilean-copper-sector-made-possible-by-two-people; B. Epp, "Decarbonization – A Winning Card for Industry", Solar Thermal World, 2 November 2023, https://solarthermalworld.org/news/decarbonization-a-winning-card-for-industry; GlassPoint, "GlassPoint Partners with MISA to Build a Solar Manufacturing Facility in Saudi Arabia", 24 October 2023, https://www.prnewswire.com/news-releases/glasspoint-partners-with-misa-to-build-a-solar-manufacturing-facility-in-saudi-arabia-301966565.html; SolarPACES, "Ma'aden and GlassPoint Unveil Plans to Build Solar Thermal Technology Showcase", 11 January 2023, https://www.solarpaces.org/glasspoint-and-saudis-maaden-unveil-9-tons-hr-solar-steam-demo-plan; energy price volatility and solar thermal solutions from Papa, op. cit. this note.

86 M. de Kempenaer et al., "Net-Zero Heat: Is It Too Hot to Handle?" McKinsey, 22 July 2022, https://www.mckinsey.com/capabilities/sustainability/our-insights/sustainability-blog/net-zero-heat-is-it-too-hot-to-handle.

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88 Data assessed from annual surveys (2017-2024) of the companies listed in Solar Payback, "Turnkey SHIP Supplier World Map", cited in B. Epp, "The Netherlands and Spain Drive SHIP Market 2023", Solar Thermal World, 28 March 2024, https://solarthermalworld.org/news/the-netherlands-and-spain-drive-ship-market-2023. The 116 systems completed during 2022 totalled 31 MW_{th} of capacity, from idem. Capacity was calculated by Epp using the factor 0.7 kW/m² for all collector types.

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90 W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2023, Detailed Market Figures 2022, 2024 Edition", International Energy Agency Solar Heating and Cooling Programme, 2024, https://www.iea-shc.org/solar-heat-worldwide; M. Spörk-Dür, AEE – Institute for Sustainable Technologies, personal communication with REN21, March–May 2024.

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92 W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide Edition 2023", International Energy Agency Solar Heating and Cooling Programme, May 2023, p. 21, https://www.iea-shc.org/solar-heat-worldwide; B. Epp, solrico, personal communication with REN21, 6 May 2024.

93 B. Epp, "The Netherlands and Spain Drive SHIP Market 2023", Solar Thermal World, 28 March 2024, https://solarthermalworld.org/news/the-netherlands-and-spain-drive-ship-market-2023. Although most systems in operation use flat plate collectors, and they were used in almost half of new projects in 2023, their share of new collector area fell from 39% in 2022 to 12%. Around the world, the market is expanding for parabolic trough (38% of collector area in 2023), linear Fresnel and concentrating dish collectors, which combined accounted for 43% of the market across 10 projects, up from 16% in 2022, all from idem. In 2022, nine types were used, including 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 B. Epp, "High Level of Dynamism on the SHIP World Market in 2022", Solar Thermal World, 27 March 2023, https://solarthermalworld.org/news/high-level-of-dynamism-on-the-ship-world-market-in-2022.

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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 for installations during 2022 (and 2021), from B. Epp, "High Level of Dynamism…", op. cit. this note, and from W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide, Global Market Development and Trends 2022, Detailed Market Figures 2021, 2023 Edition", International Energy Agency Solar Heating and Cooling Programme, 2023, https://www.iea-shc.org/solar-heat-worldwide. The China Academy of Building Research reported that a total of 359 SHIP systems (256,000 m^2) were added in 2021 alone; because detailed data are not available for 2021 or 2022, the systems are not included in data from Weiss and Spörk-Dür, op. cit. this note, p. 26.

95 B. Epp, "The Netherlands and Spain Drive SHIP Market 2023", Solar Thermal World, 28 March 2024, https://solarthermalworld.org/news/the-netherlands-and-spain-drive-ship-market-2023.

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97 Invest in Spain, "Heineken Opens Europe's Largest Solar Thermal Plant in Seville", 5 October 2023, https://www.investinspain.org/content/icex-invest/en/noticias-main/2023/heineken.html; S. Djunisic, "Heineken, Engie Unveil 30-MW CSP Plant in Spain", Renewables Now, 2 October 2023, https://renewablesnow.com/news/heineken-engie-unveil-30-mw-csp-plant-in-spain-835494; B. Epp, "Technical Tour to Europe's Largest Solar Industrial Heat Plant at Heineken Spain", Solar Thermal World, 30 October 2023, https://solarthermalworld.org/news/technical-tour-to-europes-largest-solar-industrial-heat-plant-at-heineken-spain; O. Haslam, "Lactalis Unveils Solar Thermal Power Plant for Sustainable Whey Production", Nutra Ingredients, 5 January 2024, https://www.nutraingredients.com/Article/2024/01/05/Lactalis-unveils-solar-thermal-power-plant-for-sustainable-whey-production; J. Malaviya, "First Big Dish System Supplies Steam for a Hospital in India", Solar Thermal World, 17 April 2023, https://solarthermalworld.org/news/first-big-dish-system-supplies-steam-for-a-hospital-in-india. India was a strong SHIP market during 2017-2020 and dropped off after the expiration of a national incentive programme for concentrating heat in 2020, from B. Epp, "High Innovation Potential of Suppliers for Concentrating Heat Solutions", Solar Thermal World, 8 June 2023, https://solarthermalworld.org/news/high-innovation-potential-of-suppliers-for-concentrating-heat-solutions.

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117 B. Epp, "PVT Flagship Projects in Four Countries", Solar Thermal World, 2 February 2024, https://solarthermalworld.org/news/pvt-flagship-projects-in-four-countries; see also A.D. Rosell, "Spain's Solar Thermal Market Impacted by Various New Policies", Solar Thermal World, 23 June 2023, https://solarthermalworld.org/news/spains-solar-thermal-market-impacted-by-various-new-policies.

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120 A.D. Rosell, "Spain's Solar Thermal Market Impacted by Various New Policies", Solar Thermal World, 23 June 2023, https://solarthermalworld.org/news/spains-solar-thermal-market-impacted-by-various-new-policies.

121 B. Epp, "Growing Production Capacities of PVT Collectors in Europe", Solar Thermal World, 1 February 2024, https://solarthermalworld.org/news/growing-production-capacities-of-pvt-collectors-in-europe. Sunmaxx PVT's plant has capacity for 120 units (50 MW-electric) per year, from idem.

ENDNOTES | WIND POWER

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2 Increase in annual additions relative to 2022 based on data from Global Wind Energy Council (GWEC), "Global Wind Report 2024", 2024, p. 149, https://gwec.net/global-wind-report-2024, from GWEC, "Global Wind Statistics 2024", unpublished document, with adjustments made for European data from WindEurope, "Wind Energy in Europe – 2023 Statistics and the Outlook for 2024-2030", 2024, pp. 7, 10, 11, 17, https://windeurope.org/intelligence-platform/product/wind-energy-in-europe-2023-statistics-and-the-outlook-for-2024-2030; updated statistics for onshore additions in France from G. Costanzo, WindEurope, personal communication with REN21, April–May, 2024; updated statistics for United States from J. Hensley, American Clean Power, personal communication with REN21, May 2024. Up in all regions except North America (due to decline in the United States) and Europe from GWEC, "Global Wind Report 2024", op. cit. this note, p. 144. Note that additions were up 34% relative to 2022 based on 2023 additions of 116,065 MW in 2023 and of 86,403 MW in 2022, from World Wind Energy Association (WWEA), "WWEA Annual Report 2023", 2024, https://wwindea.org/AnnualReport2023, and up 40% based on updated data for China, from S. Gsänger, WWEA, personal communication with REN21, 7-8 May, 2024.

3 Increase in world outside of China and China's share of global market based on data from Global Wind Energy Council (GWEC), "Global Wind Report 2024", 2024, p. 149, https://gwec.net/global-wind-report-2024, from GWEC, "Global Wind Statistics 2024", unpublished document, with adjustments made for European data from WindEurope, "Wind Energy in Europe – 2023 Statistics and the Outlook for 2024-2030", 2024, pp. 7, 10, 11, 17, https://windeurope.org/intelligence-platform/product/wind-energy-in-europe-2023-statistics-and-the-outlook-for-2024-2030; adjustments for Europe also from G. Costanzo, WindEurope, personal communication with REN21, April–May, 2024; adjustments for United States from J. Hensley, American Clean Power, personal communication with REN21, May 2024; and from World Wind Energy Association, "WWEA Annual Report 2023", 2024, https://wwindea.org/AnnualReport2023. Markets that contracted in 2023 relative to 2022 include: the United States, several countries in Europe (Belgium, France, Finland, Latvia, Norway, Poland, Spain, Sweden and the United Kingdom); in addition, several countries that have ranked among the world's top 10 in recent years (2018-2022) added relatively little capacity in 2023 (outside of Europe, these include Argentina, Australia, Mexico, Türkiye and Viet Nam), all based on data from idem (all sources), and from REN21, "Renewables Global Status Report", multiple editions.

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31 Regional shares based on data from the following: Global Wind Energy Council (GWEC), "Global Wind Report 2024", 2024, https://gwec.net/global-wind-report-2024; GWEC, "Global Wind Statistics 2024", unpublished document; WindEurope, "Wind Energy in Europe – 2023 Statistics and the Outlook for 2024-2030", 2024, pp. 10, 11, https://windeurope.org/intelligence-platform/product/wind-energy-in-europe-2023-statistics-and-the-outlook-for-2024-2030; G. Costanzo, WindEurope, personal communication with REN21, April–May 2024; J. Hensley, American Clean Power, personal communication with REN21, May 2024. Numbers in text are based on regional groupings that include Türkiye as part of Asia, rather than Europe; other regional shares include the Pacific with just under 1% of the total added in 2023 (down from just over 2% of the total added in 2022), and Africa and the Middle East with more than 0.8% (down from 1.9% in 2022), based on data from idem, all sources.

32 Global Wind Energy Council (GWEC), "Global Wind Report 2024", 2024, https://gwec.net/global-wind-report-2024; GWEC, "Global Wind Statistics 2024", unpublished document; WindEurope, "Wind Energy in Europe – 2023 Statistics and the Outlook for 2024-2030", 2024, pp. 10, 11, https://windeurope.org/intelligence-platform/product/wind-energy-in-europe-2023-statistics-and-the-outlook-for-2024-2030; G. Costanzo, WindEurope, personal communication with REN21, April–May 2024; J. Hensley, American Clean Power, personal communication with REN21, May 2024.

33 Based on data from the following: Global Wind Energy Council (GWEC), "Global Wind Report 2024", 2024, https://gwec.net/global-wind-report-2024; GWEC, "Global Wind Statistics 2024", unpublished document; WindEurope, "Wind Energy in Europe – 2023 Statistics and the Outlook for 2024-2030", 2024, pp. 10, 11, https://windeurope.org/intelligence-platform/product/wind-energy-in-europe-2023-statistics-and-the-outlook-for-2024-2030; G. Costanzo, WindEurope, personal communication with REN21, April–May 2024; J. Hensley, American Clean Power, personal communication with REN21, May 2024. Note that the ranking is the same from the World Wind Energy Association (WWEA) except that their data puts France ahead of Sweden for additions in 2023, from WWEA, "WWEA Annual Report 2023", 2024, p. 10, https://wwindea.org/AnnualReport2023. BloombergNEF has the same top five, followed by Sweden, the United Kingdom, Finland, Canada and the Netherlands, from BloombergNEF, "China's Goldwind Retains Turbine Supplier Lead, as Global Wind Additions Hit New High, According to BloombergNEF", 27 March 2024, https://about.bnef.com/blog/chinas-goldwind-retains-turbine-supplier-lead-as-global-wind-additions-hit-new-high-according-to-bloombergnef. Top markets in 2022 and installation levels to rank among top 10 are based on data from the following: GWEC, op. cit. this note (both sources); GWEC, "Global Wind Report 2023", 2023, unpublished document; American Clean Power, "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 – 2023…", op. cit. this note; Costanzo, op. cit. this note; WindEurope, "Wind Energy in Europe: 2022 Statistics and the Outlook for 2023-2027", 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, personal communication with REN21, 13 March 2023. **Figure 34** based on country-specific data and sources provided throughout this section, and drawn largely from the following: GWEC, "Global Wind Report 2024", op. cit. this note; GWEC, "Global Wind Statistics 2024", op. cit. this note; WindEurope, "Wind Energy in Europe – 2023…", op. cit. this note, pp. 10, 11; Costanzo, op. cit. this note, April–May 2024; WWEA, op. cit. this note.

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36 Based on data from Global Wind Energy Council (GWEC), "Global Wind Report 2024", 2024, https://gwec.net/global-wind-report-2024, from GWEC, "Global Wind Statistics 2024", unpublished document, from WindEurope, "Wind Energy in Europe – 2023 Statistics and the Outlook for 2024-2030", 2024, pp. 10, 11, https://windeurope.org/

intelligence-platform/product/wind-energy-in-europe-2023-statistics-and-the-outlook-for-2024-2030, G. Costanzo, WindEurope, personal communication with REN21, April–May 2024, and from J. Hensley, American Clean Power, personal communication with REN21, May 2024. China's share in 2023 was 66%, from S. Gsanger, World Wind Energy Association (WWEA), personal communication with REN21, 7 May 2024, and in 2022 it was 58%, from WWEA, "WWEA Annual Report 2023", 2024, p. 5, https://wwindea.org/AnnualReport2023.

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44 Global Wind Energy Council (GWEC), "Wind Turbine Manufacturers See Record Year Driven by Growth in Home Markets", 9 May 2024, https://gwec.net/wind-turbine-manufacturers-see-record-year-driven-by-growth-in-home-markets; F. Zhao, GWEC, personal communication with REN21, 6 May 2024. The top 15 wind turbine manufacturers in 2023, based on a record 120.7 GW of new capacity mechanically installed and provided by 30 manufacturers, were Goldwind (China, 13.9%), Envision (China, 13.2%), Vestas (Denmark, 10.5%), Windey (China, 8.7%), Mingyang (China, 8.4%), Siemens Gamesa (Germany, 6.4%), GE Vernova (United States, 6.3%), SANY (China, 6.2%), Nordex Group (Germany, 5.7%), Dongfang (China, 4.6%), Sewind (China, 3.8%), CRRC (China, 3.4%), CSSC Haizhuang (China 3.1%), Enercon (Germany, 2.0%) and United Power (China 1.4%), from GWEC, op. cit. this note, from F. Zhao, op. cit. this note, and from GWEC Market Intelligence, "Global Wind Market Development: Supply Side Data 2023", 2024, unpublished document. The top 10 wind turbine manufacturers, based on 118 GW of total commissioned capacity, were: Goldwind, which supplied 16.4 GW of turbines for projects in 2023, 95% of which were in China, followed by Envision (15.4 GW); Vestas (13.4 GW); Windey (10.4 GW) and Mingyang (9.0 GW), both of China; GE (8.1 GW), which fell from third to sixth, largely due to the decline in the US market; Sany (7.9 GW, China); Siemens Gamesa (7.7 GW), Nordex (6.7 GW) and Dongfang Electric (6.0 GW, China), and Goldwind, Envision and Windey all consolidated their lead in China's market during 2023, accounting for more than half of all turbines installed, and Vestas was the only non-Chinese manufacturer to install turbines in China during 2022 and 2023, all from BloombergNEF, "China's Goldwind Retains Turbine Supplier Lead, as Global Wind Additions Hit New High, According to BloombergNEF", 27 March 2024, https://about.bnef.com/blog/chinas-goldwind-retains-turbine-supplier-lead-as-global-wind-additions-hit-new-high-according-to-bloombergnef. Six of the top 10 also were from China in 2022, from BloombergNEF, "Goldwind and Vestas in Photo Finish for Top Spot as Global Wind Power Additions Fall", 23 March 2023, https://about.bnef.com/blog/goldwind-and-vestas-in-photo-finish-for-top-spot-as-global-wind-power-additions-fall, and from GWEC, "Global Wind Market Development: Supply Side Data 2022", p. 7, unpublished document.

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