Electricity Market Report Update

Outlook for 2023 and 2024

International Energy Agency

INTERNATIONAL ENERGY AGENCY

The IEA examines the full spectrum of energy issues including oil, gas and coal supply and demand, renewable energy technologies, electricity markets, energy efficiency, access to energy, demand side management and much more. Through its work, the IEA advocates policies that will enhance the reliability, affordability and sustainability of energy in its 31 member countries, 11 association countries and beyond.

IEA member countries:

Australia
Austria
Belgium
Canada
Czech Republic
Denmark
Estonia
Finland
France
Germany
Greece
Hungary
Ireland
Italy
Japan
Korea
Lithuania
Luxembourg
Mexico
Netherlands
New Zealand
Norway
Poland
Portugal
Slovak Republic
Spain
Sweden
Switzerland
Republic of Türkiye
United Kingdom
United States

The European Commission also participates in the work of the IEA

IEA association countries:

Argentina
Brazil
China
Egypt
India
Indonesia
Kenya
Morocco
Senegal
Singapore
South Africa
Thailand
Ukraine

Source: IEA.
International Energy Agency
Website: www.iea.org

Abstract

Since the release of the IEA's Electricity Market Report 2023 in February, the global energy crisis has continued to affect many parts of the world. Higher costs for energy commodities as well as economic slowdowns in various regions are still impacting electricity market trends across the globe.

This report presents our latest data for 2022 as well as forecasts for global electricity demand, supply and emissions through 2024. The latest developments in China, United States, European Union, and India are explored. Wholesale electricity prices, which remain above pre-2021 levels in many regions, are also discussed in detail.

The update includes a special focus on the recent evolution of electricity demand in Europe and its drivers. The impact of weather on electricity demand and supply, which is increasingly evident globally, is also covered in a dedicated analysis.

Acknowledgements, contributors and credits

This study was prepared by the Gas, Coal and Power Markets (GCP) Division of the International Energy Agency (IEA). It was designed and directed by Eren Çam, Energy Analyst for Electricity.

The main authors are: Eren Çam, John Moloney, and Francys Pinto Miranda.

Keisuke Sadamori, director of the IEA Energy Markets and Security (EMS) Directorate and Dennis Hesseling, Head of GCP provided expert guidance and advice. Valuable comments and guidance were provided by other senior management within the IEA, in particular, Laura Cozzi. Expert guidance and valuable input of Carlos Fernández Álvarez, Senior Energy Analyst is greatly appreciated.

Many IEA colleagues provided valuable input, comments and feedback, in particular Yasmina Abdelilah, Heymi Bahar, Stéphanie Bouckaert, Louis Chambeau, Elizabeth Connelly, Javier Jorquera Copier, Carole Etienne, Keith Everhart, Takeshi Furukawa, Pablo Hevia-Koch, Arne Lilienkamp, Gergely Molnár, Yannick Monschauer, Hiroyasu Sakaguchi, Brent Wanner.

The authors would also like to thank Gregory Viscusi and Julia Horowitz for skilfully editing the manuscript, and also Astrid Dumond and Jethro Mullen from the IEA Communication and Digital Office for their assistance.

Table of contents

Executive summary

Falling electricity consumption in advanced economies weighs on global growth in power demand

Global electricity demand growth is expected to ease in 2023 before accelerating in 2024. Demand is expected to grow by slightly less than 2% in 2023, down from a rate of 2.3% in 2022 and the average annual growth rate of 2.4% observed over the 2015-2019 period. This moderation is strongly driven by declining electricity demand in advanced economies, which are dealing with the ongoing effects of the global energy crisis and slower economic growth. In 2024, as expectations for the economic outlook improve, global electricity demand growth is forecast to rebound to 3.3%.

Electricity demand in the European Union is set to decline in 2023 for the second year in a row, falling to its lowest level in two decades. EU electricity demand is expected to record a 3% drop in 2023, after already falling 3% in 2022. This is despite strong growth in electrification with a record number of electric vehicles and heat pumps sold. Following these two consecutive declines, which together amount to the region's largest slump in demand on record, EU electricity demand is set to drop to levels last seen in 2002.

Europe's energy-intensive industries have not yet recovered from last year's production slump, as evidenced by the staggering 6% year-on-year decline in total EU electricity demand during the first half of 2023. Almost two-thirds of the net reduction in EU electricity demand in 2022 is estimated to be from energy-intensive industries grappling with elevated energy prices. This trend has continued well into 2023, despite the prices for energy commodities and electricity falling from their previous record highs. As policy developments abroad courting industrial investment put pressure on Europe's industrial competitiveness, the European Union is at a crossroads. The outcome of policy discussions now underway could determine the future of its energy-intensive industrial sector.

The substantial demand declines in advanced economies contrast sharply with the growth observed in emerging economies such as China and India. Japan is similarly expected to record a significant 3% fall in electricity demand in 2023, while the United States is set to see a decrease of almost 2%. In contrast, China's electricity demand is expected to increase by 5.3% in 2023 and 5.1% in 2024, slightly below its 2015-2019 average of 5.4%. India is set to have an average annual growth rate of 6.5% over the outlook period, surpassing its 2015-2019 average of 5.2%.

Declines in fossil-fired electricity generation are becoming structural

The accelerated pace of new renewable capacity additions shows that renewable generation could surpass coal as early as 2024, if weather conditions are favourable. This is supported by the expectation that coal-fired generation will slightly decline in 2023 and 2024 after rising 1.5% in 2022, when high gas prices boosted demand for alternatives. Increases in coal-fired generation in Asia in 2023 and 2024 are poised to be offset by strong drops in the United States and Europe.

Renewables are set to meet all additional demand in 2023 and 2024. With global demand growth easing in 2023, incremental increases in renewables alone are expected to cover all additional demand not only this year, but also in 2024, when demand growth is expected to accelerate again. By 2024, the share of renewable generation in global electricity supply will exceed one-third for the first time.

By 2024, electricity generation from fossil fuels is expected to have fallen four times in six years. Declines in fossil-fired generation were rare in the past and occurred primarily after global energy and financial shocks, such as following the oil crises of the 1970s or during the Great Recession in 2009, when overall electricity demand was suppressed. But in recent years, fossil-fired supply has lagged or fallen even when electricity demand expanded. These trends – driven by the strong growth in renewable generation – suggest the declines in fossil electricity generation are becoming structural. The world is rapidly moving towards a tipping point where global electricity generation from fossil fuels begins to decline and is increasingly replaced by electricity from clean energy sources.

Emissions from power generation are poised to dip slightly through 2024

Increases in emissions from power generation in China and India are expected to be more than offset by declines in other regions. The European Union alone accounts for 40% of the total decline in emissions from power generation expected to occur in 2023 and 2024, excluding China and India. The EU is followed by the United States, where renewables deployment is growing strongly, and gas is increasingly replacing coal-fired supply. Extreme weather, unexpected economic shocks and changes to government policies can cause an uptick in emissions in specific years. However, the overall trend of global power sector emissions plateauing is expected to persist, with years in which emissions decline, not rise, becoming more frequent.

Wholesale electricity prices signal increased need for flexibility

The number of hours in which electricity prices dropped below zero doubled in European countries such as Germany and Netherlands in the first half of 2023 compared to the same period in 2022. This was driven by strong renewables output at times of significantly reduced demand. Meanwhile, in other markets such as South Australia, which has a very high penetration of variable renewables, the trend was even starker. Prices on the wholesale electricity market there fell below zero almost 20% of the time in 2022, compared to less than 1% of the time in Germany and the Netherlands. Negative prices indicate generation is not sufficiently flexible, the demand side is not adequately price-responsive or there is not enough storage to conduct energy arbitrage. Negative prices also provide signals to invest in solutions and technologies to improve system flexibility. These signals will have to be accompanied by updated regulatory frameworks to incentivise demand-side flexibility and storage in order to increase the flexibility of the broader system.

Wholesale electricity prices remain elevated in many countries despite substantial declines, although there are regional differences. As prices for energy commodities such as gas and coal have fallen significantly in the first half of 2023, wholesale electricity prices in many regions have declined from their previous peaks. European wholesale prices halved from their record highs in 2022, falling closer to their 2021 average. Despite this, average prices in Europe are still more than double 2019 levels. Similarly, average wholesale electricity prices in India in the first half of 2023 were still 80% higher than 2019 levels, and in Japan they were 30% higher compared to 2019. In contrast, wholesale electricity prices in the United States have almost fallen back to 2019 levels.

Impact of weather on electricity demand and supply is increasingly noticeable

Rising demand for cooling is straining the world's power systems. Summers with extreme temperatures are becoming more frequent in many regions, elevating electricity demand for cooling systems and stretching power supplies. As more households start purchasing air conditioners, the impact will increase in many countries – especially in emerging economies that currently have a much lower share of households with AC than advanced economies with comparable climates. Setting higher efficiency standards for air conditioning would greatly help limit the impact of additional cooling demand on power systems. To ensure system reliability, it will be crucial to have adequate backup generation capacities, encourage demand management and energy storage, accelerate grid investments, and enhance fuel supply security for power plants. Insufficient

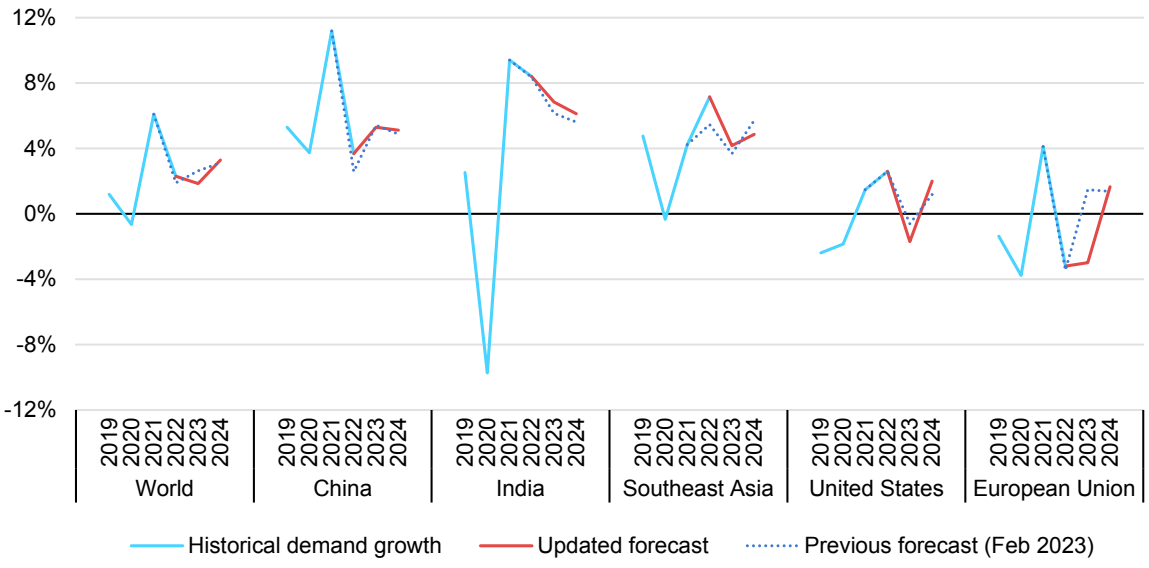
preparedness in these areas could lead to more frequent stress on grids, resulting in load-shedding and blackouts.

The availability of hydropower requires greater attention. The capacity factor of global hydropower has been in decline over the past decade, falling from an average of 38% in 1990-2016 to about 36% in 2020-2022. This difference of two percentage points means that, globally, today's hydropower capacity is producing about 240 TWh less electricity per year than would have been the case if capacity factors had remained unchanged. This indicates a volume of energy as large as Spain's annual electricity consumption needs to be supplied instead by other sources, a gap that is currently filled mostly by fossil-fired generation. Recent years saw intense droughts that caused a significant reduction in hydropower availability in affected regions such as Europe, Brazil and China. Anticipating challenges on hydropower related to climate change, and planning accordingly, will be crucial for the efficient and sustainable use of hydro resources.

Demand: Global electricity demand growth expected to ease in 2023

Russia's invasion of Ukraine and the ensuing global energy crisis ignited inflation and stifled economic growth in many parts of the world, as spiking gas and coal prices raised the cost of power generation and drove up electricity bills. Despite these headwinds, global electricity demand remained resilient in 2022, growing by 2.3%. The impacts of the crisis continued into 2023, with economic slowdowns observed in various regions and particularly pronounced declines in electricity demand in advanced economies. As a result, despite robust growth in emerging economies as well as record electric vehicle and heat pump sales leading to rising electrification rates in the transport and residential sectors, global electricity demand growth is expected to be subdued in 2023. Our previous growth forecast of 2.6% has been revised downward to 1.9%, which is slower than the 2.4% average annual growth over the 2015-2019 period. We forecast global electricity demand will grow at a higher 3.3% rate in 2024 as the economic outlook improves.

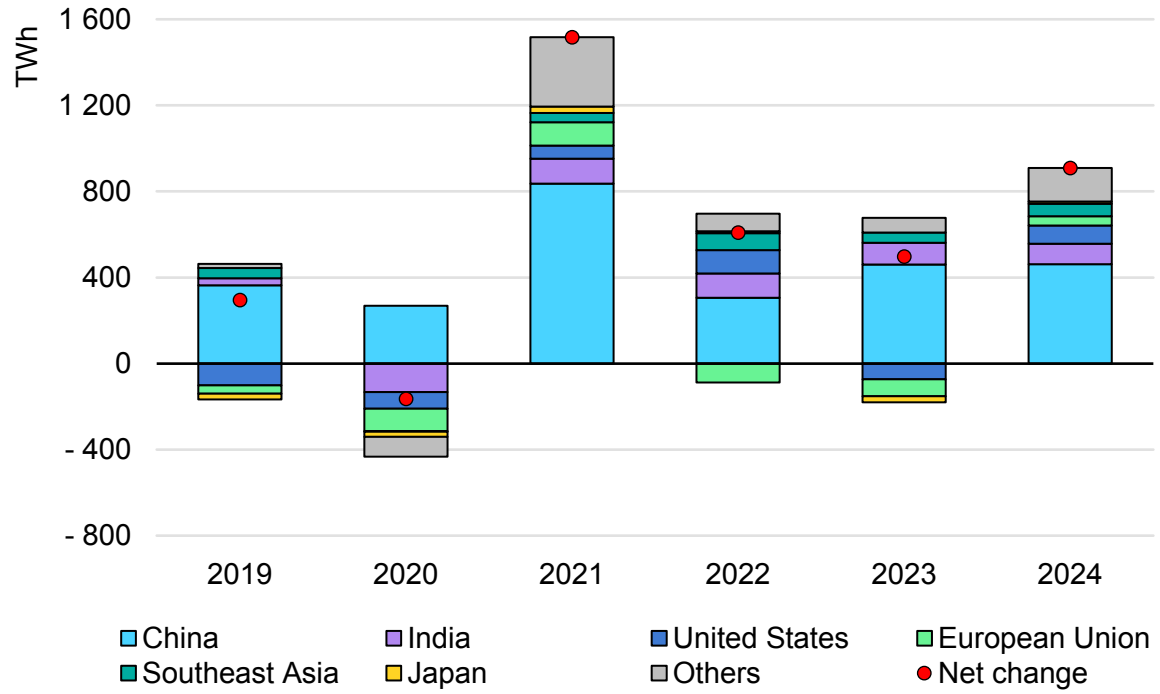
Year-on-year percent change in electricity demand in selected regions, 2019-2024



Robust growth in electricity demand in China and India, declines in the USA and the EU

After a moderate 3.7% year-on-year increase in electricity demand in 2022, we expect the People's Republic of **China** (hereafter, "China") to see 5.3% growth in 2023. Although the economic rebound following the easing of strict pandemic restrictions has not been as strong as some had anticipated, increasing cooling demand in the summer of 2023 is expected to further boost electricity demand. For 2024, we forecast demand growth to be slightly lower at 5.1%.

Year-on-year change in electricity demand in selected regions, 2019-2024



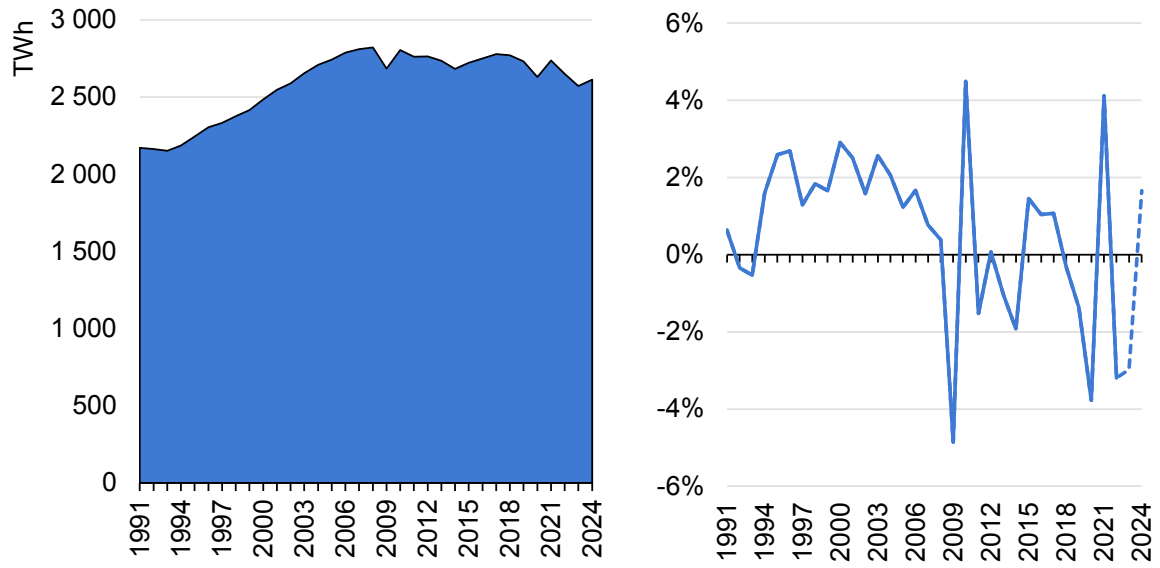
Note: The figures for 2023 and 2024 are forecast values.

In **India**, the strong post-pandemic recovery, combined with intense heatwaves, drove electricity demand up by 8.4% in 2022. We expect the strong growth trend to continue in 2023, at a rate of 6.8%. Growth of 6.1% is forecast in 2024, by when India's electricity consumption is expected to surpass that of Japan and Korea combined. The rapidly increasing demand in India will continue to be driven by an uptick in household appliances, a rise in electrical machinery usage, an increase in electric vehicles, and further expansion in cooling systems.

Electricity demand in the **United States** rose by 2.6% in 2022, driven by economic growth as well as increased heating and air conditioning use. While the weather in early 2023 has been milder than a year earlier, scorching summer temperatures,

especially in Texas, are expected to drive up electricity consumption for cooling. Despite that, overall cooling demand is estimated to have fallen year-on-year during H1 2023, as other regions have had a milder summer so far. At the same time, slowing economic growth is putting downward pressure on electricity demand, as indicated by the 16% year-on-year decline in the average manufacturing Purchasing Managers' Index in H1 2023. We expect electricity consumption in the US to decline by 1.7% in 2023 and then rebound in 2024 at a moderate 2% rate.

Evolution of electricity demand in the European Union (left) and its year-on-year percent change (right), 1991-2024



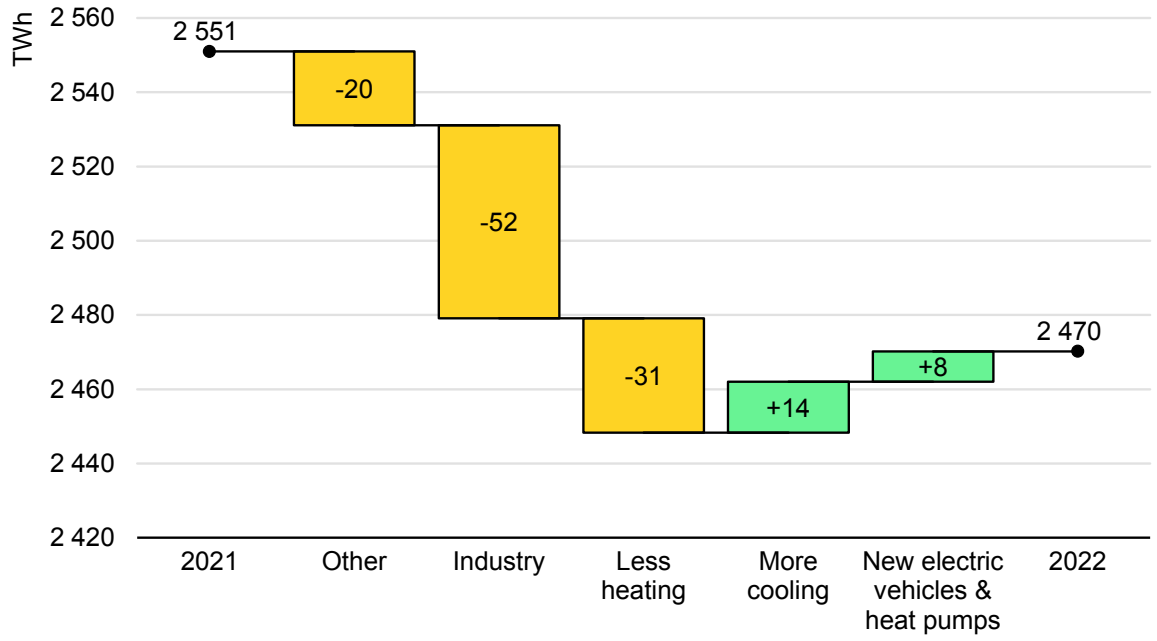
Note: The figures for 2023 and 2024 are forecast values.

The **European Union**'s electricity consumption decreased by 3.2% in 2022, the second largest drop since the 2009 global financial crisis, exceeded only by 2020's plunge due to Covid-19. The downward trend became apparent in the second half of 2022 and continued well into the first half of 2023. EU electricity demand in H1 2023 fell almost 6% from the same year-ago period. For the full year we expect an overall drop in demand of 3%. With that, EU electricity consumption will have declined for two years in a row at a rate unprecedented since the foundation of the Union. We anticipate a modest 1.7% rebound in 2024, but with significant uncertainty linked to the recovery of industrial demand. The biggest question is how much of the reduction in demand was temporary and how much will be permanent.

Is energy-intensive industry leaving Europe?

In a recent analysis discussing EU electricity demand in 2022, we showed that weather had a more limited effect than previously thought, as the exceptionally mild winter was partly offset by additional cooling needs during the hotter summer. Most of the demand reduction occurred because of non-weather-related factors, with nearly two-thirds of the net decline estimated to be due to the reduction in demand from energy-intensive industries amid high energy prices. Behavioural changes in the residential and services sectors, voluntary energy savings, affordability issues, and a variety of efficiency improvements also played a significant role.

Estimated drivers of change in electricity demand in the European Union, 2022 vs. 2021



Note: *Other* encompasses behavioural changes in consumption in the residential and services sectors, energy savings, reductions due to affordability issues and efficiency gains.

Many energy-intensive industries reduced or ceased production in 2022

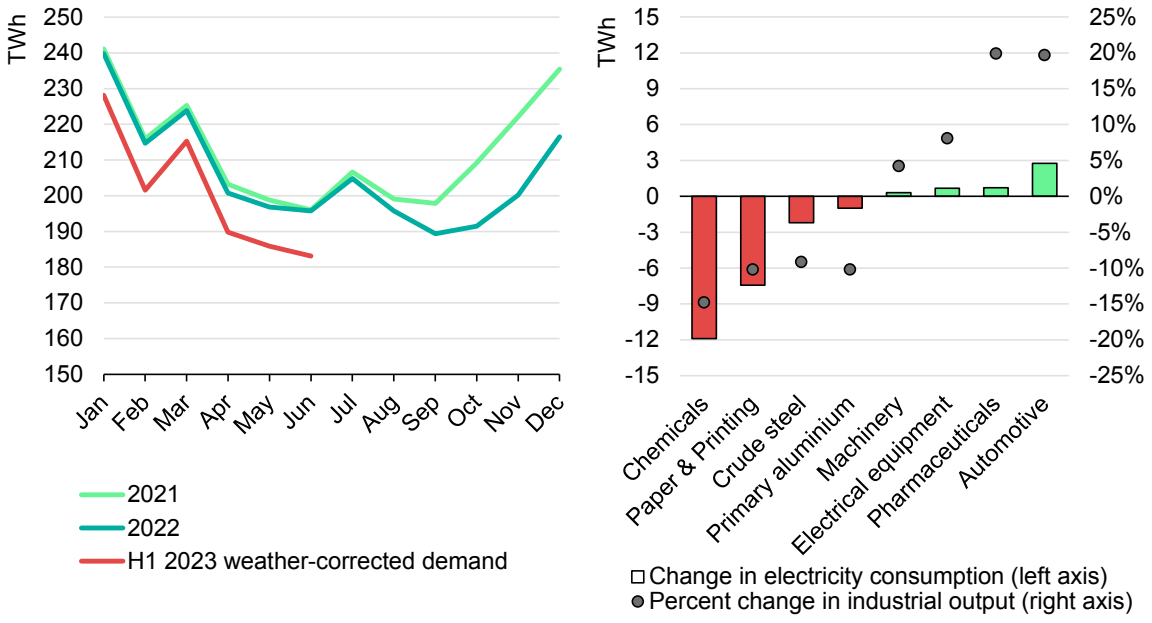
Among the energy-intensive sectors which significantly reduced production in 2022 because of plant shutdowns and production curtailments were primary aluminium (-12%), crude steel (-10%), paper (-6%) and chemicals (-5%). The decrease in domestic chemical production led to Europe becoming a net importer of chemicals in 2022 as key industry players such as BASF and OCI reduced output in the region. The fertiliser industry has seen a sharp reduction with large

European producers such as Yara and Grupa Azoty curtailing production of ammonia, urea, nitrates and NPK (nitrogen, phosphorus, and potassium) fertiliser. Steel production in Europe has decreased significantly as companies such as ArcelorMittal temporarily shut furnaces in France, Poland, Spain and Germany. Aluminium producers have been badly hit by increased electricity prices given the electricity-intensive nature of the sector, with several companies such as Speira GmbH and Alro cutting production.

No rebound in overall energy-intensive industrial output in sight in the first half of 2023

For the first half of 2023, weather had a limited impact on the staggering 6% year-on-year decline in overall electricity demand in Europe as a milder January was largely offset by a colder February. Consequently, the main drivers of the decline in H1 2023 have been non-weather-related factors, with no significant rebound in the overall output of energy-intensive industries despite wholesale prices coming down from their record highs. Some companies in the steel industry started reversing their curtailments that had been implemented in 2022. However, in sectors such as aluminium, temporary production cuts were followed by permanent closures, producers such as Talum and Slovalco being two examples of companies permanently halting the production of primary aluminium.

Monthly electricity demand in 2021-2023YTD in the European Union (left) and year-on-year changes in Q1 2023 in industrial output and estimated electricity consumption in selected industries (right)



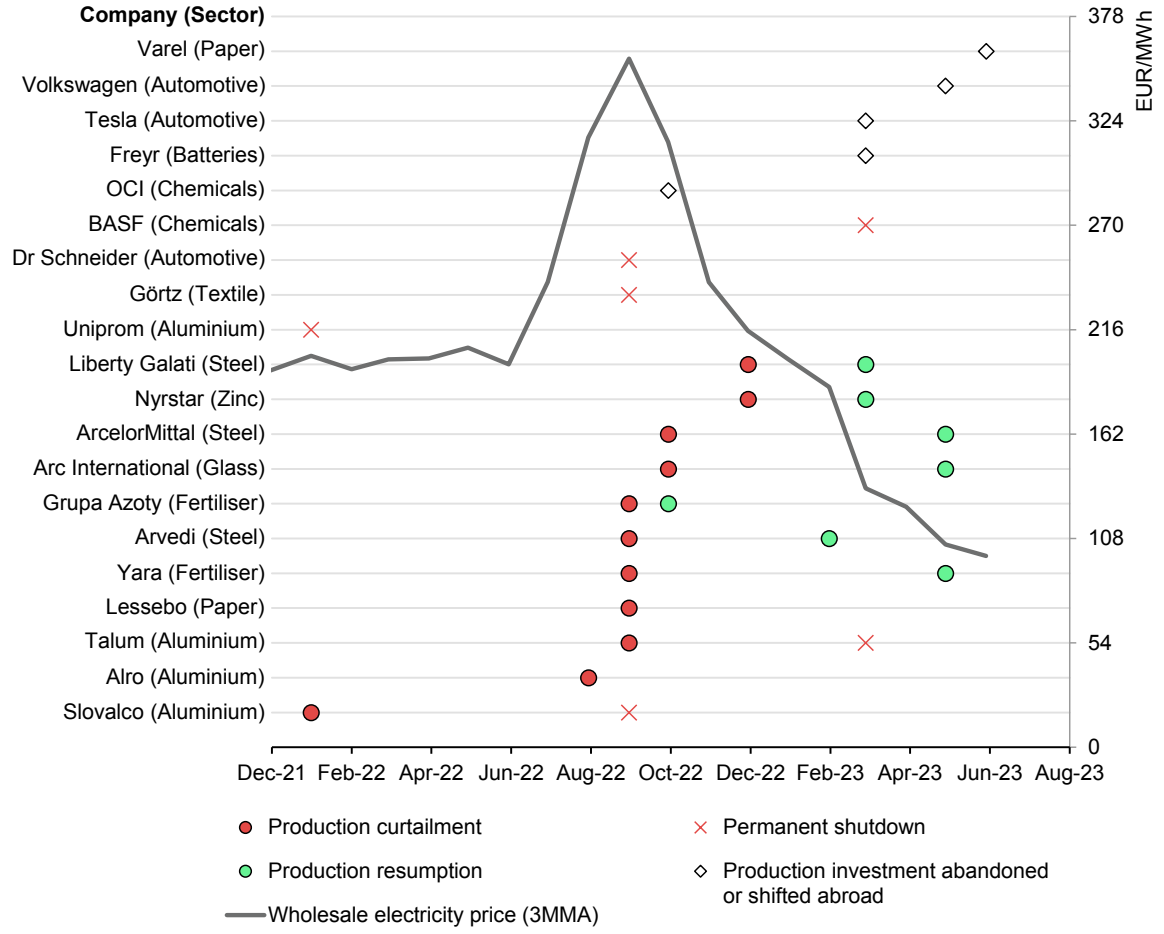
Source: IEA analysis based on data from IEA (2023), Monthly Electricity Statistics; Eurostat (2023), Final Energy consumption in industry; CEFIC Chemical Monthly Report, International Aluminium Institute, World Steel Association.

Industrial competitiveness in Europe is under pressure

The competitiveness of European energy-intensive industry is threatened by high energy costs. Another challenge is support packages overseas, such as the Inflation Reduction Act (IRA) in America, the Green Transformation Act in Japan and tax incentives in China. These developments are influencing production curtailment, plant closures, and the pausing and diverting of investment. Chemical group BASF has announced plant closures and permanent downsizing in Europe. Volkswagen paused plans for a battery plant in Eastern Europe and is instead building a factory in Canada, taking advantage of lower electricity prices and the Canadian Inflation Reduction Act. German paper producer Varel abandoned plans to expand production capacity, citing high costs and uncertain economic outlook as the reasons of its decision. Small and medium-sized businesses in industries such as paper and automation have gone insolvent as high energy prices mean they are no longer profitable. Bankruptcies among EU businesses reached a record high in Q4 2022, up about 27% percent from the previous quarter, with high energy costs being a major driver. The vast majority were small and medium-sized enterprises.

The EU has taken several steps to support industry, first relaxing state aid rules by adopting the Temporary Crisis Framework in response to Russia's invasion of Ukraine and then expanding this to the Temporary Crisis and Transition Framework. These frameworks enable member states to compensate companies for high electricity costs, and governments across Europe consequently enacted policies to support energy-intensive industry. For example, both Germany and France launched EUR 5 billion aid programmes with up to EUR 50 million available for each of the worst affected companies. Germany has proposed an electricity price cap for energy-intensive companies to ensure that they remain in Germany and do not relocate abroad. The Temporary Crisis and Transition Framework also allows state aid for investment in industries necessary for the transition to a net zero carbon economy. In conjunction with the Commission's Green Deal Industrial Plan, these measures add up to an effort to create a more supportive environment to the industry that is facing competition from abroad.

A selection of companies in Europe that have announced curtailment, permanent shutdowns and abandoning of investment plans, and the average wholesale electricity price in the European Union



Note: The companies shown were selected according to the availability of public data on their operations. The figure shows the date of the announcement and does not necessarily mean the exact date on which the production decisions were implemented. Announcement dates have been rounded to the nearest month for clarity in presentation. Average monthly wholesale prices shown in this figure are demand-weighted. 3MMA stands for the 3-month moving average. The wholesale electricity price does not directly correspond to the price paid by the industry, but is intended to provide an overview of the development of energy costs. It should also be noted that in some industries that consume large amounts of electricity, gas has a higher share of energy consumption (e.g., glass industry) or is used as a feedstock (e.g., chemical industry). In these industries, the price of gas plays a more significant role in costs and operational decisions than the electricity price.

Sources: Yara, Yara implements further production curtailments in Europe; Green Markets, Yara Ending Nitrate and NPK Curtailments Amid Stronger European Demand; GMK Center, ArcelorMittal begins temporary shutdowns of steel plants capacities in Europe; GMK Center, ArcelorMittal Dunkirk plans to restart BF №4 in June 2023; Reuters, Nyrstar's Auby zinc plant on care and maintenance until further notice; Nyrstar, Nyrstar's plant in Auby, France resumes production on a variable basis; Alro, The prohibitive power and natural gases prices force ALRO Group to take decisive decisions for preserving the Group's assets value; Reuters, Grupa Azoty halts production of fertilizers due to high gas prices; Grupa Azoty, Grupa Azoty Group companies resume production; GMK Center, The Italian rolling mill Alvedi shut down three electric arc furnaces; S&P Global, Back in action: European mills restart idled blast furnaces on higher flat steel prices; The New York Times, 'Crippling' Energy Bills Force Europe's Factories to Go Dark; Lessebo Paper, €16 million in increased electricity cost forces Lessebo Paper to halt production; Financial Times, BASF outlines further cost-cutting and 2,600 job losses as it downsizes in Germany; Reuters, Germany to loosen insolvency rules as energy crisis hits hard; Hydro, Slovalco will stop primary aluminium production; SeeNews, Slovenia's Talum to halt primary aluminium output, cut 120 jobs - report; Reuters, Battery start-up Freyr accelerates U.S. plans on IRA support; The Wall Street Journal, High Natural-Gas Prices Push European Manufacturers to Shift to the U.S; Reuters, Tesla scales back German battery plans, won over by U.S. incentives; The Wall Street Journal, Volkswagen Pivots to North America as Europe Loses Its Shine; Reuters, Factbox: Europe's aluminium smelters cut output as power crunch intensifies; Glass International, French glass production plants reignite furnaces after energy shutdowns; Reuters, Column: Europe's power crunch sparks aluminium smelter meltdown: Andy Home; Reuters, Slovenia's Talum cuts primary aluminium output to 20% of capacity.

The future of EU energy-intensive industry is at a crossroads

In the face of rising energy costs, the European Union stands at a critical juncture to decide its course of action regarding energy-intensive industries. The options range from minimal aid, which would require a shift to a high-value goods economy but also increase vulnerability to geopolitical tensions. A targeted aid strategy could provide fiscal prudence while retaining control over key sectors. Another option entails extensive support through energy price subsidies, preserving industry and jobs but burdening other consumers and taxpayers, and necessitating a long-term commitment. Lastly, the EU could ramp-up decarbonisation and renewable energy efforts to fuel green heavy industry, which would be in line with its climate goals but bear significant upfront costs. There is no easy path forward, as each choice comes with its own set of challenges and potential benefits.

Cooling demand is an increasing challenge for the world's power systems

Extreme summer temperatures are becoming more frequent in many regions of the world, raising electricity demand for cooling and straining power systems. As highlighted by the IEA's report on the Future of Cooling, there is enormous upside potential for new air conditioner installations in the world. The share of households equipped with air conditioners in emerging economies such as Mexico, Brazil and Indonesia is less than one-third of those in advanced economies such as the United States, Japan and Korea. As more homes install ACs, their impact on power systems will grow in many countries.

Setting higher efficiency standards for ACs can reduce their energy burden. For system reliability, it will be crucial to maintain the necessary backup generation capacities, incentivise demand management and storage, accelerate investments in grids and strengthen the security of fuel supply to power plants. Insufficient preparedness could put additional strain on grids, increasing the likelihood of load-shedding and eventually power outages.

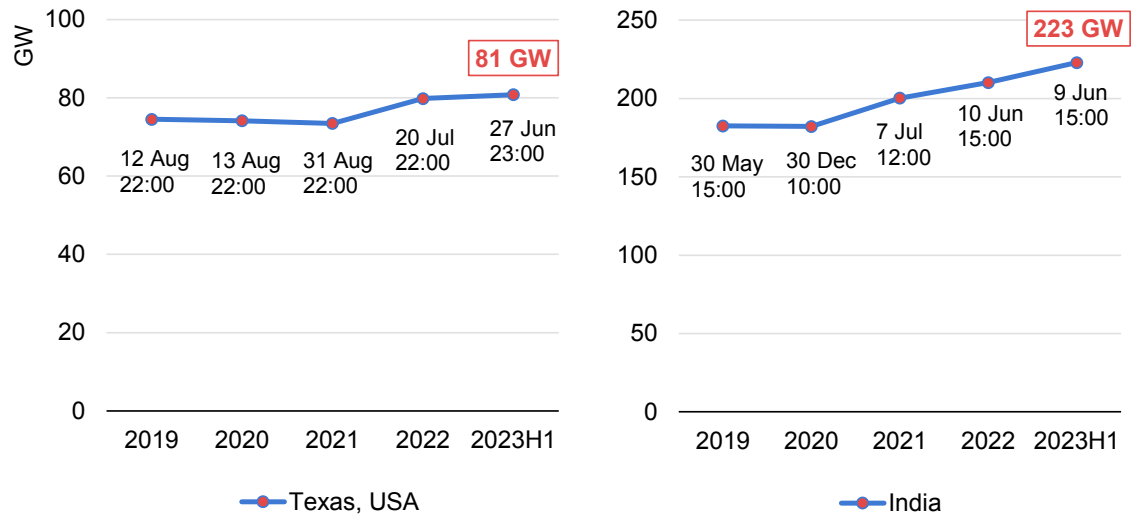
During the summer of 2022, the Texas power grid witnessed 11 peak demand records, leading ERCOT officials to urge energy conservation. Similarly, in Sichuan, China, unusually high temperatures in August 2022 led to a substantial surge in electricity demand for cooling, straining the grid and causing a power shortage. As a result, consumers were asked to take steps to conserve energy. India also experienced widespread electricity outages and load-shedding in over half of its states during the heatwaves of April-May 2022, as the energy system struggled to meet record power usage.

Summer 2023 is becoming another stress test for system adequacy in many regions

In **China**, the China Electricity Council estimates that peak demand will reach 1 370 GW in 2023, an increase of about 80 GW compared to 2022. In case of extreme weather, China's maximum power load is expected to increase by about an additional 20 GW. Chinese power supply and demand balance is therefore set to remain tight this summer. To prepare for large-scale power outages, in June 2023 China conducted its first emergency drill with the National Energy Administration and regional governments from East China. Energy regulators, power grid and power generation companies, the Shanghai subway network, hospitals and the chemical industry also participated in the exercise.

In the **United States**, the National Oceanic and Atmospheric Administration forecasts a 50% to 70% likelihood of higher-than-average temperatures for June through September 2023 in most parts of the country. According to the 2023 Summer Reliability Assessment of NERC, while all regions in North America have sufficient generation to meet summer demand and reserve requirements under normal conditions, energy shortages may still occur during extreme operating conditions caused by heat, wildfires, and other grid disturbances. The NERC suggests that the retirement of generation facilities amid increased penetration of variable energy resources, high demand in multiple locations, project delays or generator maintenance could further exacerbate reliability risks.

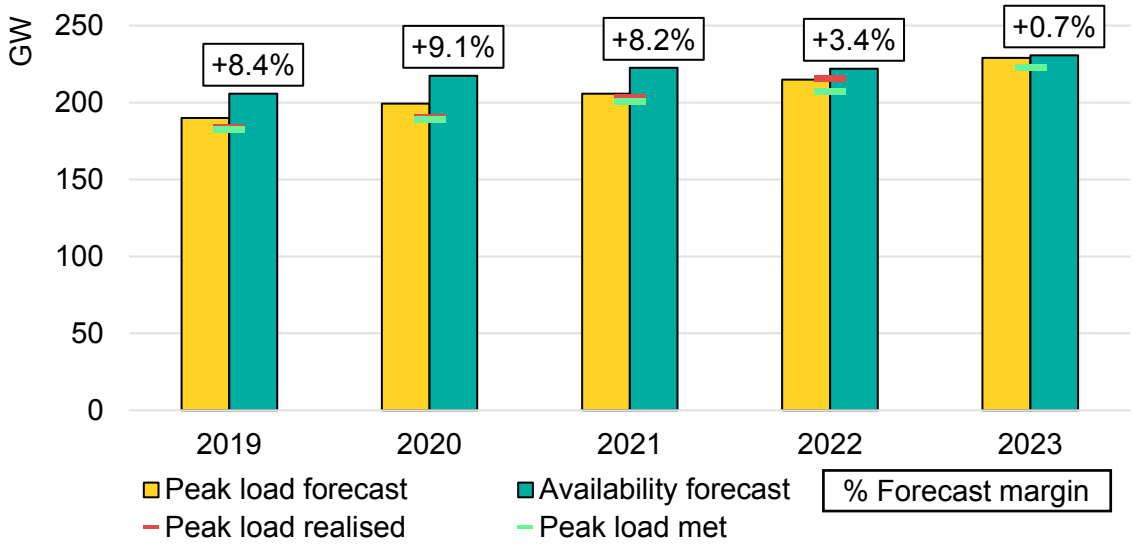
Evolution of the annual grid peak load in Texas (left) and in India (right), 2019-2023H1



Sources: IEA analysis based on data from Load Generation Balance Reports of the Indian Central Electricity Authority and ERCOT

In **India**, Central Electricity Authority's Load Generation Balance Report 2023-24, published in March 2023, estimates that sub-regions in India may face power supply deficits ranging from 4% to 11.3% of their respective peak demand. However, as each region is expected to experience its peak demand at different times, power imports and exports between regions would allow for some balancing. The country as a whole is expected to have a surplus of only 0.7% to meet the peak electricity demand (estimated at around 230 GW), indicating a tight supply situation. In June 2023, with increasing temperatures, peak demand of 223 GW was already observed. India has installed significant solar generation capacities in recent years, which helps meet daytime peak demand for cooling. However, evening peaks when the sun does not shine but temperatures remain very high pose a significant challenge to the system. In such evening hours, the sufficient availability of dispatchable capacities of hydro, coal- and gas-fired power plants becomes crucial. New generation capacity additions in recent years have lagged behind the increase in peak power demand, leading the Ministry of Power in June 2023 to issue guidelines for Resource Adequacy Planning Framework for electricity to ensure that generation capacity is added at a pace matching growth in demand. A new tariff scheme was also outlined, which introduces varying time-of-day tariffs between solar hours, normal hours and peak hours to incentivise the shifting of demand from the evening to daytime. The new tariffs are to come into effect during 2024 and 2025.

Evolution of the forecasts for peak load, availability and margin of the Indian Central Electricity Authority vs. the realised and met peak load, 2019-2023



Note: The peak load met for 2023 shows the highest peak load recorded to date in the first half of 2023 (223 GW on 9 June) that was met. Forecast margin refers to the relative difference between the availability forecast and peak load forecast.

Source: IEA analysis based on Load Generation Balance Reports of the Indian Central Electricity Authority.

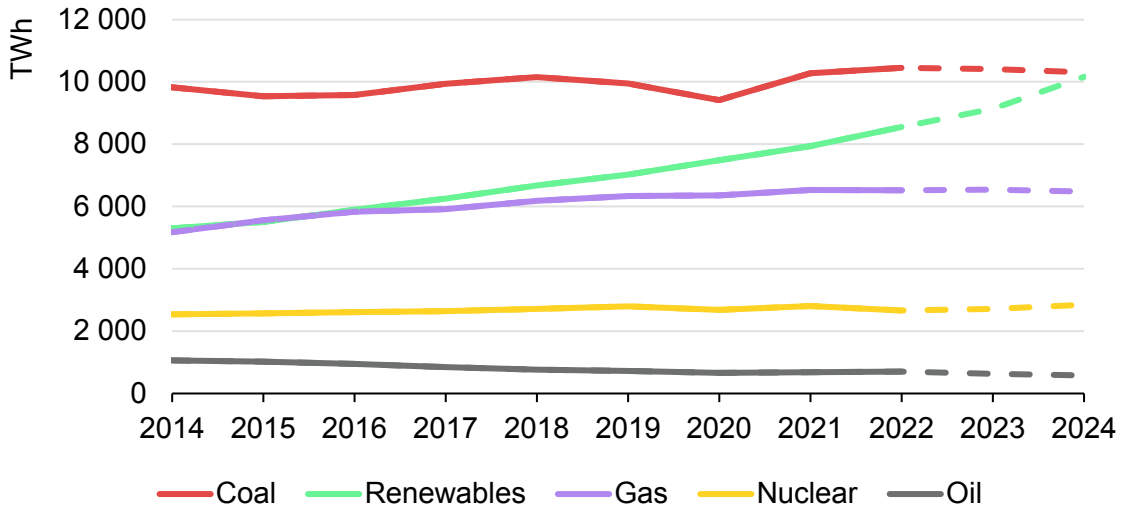
In **Europe**, according to the summer outlook of the European Network of Transmission System Operators for Electricity (ENTSO-E), no major adequacy risks are expected for the summer of 2023. Nevertheless, as shown in our recent analysis, additional demand from cooling remains substantial, especially in Southern Europe and France. In the case of unexpected unavailabilities, electricity imports will play a significant role to meet demand, as also highlighted by the ENTSO-E outlook.

Supply: Renewable generation set to overtake coal

In December 2022, IEA's Renewables 2022 report estimated that renewable generation will overtake coal as the largest source of electricity by early 2025. Our analysis now shows this moment could come as early as 2024 under favourable weather conditions as a result of the accelerated pace of renewable capacity additions highlighted in the Renewables June 2023 Update, as well as because of the plateauing of electricity generation from coal. Coal-fired generation grew by 1.7% in 2022, supported by gas-to-coal switching in many regions due to high gas prices, but is expected to decline slightly in 2023 and 2024 as increases in Asia are offset by strong declines in the USA and Europe.

Gas-fired power generation remained relatively flat in 2022 and we expect a slight increase of less than 1% in 2023. This upward revision from our previous forecast is mainly driven by strong increases in the United States as well as a return to coal-to-gas switching in various other regions because of lower gas prices. However, a colder winter and potential supply issues, especially in Europe, could boost gas prices again and support renewed gas-to-coal switching.

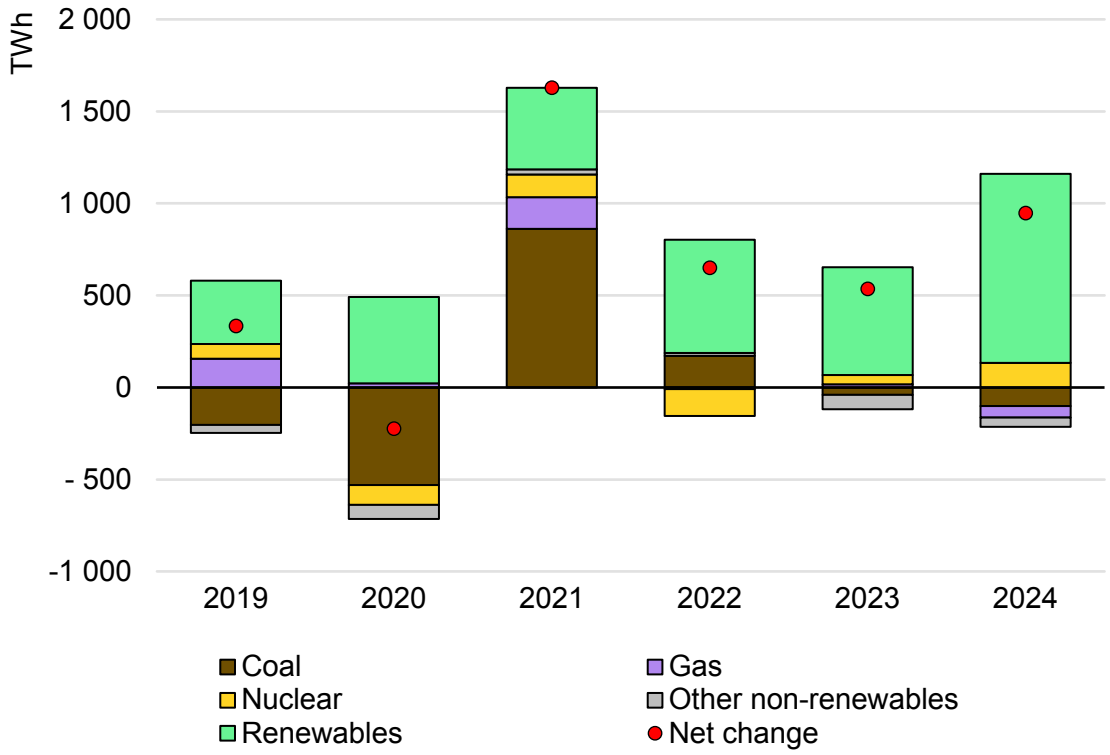
Global electricity generation by source, 2014-2024



Renewables alone are expected to meet all electricity demand growth in 2023 and 2024

Despite reduced hydropower generation due to droughts in many regions, global renewable generation grew in 2022 by 7.8%, its highest growth rate over the last 30 years. We expect growth of slightly less than 7% in 2023, as hydropower is reduced in some regions by recurring droughts. Renewable electricity generation should then grow by 11% in 2024, driven by continued wind and solar capacity expansions and assumed hydropower recovery in various regions. By 2024, the share of renewables in global electricity generation is expected to exceed one-third for the first time in history. With demand growth easing in 2023, the incremental growth in renewable generation alone is expected to cover all the additional demand increase, and will do the same in 2024 even as demand growth is expected to accelerate again.

Year-on-year global change in electricity generation by source, 2019-2024

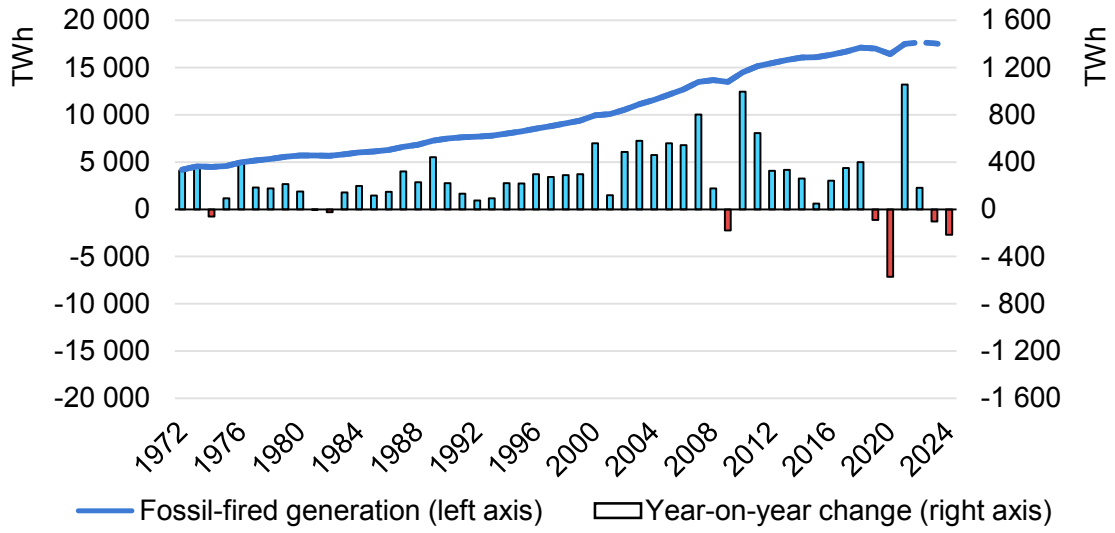


Note: *Other non-renewables* includes oil, waste and other non-renewable energy sources. The figures for 2023 and 2024 are forecast values.

Declines in fossil-fired electricity generation are becoming structural

In 2024, electricity generation from fossil fuels will have declined for the fourth time in six years. After subdued 1% growth in 2022, fossil-fired generation is set to fall slightly by 0.6% in 2023 and by 1.2% in 2024. Declines in fossil electricity generation were rare in the past, coming primarily when overall electricity demand was depressed by major global energy and financial crises, such as in the aftermath of the oil crises of 1970s or during the Great Recession in 2009. But in recent years fossil-fired generation has lagged or fallen even when overall electricity demand expanded.

Evolution of global electricity generation from fossil fuels, 1972-2024



Note: The figures for 2023 and 2024 are forecast values.

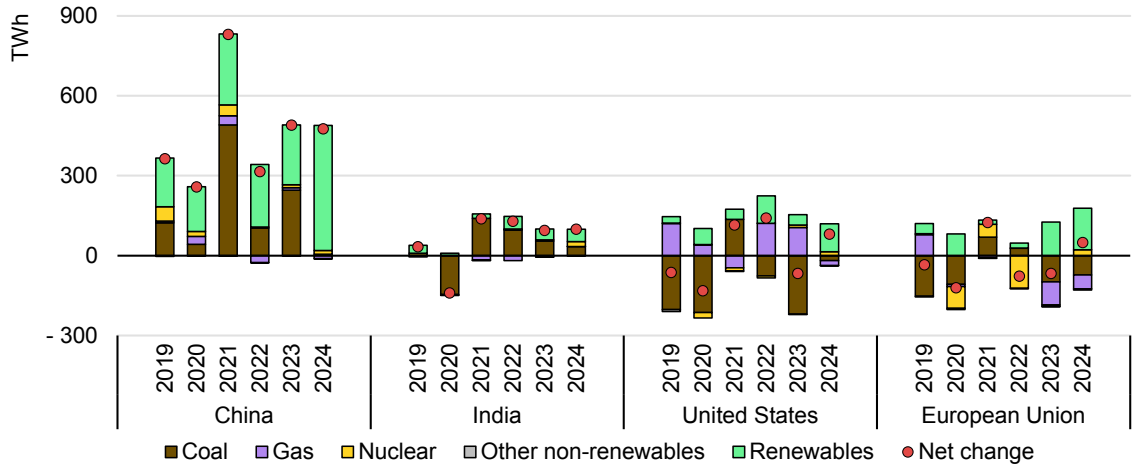
In 2019, generation from fossil fuels decreased as mild weather both restrained demand growth and was favourable for renewable generation. The 2020 decline in fossil-fired generation was driven by an exceptional economic slowdown because of the global pandemic, while a strong 6% rebound in 2021 was short-lived. There was only modest growth in electricity supply from fossil fuels in 2022, despite demand growing by 2.3%. Similarly, expected declines in fossil-fired output in 2023 and 2024 will occur during predicted significant demand growth, while renewable generation continues to increase strongly. While droughts, global economic events or government policies can cause isolated rebounds in fossil-fired electricity, recent demand and generation trends suggest that declines are becoming structural. Hence, the world is accelerating toward a tipping point where global fossil-fired generation begins to fall as it is increasingly replaced by supply from clean energy sources.

Coal-fired generation increases in China and India, while it shrinks in the US and the EU

As in 2022, **China** again suffered droughts in 2023. The substantial 23% decline in hydropower output in the first half of 2023 meant more coal-fired generation was needed to fill the gap, which is estimated to have increased by almost 8% in H1 2023 amid significant growth in demand. The sharp year-on-year increase was also driven by a comparison effect with the same period in 2022 when demand growth and coal-fired generation slumped during strict Covid measures. Wind generation grew by about 20% in H1, supported by growth in installed capacities and favourable weather. We expect coal-fired output to increase by 4.5% for the full year, and then to stay roughly flat in 2024, as strong growth in renewables and nuclear puts downwards pressure on coal. Gas-fired supply is expected to increase about 3% in 2023 and to decline by 4% in 2024.

India recorded a 3.8% increase in coal-fired generation in H1 2023, boosted by strong demand growth amid reduced hydropower output (-8%). With heat waves expected to cause surges in peak demand due to increased cooling, the government ordered coal plants to run at full capacity from 16 March to 30 September 2023 to increase security of supply. This order is expected to especially affect coal plants that use imported coal and were not operating at full capacity. Solar generation also increased strongly in H1 2023 by 26% compared to previous year. We forecast coal-fired generation in India for the full year to increase by 4.2%, and to continue its increase in 2024, albeit at a slower pace of 2.5%, as renewables and nuclear are expected to expand significantly to meet a higher share of the growing electricity demand.

Year-on-year change in electricity generation by source in selected regions, 2019-2024



Note: *Other non-renewables* includes oil, waste and other non-renewable energy sources. The figures for 2023 and 2024 are forecast values.

The **United States** saw significant growth in solar power generation of 10% in the first half of 2023 compared to the same period in 2022. In contrast, generation from wind underperformed, recording a 1% year-on-year decline. Coal-fired plants continued to close, with coal-fired generation falling by almost 30% in H1 2023 compared to H1 2022. A total of more than 10 GW of coal-fired capacity is planned to be retired this year. Gas-fired generation grew by 8%, supported by the fall in gas prices and because gas increasingly had to meet residual demand amid declining coal generation. We expect this trend to continue for the full year, with coal ending 2023 with a decline of 24% and gas with an increase of 6%. The decline in coal-fired supply is expected to be significantly narrower in 2024 at 3%, and gas is expected to decline slightly by about 1%.

In the first half of 2023 the **European Union** saw hydropower generation rebound by 10%, as drought conditions eased. The increase in wind generation was limited to about 5% due to unfavourable weather, while solar saw big gains with 14% growth. The share of renewables in total generation in H1 2023 rose to a record 43%, the previous high being 39% during the exceptional pandemic year of 2020. This record was also driven by electricity demand declining by almost 6% in the same period, with a strong year-on-year drop of 22% in coal-fired generation in H1 and an 18% decline in gas-fired generation. We expect these trends to continue, and assuming normal weather conditions for the winter and a full year demand decline of 3%, we forecast for the full year 2023 an almost 16% decline for gas and a 20% decline for coal. As renewables continue to increase and the French nuclear fleet continues to recover, gas (-11%) and coal (-19%) are expected to further decline in 2024.

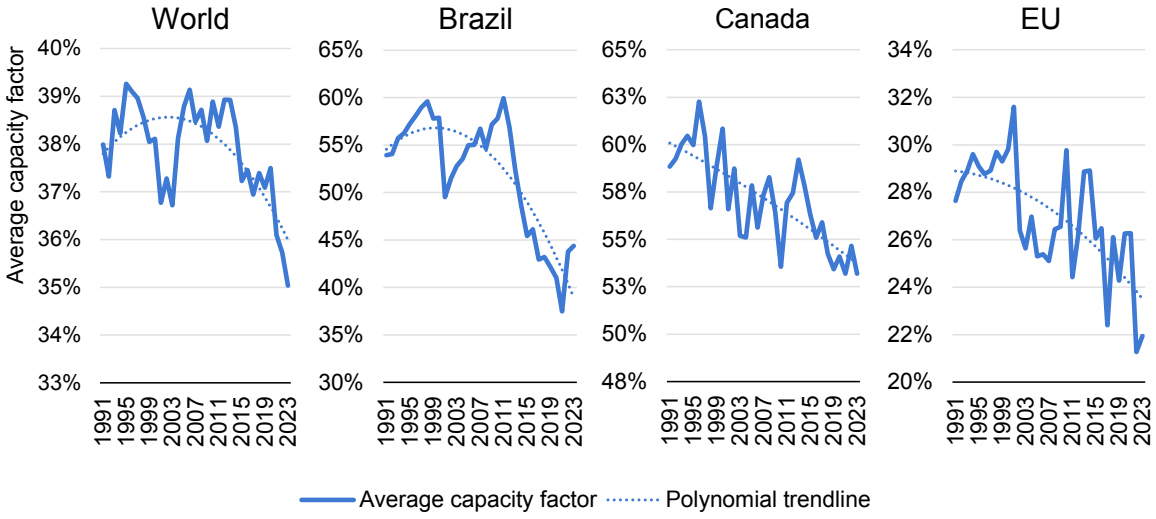
Are lower hydropower capacity factors the new normal in some regions?

The capacity factor of global hydropower has been on a declining trend over the last decade, falling from an average of 38% in 1990-2016 to about 36% in the recent years 2020-2022. This two-percentage-point difference means that, globally, today's hydropower installed base is producing about 240 TWh less electricity annually than what it would have produced had capacity factors stayed where they were a decade ago. As a result, an amount of energy as large as Spain's annual electricity consumption needs to be produced by other dispatchable sources of power, which is currently supplied mainly by fossil-fired generation. Hydropower is typically considered a dispatchable source of electricity generation; however, its output is dependent on hydrological conditions, primarily precipitation. Hydropower generation is therefore substantially affected in the case of droughts. In river basins that depend on snow melts, temperature patterns also come into play.

Average capacity factors in Brazil, Canada, and the European Union have declined over the last two decades

The most striking fall has been in **Brazil**, where hydro capacity factors recorded a staggering drop from an average of 56% in 1990-2012 to an average of 44% in 2013-2022. Severe droughts in 2014-2017 and 2019-2021, especially in states like Sao Paulo, Rio de Janeiro, and Minas Gerais, caused water shortages, crop production declines, and power cuts. During droughts, priority access to water is given to human and animal consumption, followed by irrigation, and only then hydropower. The outlook for hydropower generation in 2023 is much improved. Hydroelectric reservoir levels reached a 12-year high by May 2023 due to heavy rainfall and average capacity factors are expected to rebound significantly for 2023. Nevertheless, insufficient reservoirs are resulting in the release of surplus water and curtailment of potential hydropower generation as reservoirs maintain a waiting volume to reduce the risk of flooding in the case of heavy rain.

Evolution of annual hydropower capacity factors in selected regions, 1991-2023



Note: 2023 values are based on the latest IEA Renewable Energy Market Update projections.

Canada has also seen reduced hydropower capacity factors, dropping from an average of 58% between 1990 and 2015 to 54% from 2016 to 2022. Western Canada, including British Columbia and Alberta, has faced recurrent droughts. In 2015, southern British Columbia experienced the highest drought rating, and Alberta declared an Agricultural Disaster Area with strict water restrictions. Droughts in 2017 and 2020-2021 in the south and west of Canada further impacted agriculture, ecosystems, and water resources. Moreover, regional differences in precipitation and hydropower generation can be observed across Alberta, British Columbia, Ontario and Quebec.

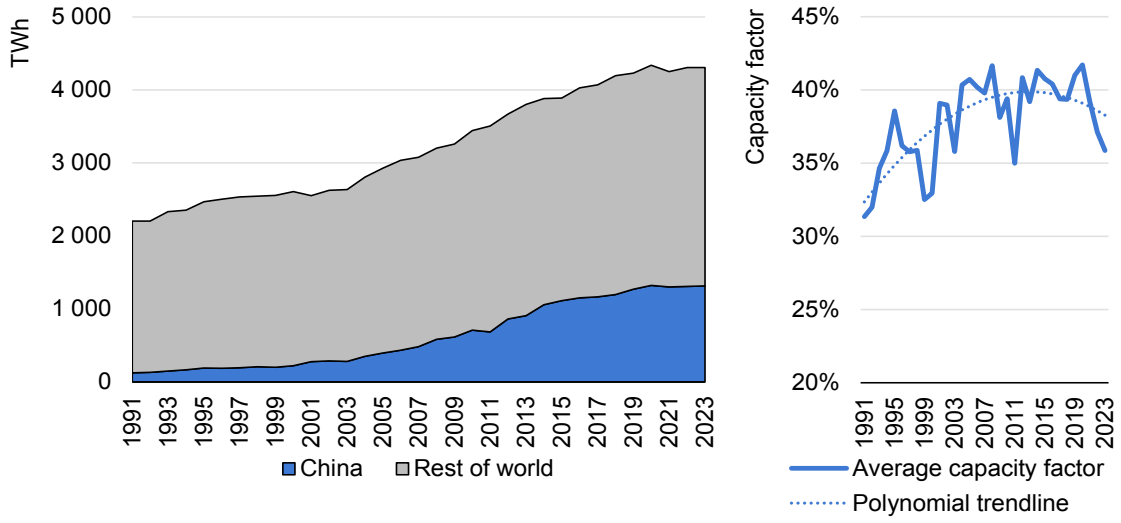
The **European Union** also witnessed a downward trend in hydropower capacity factors, declining from an average of 28% between 1990 and 2014 to 25% from 2015 to 2022. Severe droughts hit Southern Europe in 2017, and Central and Eastern Europe in 2018. The drought in 2022, reported as the worst in Europe in 500 years, affected a large number of countries across Europe, hurting agricultural production, hydropower generation, and even putting pressure on nuclear power cooling systems due to insufficient water availability. EU hydropower generation was down by almost 19% in 2022 compared to 2021 – a historic decline in the last 30 years.

Upward trend in China is constrained by droughts three years in a row

Although average capacity factors in regions like Brazil, Canada and the EU have been on a downward trend in recent years, the decline in the world average has been somewhat limited, primarily due to additions of newer and more efficient plants in countries such as **China.** As of 2022, 30% of world's hydropower generation took place in China. This massive scale means that any changes in Chinese hydro regimes have a large impact on global statistics.

The capacity factor in China rose from an average of 37% over 1990-2008 to an average of 39% in 2009-2022, resulting from the building of large, more efficient hydropower plants such as the Three Gorges Dam. There was a significant fall in 2021 and 2022 due to major droughts, and the current drought in 2023 prevents a significant uptick.

Evolution of hydropower generation (left) and annual capacity factor of hydropower (right) in China, 1991-2023



IEA. CC BY 4.0.

Note: 2023 values are based on the latest IEA Renewable Energy Market Update projections.

Location, increasing VRE share, and water priority rules also play a role in hydropower output

Aside from droughts, hydropower utilisation is affected by multiple other complex drivers. One of the potential factors is that, generally, the best locations are already exploited, leaving additional capacities to be built at sites with comparatively less potential. In addition, there are significant disparities in the ages of the hydropower plants in different regions. As highlighted in the IEA Hydropower Special Market Report, North America has the oldest hydropower fleets (50 years on average), whereas China has the youngest (15 years). Age differences in power plants can also influence the average capacity factors, with older plants likely to have lower capacity factors compared to newer plants of the same type and characteristics.

The need to balance growing shares of variable renewable energy (VRE) in many countries is also likely to impact how hydropower plants are operated. Hydropower capacities – especially hydro reservoir plants – may be operating more flexibly than in the past, resulting in reduced capacity factors. Another aspect is that some regions may prioritise other objectives such as flood control, irrigation, recreation, or navigation. As shown in the IEA Hydropower Special Market Report as well as by the Climate Impacts on Latin American Hydropower Report, projected impacts of climate change on hydropower generation vary by country and by plant type. Anticipating the climate change-related challenges on hydropower, and planning accordingly, will be crucial for efficient and sustainable use of hydro resources.

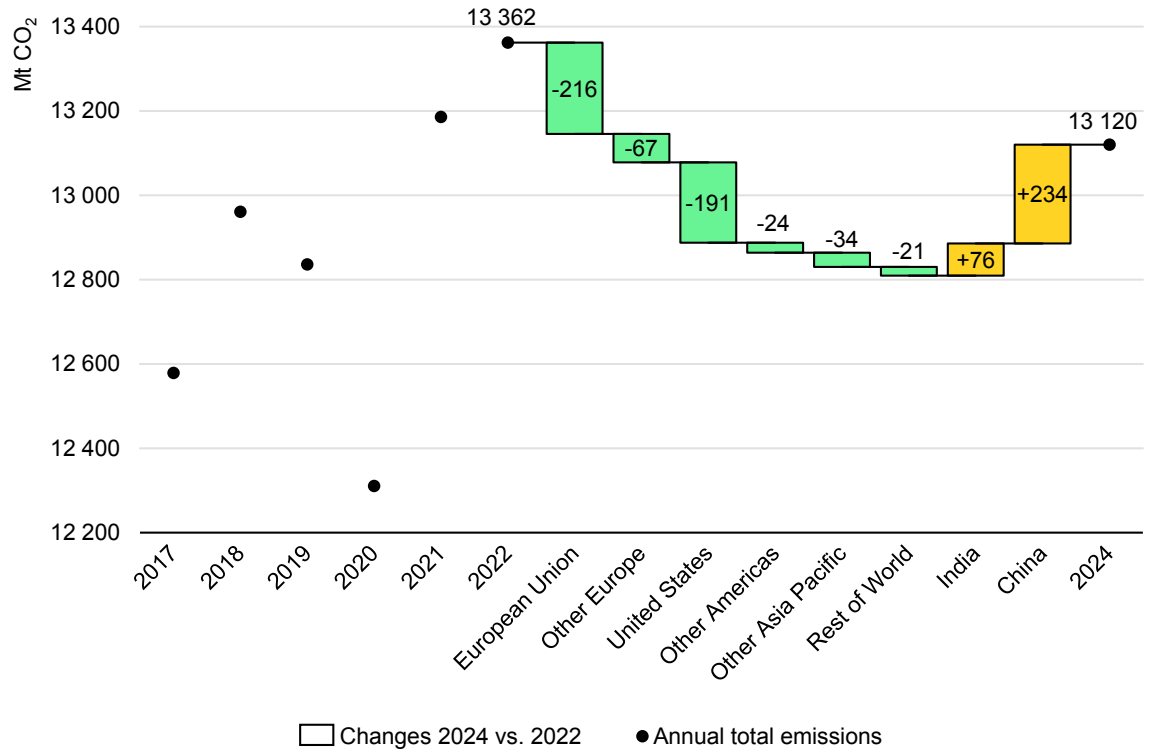
Emissions: Emissions from power generation poised to dip slightly through 2024

After rebounding strongly in 2021 when they grew by 7%, global emissions from electricity generation increased by just 1.3% in 2022. And as electricity generation from fossil fuels shrinks, we expect emissions to record slight declines around 1% both in 2023 and in 2024. Falling coal-fired generation is the main driver of this decline, with a drop in total CO_2 emissions of about 140 Mt over the period out to 2024. Oil follows with a decrease of 100 Mt. Total change in emissions from gas-fired generation out to 2024 is expected to be close to zero, as slight increases in 2023 are expected to be offset by declines in 2024.

Increases in emissions in Asia are offset by declines in other regions

Out to 2024, the major increases in power generation emissions will mostly be in China and India due to their growing coal use. However, these increases are more than offset by projected declines in other regions. The European Union alone makes up 40% of the total decline expected outside China and India, as generation from fossil fuels is set to fall substantially. The United States follows due to continued strong coal-to-gas switching along with growth in renewables. Other regions similarly see reductions in emissions as moderating gas prices support coal-to-gas switching, and as renewables keep expanding. While extreme weather, strong economic shocks and government policies can cause upticks in individual years, the overall trend of global power sector emissions plateauing is expected to remain stable, with individual years recording declines in emissions from power generation becoming more frequent.

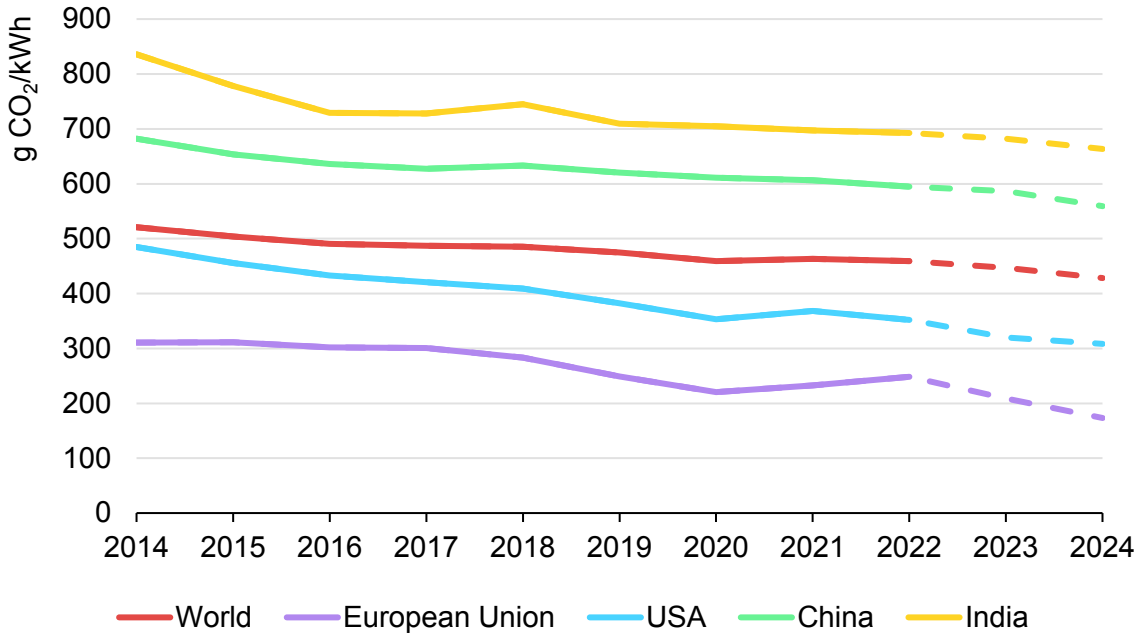
Changes in global CO_2 emissions from electricity generation, 2024 vs. 2022



Emission intensity of power generation is set to fall at a faster pace

Whereas global CO_2 emissions from power generation are expected to plateau and slightly decline out to 2024, its emission intensity is set to fall at a faster pace. We expect a 3% decline in 2023, followed by a 4% drop in 2024, which would be the largest decline in emissions intensity over the period 2014-2024. In 2022, the European Union was the only major region that saw a year-on-year increase (+7%) due to increased coal-fired generation. But with the expected strong drop in fossil electricity generation in the next two years, the EU is set to have the fastest rate of decline (averaging 17%) in emission intensity among large-scale energy consuming regions.

CO_2 intensity of electricity generation in selected regions, 2014-2024



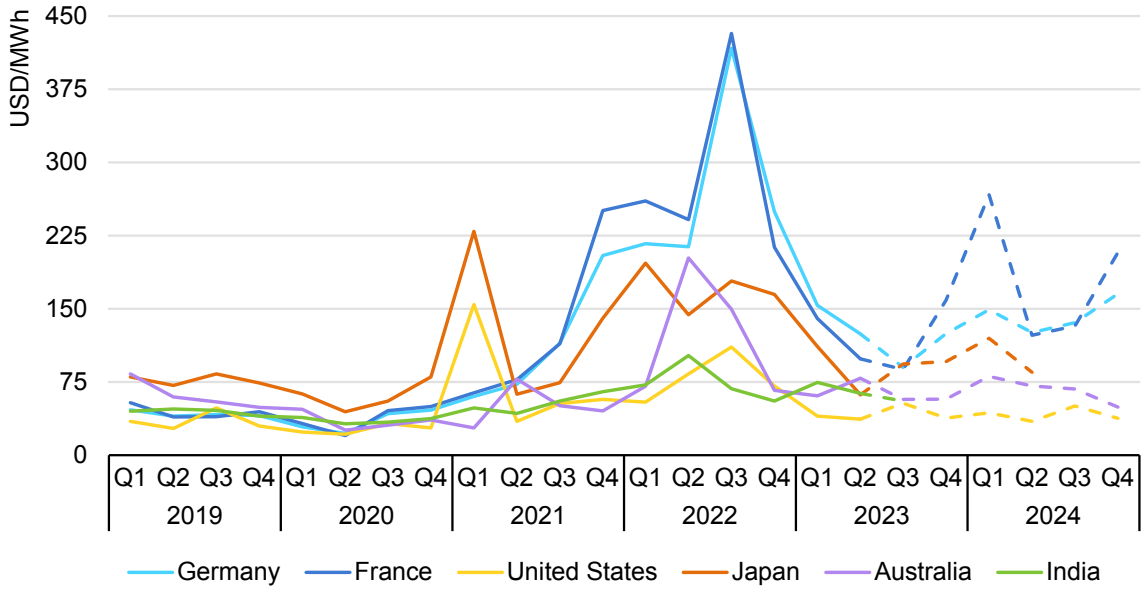
Note: The CO_2 intensity is calculated as total CO_2 emissions divided by total generation.

Prices: Wholesale electricity prices remain elevated in many regions

As tight market conditions eased, prices of energy commodities such as gas and coal fell from record highs in the third quarter of 2022. This fed into a decline in wholesale electricity prices that started in the fourth quarter of 2022 and continued well into 2023. Nevertheless, electricity prices remain elevated compared to their pre-2021 levels in many parts of the world, although there are regional differences.

High prices in Europe contrast with lower prices in the United States

Quarterly average wholesale prices for selected regions, 2019-2024



Note: The prices for Australia and the United States are calculated as the demand-weighted average of the available prices of their regional markets. Continuous lines show historical data and dashed lines refer to forward prices.

Source: IEA analysis using data from RTE (France) – accessed via the ENTSO-E Transparency Platform; Bundesnetzagentur (2023), SMARD.de; AEMO (2023), Aggregated price and demand data; EIA (2023), Short-Term Energy Outlook January 2023; IEX (2023), Area Prices; EEX (2023), Power Futures; ASX (2023), Electricity Futures © ASX Limited ABN 98 008 624 691 (ASX) 2020. All rights reserved. This material is reproduced with the permission of ASX. This material should not be reproduced, stored in a retrieval system or transmitted in any form whether in whole or in part without the prior written permission of ASX. Latest update: 14 July 2023.

In many **European** countries, including France and Germany, wholesale electricity prices continued to decline in Q1 2023 from their peak in Q3 2022. While European prices in H1 2023 have fallen back close to their 2021 average of around

100 EUR/MWh, they are on average still more than double the 2019 level of about 40 EUR/MWh. Electricity futures show a declining price trend into Q3 2023 with the onset of the summer season, but an increase towards the end of the year, reaching a peak in Q1 2024. This is driven by the expectation of winter conditions leading to a comparative tightening of the gas market – which can push the electricity prices up, as gas is generally the marginal source of electricity generation in Europe that sets the market price. France is a specific case, with uncertainty over the extent of the recovery of its nuclear generation pushing French winter prices much higher than those of its neighbours.

In the **United States**, record high temperatures in early summer 2023 in Texas caused surging electricity demand driven by cooling, which combined with higher-than-normal levels of forced generation outages, resulted in price spikes in the ERCOT real-time market reaching up to USD 5 000/MWh. Nevertheless, the average price in the United States in H1 2023 is significantly lower than in 2022 amid lower prices for energy commodities, and is only 10% higher than the 2019 average. Over the outlook period, forward prices for 2023 and 2024 indicate a relatively stable price level, with comparatively higher summer prices (Q3) that are mainly driven by expectations of tighter supply in the summer in many US regions.

Japanese wholesale prices also declined in Q1 2023 with forward prices indicating a a similar downward trend into Q2 2023. However, potential price spikes cannot be ruled out over the summer, as the government has called on households and industries around Tokyo to save electricity during the summer months in order to avoid a tight supply situation in the case of heatwaves. After increasing until Q1 2024, futures prices show a decline in Q2 2024, driven largely by the expected restart of the Onagawa-2 and the Shimane-2 reactors.

Wholesale electricity prices in **Australia** have eased from their highs in Q2 and Q3 2022, following declining prices for energy commodities. Average Australian prices in H1 2022 were about 20% higher than their 2019 levels. Futures prices indicate a relatively stable price level with troughs in Q4 of both 2023 and 2024.

In **India**, the easing of gas and coal prices resulted in a year-on-year decline of 14% in wholesale electricity prices during the first half of 2023. Prices remain nevertheless 80% higher than 2019's average, also supported by surging electricity demand driven by economic growth and by additional cooling needs.

Prices underscore increased need for flexibility

European power markets in the summer of 2023 have been characterised by wholesale prices at times dropping to negative levels. The number of hours with

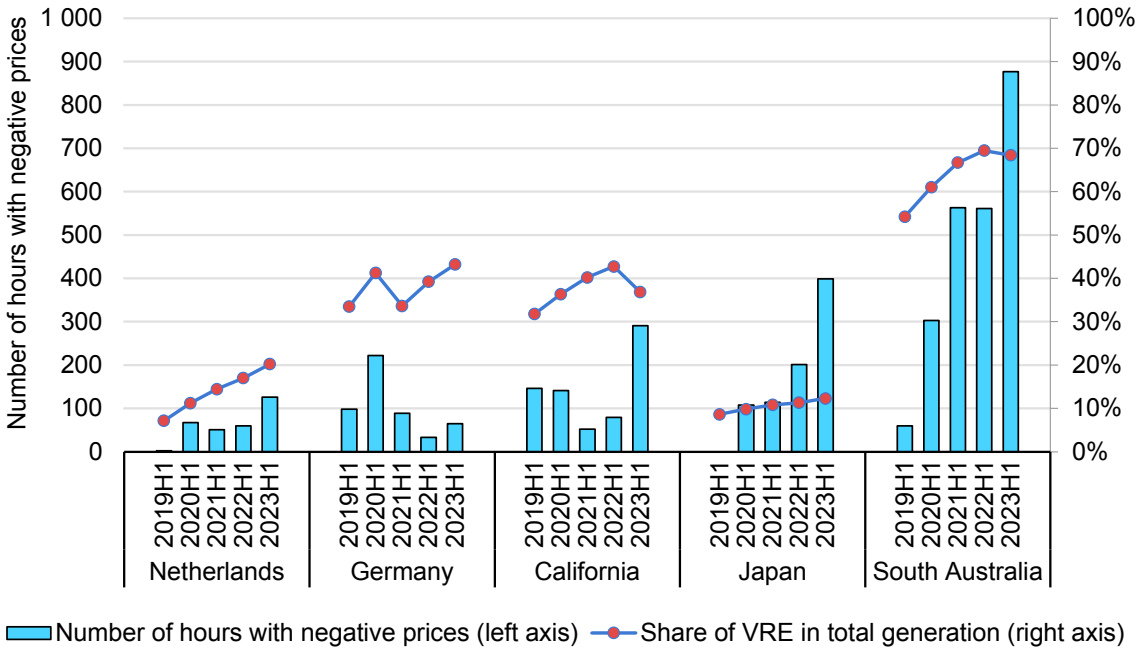
wholesale electricity prices below zero doubled year-on-year in countries such as Germany and Netherlands in the first half of 2023. This became prominent in late May and continued well into July, due to consecutive daylight hours with very high solar generation amid reduced electricity demand. In order to avoid triggering repeat auctions and to increase the stability of market coupling, market operators agreed to lower the negative price threshold on the day-ahead market, from 16 June onward, to EUR -500/MWh from the previous threshold of EUR -150/MWh.

Prices below zero occur when there is over-generation compared to demand, signalling that either generation needs to decrease or demand needs to increase. Renewables that produce according to subsidy schemes and not market price signals contribute to this imbalance. Limited opportunities for electricity exports due to insufficient interconnection capacity may also intensify the situation. In addition, larger and less flexible power plants (e.g., coal and nuclear) with high start-up and ramping costs bid negative prices, ensuring that they can continue to generate electricity rather than shut-off during periods of excess renewable generation. Negative prices therefore imply insufficient flexibility in the system, with generation that is not flexible enough, a demand side not sufficiently price-responsive or there is not enough storage to conduct energy arbitrage. At the same time, negative prices can also provide price signals to invest in solutions and technologies to improve system flexibility.

Negative prices have become more common in past years in many electricity markets in the world

Over the past few years, wholesale electricity prices below zero have become more common in regions that have seen significant increases in the share of VRE in total generation. California, with a VRE share ranging from 30% to 40% during 2019-2022, saw negative prices in individual hours about 1% of the time. South Australia has seen a strong growth in the share of VRE in recent years and as a result prices on the wholesale electricity market were below zero almost 20% of the time in 2022. The Japan Electric Power Exchange does not have a mechanism for negative prices, but there has been a significant increase in the number of hours with effectively a zero wholesale electricity price, driven by the growth in solar generation. Germany had an increasing trend of negative prices between 2017-2020. Following the peak in the number of negative hours in 2020 due to weak demand, there was a drop in 2021, with subsequent years remaining below the level of 2020. The halting of this upward trend is attributed to an increased flexibility of plants in the power system as well as a tightening of supply.

Number of hours with negative wholesale electricity prices and share of variable renewable energy in total electricity generation in selected regions in the first half of the year, 2019-2023



Note: Japan does not allow negative prices in the wholesale electricity market, the lowest possible price is limited to zero. The number of hours shown here for Japan therefore represents the hours when prices were zero. The California prices refer to wholesale prices from the electricity hub SP-15.

Source: IEA analysis based on data from ERCOT, CAISO, AEMO NEM, and ENTSO-E Transparency Platform.

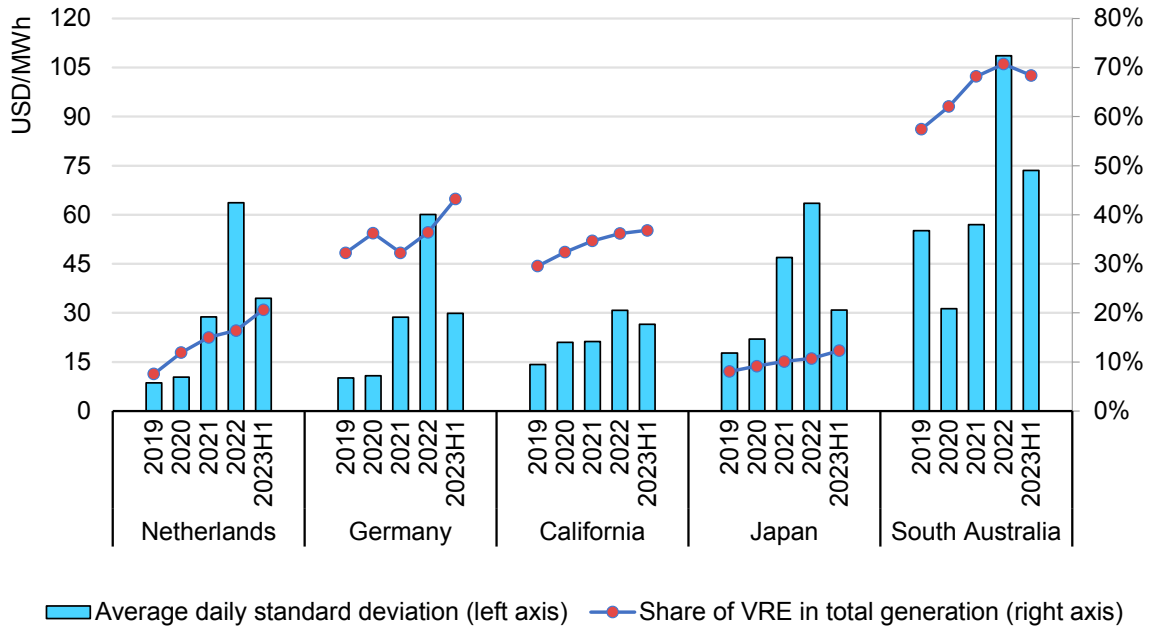
Demand-side flexibility and storage can benefit from updated regulatory and market frameworks

As power systems are normally sized to meet their peak loads, grid fees for consumers have traditionally been designed to incentivise flat load profiles and discourage greater load swings. For example, the grid fee structure in various countries in Europe favours base-load consumption with high full-load hours, which in turn can disincentivise flexible operation. For this reason, some industries may prefer not to deviate from their base load to avoid higher grid fees even during negative prices, despite prices below zero meaning that they would get paid to consume more energy. Therefore, it becomes important to update regulatory schemes to encourage flexible load operations. Increased digitalisation and aggregating demand flexibility via virtual power plants are other means to make demand more price-responsive. Time-of-use tariffs and smart charging of electric vehicles are similarly important factors that would contribute to increased demand-side flexibility.

The design of grid fees for storages is an aspect that can hamper their deployment. Across the European Union, for example, significant variations exist in tariff structures between different storage technologies as well as their position in the power system (i.e., behind the meter vs. front of the meter). Updating regulatory frameworks to incorporate reflective tariff structures would ensure fair competition between different flexibility options. Eliminating non-cost-reflective double grid tariff fees for storages would also help improve the business case for storages.

The business case for energy arbitrage is becoming more attractive

Average daily standard deviation and share of variable renewable energy in total electricity generation in selected regions, 2019-2023H1



Note: The California prices refer to wholesale prices from the electricity hub SP-15.
Source: IEA analysis based on data from ERCOT, CAISO, AEMO NEM, and ENTSO-E Transparency Platform.

Arbitraging price differences using storage systems is becoming more attractive as negative prices, spreads and volatility increases. For example, in Australia, large-scale battery energy storage saw record high revenue in 2022. The average daily standard deviation of prices represents the daily volatility and can be used as a good proxy to compare energy arbitrage potential, especially for storage systems with shorter charging and discharging cycles such as battery systems. For example, average daily standard deviation on the hourly day-ahead market

increased in the Netherlands from about EUR 9/MWh in 2017 to a massive EUR 61/MWh in 2022, then falling to EUR 32/MWh in H1 2023. The large increase after 2020 is due to soaring gas prices, as gas is often the marginal generation source that sets electricity prices. The growing share of renewables was a contributor to the number of hours with lower prices.

Due to their fast response characteristics, the shares of batteries in the ancillary markets, especially in primary frequency control provision, has been increasing in many power markets of the world. As more batteries provide these services, frequency control markets would start to get saturated, limiting the potential profitability for additional batteries in this market segment. With increasing volatility on the spot markets, energy arbitrage can therefore provide an improved business case when stacked with other revenue sources such as ancillary services provision. Intraday markets, with their significantly higher volatility and profit potential, are expected to become increasingly important for storage systems.

General annex

Summary tables

Regional breakdown of electricity demand, 2021-2024

TWh	2021	2022	2023	2024	Growth rate 2021-2022	Growth rate 2022-2023	Growth rate 2023-2024
Africa	751	761	766	802	1.3%	0.8%	4.7%
Americas	6 172	6 330	6 286	6 399	2.6%	-0.7%	1.8%
of which United States	4 170	4 278	4 206	4 290	2.6%	-1.7%	2.0%
Asia Pacific	13 182	13 717	14 307	14 967	4.1%	4.3%	4.6%
of which China	8 307	8 613	9 070	9 535	3.7%	5.3%	5.1%
Eurasia	1 296	1 315	1 329	1 341	1.4%	1.1%	0.9%
Europe	3 814	3 671	3 577	3 637	-3.7%	-2.6%	1.7%
of which European Union	2 736	2 649	2 570	2 612	-3.2%	-3.0%	1.7%
Middle East	1 168	1 199	1 222	1 251	2.6%	1.9%	2.4%
World	26 382	26 991	27 491	28 397	2.3%	1.9%	3.3%

Notes: Data for 2022 are preliminary; 2023-2024 are forecasts. Differences in totals are due to rounding.

Breakdown of global electricity supply, 2021-2024

TWh	2021	2022	2023	2024	Growth rate 2021-2022	Growth rate 2022-2023	Growth rate 2023-2024
Nuclear	2 805	2 659	2 709	2 842	-5.2%	1.9%	4.9%
Coal	10 279	10 450	10 409	10 309	1.7%	-0.4%	-1.0%
Gas	6 531	6 522	6 540	6 477	-0.1%	0.3%	-1.0%
Other non-renewables	114	112	113	113	-1.9%	0.6%	0.4%
Total renewables	7 931	8 546	9 132	10 160	7.8%	6.9%	11.3%

Notes: Data for 2022 are preliminary; 2023-2024 are forecasts. Differences in totals are due to rounding. Unless otherwise specified, generation numbers refer to gross generation.

Global CO_2 emissions from power generation, 2021-2024

Mt CO_2	2021	2022	2023	2024	Growth rate 2021-2022	Growth rate 2022-2023	Growth rate 2023-2024
Total emissions	13 186	13 362	13 270	13 120	1.3%	-0.7%	-1.1%

Regional and country groupings

Africa – Algeria, Angola, Benin, Botswana, Cameroon, Congo, Democratic Republic of the Congo, Côte d'Ivoire, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Ghana, Kenya, Libya, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Senegal, South Africa, South Sudan, Sudan, United Republic of Tanzania, Togo, Tunisia, Zambia, Zimbabwe and other African countries and territories.[1]

Asia – Bangladesh, Brunei Darussalam, Cambodia, Chinese Taipei, India, Indonesia, Japan, Korea, Democratic People's Republic of Korea, Lao People's Democratic Republic, Malaysia, Mongolia, Myanmar, Nepal, Pakistan, People's Republic of China,[2] Philippines, Singapore, Sri Lanka, Thailand, Viet Nam and other Asian countries, territories and economies.[3]

Asia Pacific – Australia, Bangladesh, Brunei Darussalam, Cambodia, Chinese Taipei, India, Indonesia, Japan, Korea, Democratic People's Republic of Korea, Lao People's Democratic Republic, Malaysia, Mongolia, Myanmar, Nepal, New Zealand, Pakistan, People's Republic of China,[2] Philippines, Singapore, Sri Lanka, Thailand, Viet Nam and other Asian countries, territories and economies.[4]

Central and South America – Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Curaçao, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Nicaragua, Panama, Paraguay, Peru, Suriname, Trinidad and Tobago, Uruguay, Venezuela and other Latin American countries and territories.[5]

Eurasia – Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Russian Federation, Tajikistan, Turkmenistan and Uzbekistan.

Europe – Albania, Austria, Belgium, Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus,[6,7] Czech Republic, Denmark, Estonia, Finland, France, Germany, Gibraltar, Greece, Hungary, Iceland, Ireland, Italy, Kosovo[8] Latvia, Lithuania, Luxembourg, Malta, Montenegro, Netherlands, North Macedonia, Norway, Poland, Portugal, Republic of Moldova, Romania, Serbia, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Republic of Türkiye, Ukraine and United Kingdom.

European Union – Austria, Belgium, Bulgaria, Croatia, Cyprus,[6,7] Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain and Sweden.

Middle East – Bahrain, Islamic Republic of Iran, Iraq, Israel[9], Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, United Arab Emirates and Yemen.

Nordics – Denmark, Finland, Norway, Sweden

North Africa – Algeria, Egypt, Libya, Morocco and Tunisia.

North America – Canada, Mexico and United States.

Southeast Asia – Brunei Darussalam, Cambodia, Indonesia, Lao, People's Democratic Republic, Malaysia, Myanmar, Philippines, Singapore, Thailand and Viet Nam. These countries are all members of the Association of Southeast Asian Nations (ASEAN).

Advanced economies – OECD member nations, plus Bulgaria, Croatia, Cyprus, Malta and Romania.

Emerging markets and developing economies – All other countries not included in the advanced economies regional grouping.

[1] Individual data are not available and are estimated in aggregate for: Burkina Faso, Burundi, Cape Verde, Central African Republic, Chad, Comoros, Djibouti, Gambia, Guinea, Guinea-Bissau, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Reunion, Rwanda, Sao Tome and Principe, Seychelles, Sierra Leone, Somalia, Eswatini and Uganda.
[2] Including Hong Kong.
[3] Individual data are not available and are estimated in aggregate for: Afghanistan, Bhutan, Macau (China), Maldives and Timor-Leste.
[4] Individual data are not available and are estimated in aggregate for: Afghanistan, Bhutan, Cook Islands, Fiji, French Polynesia, Kiribati, Macau (China), Maldives, New Caledonia, Palau, Papua New Guinea, Samoa, Solomon Islands, Timor-Leste, Tonga and Vanuatu.
[5] Individual data are not available and are estimated in aggregate for: Anguilla, Antigua and Barbuda, Aruba, Bahamas, Barbados, Belize, Bermuda, British Virgin Islands, Cayman Islands, Dominica, Falkland Islands (Malvinas), Grenada, Guyana, Montserrat, Saba, Saint Eustatius, Saint Kitts and Nevis, Saint Lucia, Saint Pierre and Miquelon, Saint Vincent and the Grenadines, Sint Maarten, and the Turks and Caicos Islands.
[6] Note by Türkiye: The information in this document with reference to "Cyprus" relates to the southern part of the Island. There is no single authority representing both Turkish and Greek Cypriot people on the Island. Türkiye recognises the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of United Nations, Türkiye shall preserve its position concerning the "Cyprus issue".
[7] Note by all the European Union Member States of the OECD and the European Union: The Republic of Cyprus is recognised by all members of the United Nations with the exception of Türkiye. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.
[8] The designation is without prejudice to positions on status and is in line with the United Nations Security Council Resolution 1244/99 and the Advisory Opinion of the International Court of Justice on Kosovo's declaration of Independence.
[9] The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The use of such data by the OECD and/or the IEA is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.

Abbreviations and acronyms

AEMO	Australian Energy Market Operator
CAISO	California Independent System Operator
ERCOT	Electric Reliability Council of Texas
GDP	Gross domestic product
IRA	Inflation Reduction Act
MISO	Midcontinent Independent System Operator
NERC	North American Electric Reliability Corporation
NPK	Nitrogen, phosphorus, and potassium
PMI	Purchasing Managers' Index
SPP	Southwest Power Pool
VRE	Variable renewable energy
WECC	Western Electricity Coordinating Council

Units of measure

bbl	barrel
bbl/d	barrels per day
bcm	billion cubic metres
bcm/yr	billion cubic metres per year
cm/s	centimetres per second
gCO_2	gram of carbon dioxide
gCO_2/kWh	grams of carbon dioxide per kilowatt hour
GJ	gigajoule
Gt/yr	gigatonnes per year
GW	gigawatt
MW	megawatt
MWh	megawatt-hour
$MtCO_2$	million tonnes of carbon dioxide
$MtCO_2$/yr	million tonnes of carbon dioxide per year
GW	gigawatt
GWh	gigawatt hour
TWh	terawatt-hour

International Energy Agency (IEA)

This work reflects the views of the IEA Secretariat but does not necessarily reflect those of the IEA's individual Member countries or of any particular funder or collaborator. The work does not constitute professional advice on any specific issue or situation. The IEA makes no representation or warranty, express or implied, in respect of the work's contents (including its completeness or accuracy) and shall not be responsible for any use of, or reliance on, the work.

For further information, please contact:

GCP (gcp@iea.org) or Eren Çam (eren.cam@iea.org)

IEA Publications

International Energy Agency

Website: www.iea.org

Contact information: www.iea.org/about/contact

Typeset in France by IEA - July 2023

Cover design: IEA

Photo credits: © Shutterstock