Electricity
2024

Analysis and forecast to 2026

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Abstract

Electricity is central to the functioning of modern societies and economies – and its importance is only growing as technologies that run on electricity, such as electric vehicles and heat pumps, become increasingly popular. Power generation is currently the largest source of carbon dioxide (CO_2) emissions in the world, but it is also the sector leading the transition to net zero emissions through the rapid expansion of renewable energy sources such as solar and wind power. Ensuring consumers have secure and affordable access to electricity while also reducing global carbon dioxide (CO_2) emissions is one of the core challenges of the energy transition.

Given these trends, the International Energy Agency's *Electricity 2024* is essential reading. It offers a deep and comprehensive analysis of recent policies and market developments, and provides forecasts through 2026 for electricity demand, supply and CO_2 emissions. The IEA's electricity sector report, which has been published regularly since 2020, provides insight into the evolving generation mix. In addition, this year's report features in-depth analysis on the drivers of recent declines in electricity demand in Europe; the data centre sector's impact on electricity consumption; and recent developments in the global nuclear power sector.

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Executive summary

Global electricity demand rose moderately in 2023 but is set to grow faster through 2026

Falling electricity consumption in advanced economies restrained growth in global power demand in 2023. The world's demand for electricity grew by 2.2% in 2023, less than the 2.4% growth observed in 2022. While China, India and numerous countries in Southeast Asia experienced robust growth in electricity demand in 2023, advanced economies posted substantial declines due to a lacklustre macroeconomic environment and high inflation, which reduced manufacturing and industrial output.

Global electricity demand is expected to rise at a faster rate over the next three years, growing by an average of 3.4% annually through 2026. The gains will be driven by an improving economic outlook, which will contribute to faster electricity demand growth both in advanced and emerging economies. Particularly in advanced economies and China, electricity demand will be supported by the ongoing electrification of the residential and transport sectors, as well as a notable expansion of the data centre sector. The share of electricity in final energy consumption is estimated to have reached 20% in 2023, up from 18% in 2015. While this is progress, electrification needs to accelerate rapidly to meet the world's decarbonisation targets. In the IEA's Net Zero Emissions by 2050 Scenario, a pathway aligned with limiting global warming to 1.5 °C, electricity's share in final energy consumption nears 30% in 2030.

Electricity consumption from data centres, artificial intelligence (AI) and the cryptocurrency sector could double by 2026. Data centres are significant drivers of growth in electricity demand in many regions. After globally consuming an estimated 460 terawatt-hours (TWh) in 2022, data centres' total electricity consumption could reach more than 1 000 TWh in 2026. This demand is roughly equivalent to the electricity consumption of Japan. Updated regulations and technological improvements, including on efficiency, will be crucial to moderate the surge in energy consumption from data centres.

Emerging and developing economies are the engines of global electricity demand growth

About 85% of additional electricity demand through 2026 is set to come from outside advanced economies, with China contributing substantially even as the country's economy undergoes structural changes. In 2023, China's

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electricity demand rose by 6.4%, driven by the services and industrial sectors. With the country's economic growth expected to slow and become less reliant on heavy industry, the pace of Chinese electricity demand growth eases to 5.1% in 2024, 4.9% in 2025 and 4.7% in 2026 in our forecasts. Even so, the total increase in China's electricity demand through 2026 of about 1 400 TWh is more than half of the European Union's current annual electricity consumption. Electricity consumption per capita in China already exceeded that of the European Union at the end of 2022 and is set to rise further. The rapidly expanding production of solar PV modules and electric vehicles, and the processing of related materials, will support ongoing electricity demand growth in China while the structure of its economy evolves.

China provides the largest share of global electricity demand growth in terms of volume, but India posts the fastest growth rate through 2026 among major economies. Following a 7% increase in India's electricity demand in 2023, we expect growth above 6% on average annually until 2026, supported by strong economic activity and expanding ownership of air conditioners. Over the next three years, India will add electricity demand roughly equivalent to the current consumption of the United Kingdom. While renewables are set to meet almost half of this demand growth, one-third is expected to come from rising coal-fired generation. We also expect Southeast Asia to see robust annual increases in electricity demand of 5% on average through 2026, led higher by strong economic activity.

While electricity use per capita in India and Southeast Asia is rapidly rising, it has been effectively stagnant in Africa for more than three decades. Per capita consumption in Africa even declined in recent years as the population grew faster than electricity supply was made available, and we only expect it to recover to its 2010-15 levels by the end of 2026 at the earliest. Thirty years ago, a person in Africa consumed more electricity on average than someone living in India or Southeast Asia. However, strong increases in electricity demand and supply in India and Southeast Asia in recent decades – which have gone hand in hand with a boom in economic development – have transformed these regions at a spectacular pace. Meanwhile, Africa's per capita electricity consumption in 2023 was half that of India and 70% lower than in Southeast Asia. Our forecast for Africa for the 2024-26 period anticipates average annual growth in total electricity demand of 4%, double the mean growth rate observed between 2017 and 2023. Two-thirds of this growth in demand is set to be met by expanding renewables, with the remainder covered mostly by natural gas.

Electricity demand in the United States fell by 1.6% in 2023 after increasing 2.6% in 2022, but it is expected to recover in the 2024-26 outlook period. A key reason for the decline was milder weather in 2023 compared with 2022, though a slowdown in the manufacturing sector was also a factor. We forecast a

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moderate increase in demand of 2.5% in 2024, assuming a reversion to average weather conditions. This will be followed by growth averaging 1% in 2025-26, led by electrification and the expansion of the data centre sector, which is expected to account for more than one-third of additional demand through 2026.

Slim chances of a quick recovery for energy-intensive industries in the European Union

Electricity demand in the European Union declined for the second consecutive year in 2023, even though energy prices fell from record highs. Following a 3.1% drop in 2022, the 3.2% year-on-year decline in EU demand in 2023 meant that it dropped to levels last seen two decades ago. As in 2022, weaker consumption in the industrial sector was the main factor that reduced electricity demand, as energy prices came down but remained above pre-pandemic levels. In 2023, there were also signs of some permanent demand destruction, especially in the energy-intensive chemical and primary metal production sectors. These segments will remain vulnerable to energy price shocks over our outlook period.

EU electricity consumption is not expected to return to 2021 levels until 2026 at the earliest. Electricity demand in the European Union's industrial sector fell by an estimated 6% in 2023 after a similar decline in 2022. Assuming the industrial sector gradually recovers as energy prices moderate, EU electricity demand growth is forecast to rise by an average 2.3% in 2024-26. Electric vehicles, heat pumps and data centres will remain strong pillars of growth over the period – together accounting for half of expected gains in total demand.

Electricity prices for energy-intensive industries in the European Union in 2023 were almost double those in the United States and China. Despite an estimated 50% price decline in the European Union in 2023 versus 2022, energy-intensive industries in the region continued to face far higher electricity costs compared with the United States and China in the aftermath of Russia's invasion of Ukraine. The price gap between energy-intensive industries in the European Union and those in the United States and China, which already existed before the energy crisis, has widened. As a result, the competitiveness of EU energy-intensive industries is expected to remain under pressure. Policy makers are currently discussing new policy initiatives and financial instruments to enable the European Union to position itself among other global industrial heavyweights. The scope and effectiveness of these measures will likely determine the future of the European Union's energy-intensive industrial sector.

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Clean electricity supply is forecast to meet all of the world's demand growth through 2026

Record-breaking electricity generation from low-emissions sources – which includes nuclear and renewables such as solar, wind and hydro – is set to cover all global demand growth over the next three years. Low-emissions sources, which will reduce the role of fossil fuels in producing electricity globally, are forecast to account for almost half of the world's electricity generation by 2026, up from 39% in 2023. Over the next three years, low-emissions generation is set to rise at twice the annual growth rate between 2018 and 2023 – a consequential change, given that the power sector contributes the most to global carbon dioxide (CO_2) emissions today.

Renewables are set to provide more than one-third of total electricity generation globally by early 2025, overtaking coal. The share of renewables in electricity generation is forecast to rise from 30% in 2023 to 37% in 2026, with the growth largely supported by the expansion of ever cheaper solar PV. Through this period, renewables are set to more than offset demand growth in advanced economies such as the United States and the European Union, displacing fossil-fired supply. At the same time, in China, the rapid expansion of renewable energy sources is expected to meet all additional electricity demand, though the weather and the extent to which the country's demand growth eases remain key sources of uncertainty for the outlook. The strong expansion in renewable power capacity must also be accompanied by accelerated investment in grids and system flexibility to ensure its smooth integration.

The rapid growth of renewables, supported by rising nuclear generation, is set to displace global coal-fired generation, which is forecast to fall by an average of 1.7% annually through 2026. This follows a 1.6% increase in coal-fired output in 2023 amid droughts in India and China that reduced hydropower output and increased coal-fired generation, more than offsetting strong declines in coal-fired generation in the United States and the European Union. The major factor that will determine the global outlook is evolving trends in China, where more than half of world's coal-fired generation takes place. Coal-fired generation in China is currently on course to experience a slow structural decline, driven by the strong expansion of renewables and growing nuclear generation, as well as moderating economic growth. Despite the commissioning of new plants to boost the security of energy supply, the utilisation rate of Chinese coal-fired plants is expected to continue to fall as they are used more flexibly to complement renewables. Nevertheless, coal-fired generation in China will be influenced significantly by the pace of the economy's rebalancing, hydropower trends, and bottlenecks in integrating renewables into the country's power system.

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Natural gas-fired generation is expected to rise slightly over the outlook period. In 2023, sharp declines in gas-fired power generation in the European Union were more than offset by massive gains in the United States, where natural gas, which has increasingly replaced coal, recorded its highest-ever share in power generation. Global gas-fired output grew by less than 1% in 2023. Through 2026, we forecast an average annual growth rate of around 1%. While gas-fired output in Europe is expected to continue declining, global growth will be supported by significant gains in Asia, the Middle East and Africa amid rising demand for power in these regions and the availability of additional liquefied natural gas (LNG) supply from 2025 onward.

Nuclear power generation is on track to reach a new record high by 2025

By 2025, global nuclear generation is forecast to exceed its previous record set in 2021. Even as some countries phase out nuclear power or retire plants early, nuclear generation is forecast to grow by close to 3% per year on average through 2026 as maintenance works are completed within France, Japan restarts nuclear production at several power plants, and new reactors begin commercial operations in various markets, including China, India, Korea, and Europe. Many countries are making nuclear power a critical part of their energy strategies as they look to safeguard energy security while reducing greenhouse gas emissions. At the COP28 climate change conference that concluded in December 2023, more than 20 countries signed a joint declaration to triple nuclear power capacity by 2050. Achieving this goal will require tackling the key challenge of reducing construction and financing risks in the nuclear sector. Momentum is also growing behind small modular reactor (SMR) technology. The technology's development and deployment remains modest and is not without its difficulties, but R&D is starting to pick up.

Asia remains the main driver of growth in nuclear power, with the region's share of global nuclear generation forecast to reach 30% in 2026. Asia is set to surpass North America as the region with the largest installed nuclear capacity by the end of 2026, with a large number of plants currently under construction expected to be completed by then. More than half of new reactors expected to become operational during the outlook period are in China and India. Nuclear power has seen particularly strong growth in China over the past decade, with capacity additions of about 37 gigawatts (GW), equivalent to almost two-thirds of its current nuclear capacity. This resulted in China's share in global nuclear generation rising from 5% in 2014 to about 16% in 2023. China started the commercial operation of its first fourth-generation reactor in December 2023, further underscoring the country's nuclear power advances.

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Emissions from electricity generation are entering structural decline as decarbonisation gathers pace

Global CO_2 emissions from electricity generation are expected to fall by more than 2% in 2024 after increasing by 1% in 2023. This is set to be followed by small declines in 2025 and 2026. The strong growth in coal-fired power generation in 2023 – especially in China and India amid reduced hydropower output – was responsible for the rise in the global electricity sector's CO_2 emissions. As clean electricity supply continues to expand rapidly, the share of fossil fuels in global generation is forecast to decline from 61% in 2023 to 54% in 2026, falling below 60% for the first time in IEA records dating back to 1971. While extreme weather conditions, economic shocks, or changes in government policies could lead to a temporary rise in emissions in individual years, the broader decline in power sector emissions is expected to persist as renewables and nuclear power capacity continue to expand and displace fossil-fired generation.

The CO_2 intensity of global electricity generation is set to fall at twice the rate recorded in the pre-pandemic period. The forecasted average decline of 4% in CO_2 intensity between 2023 and 2026 is double the 2% observed in the period between 2015 and 2019. The European Union is expected to record the highest rate of progress in reducing emissions intensity, averaging an improvement of 13% per year. This is followed by China, with annual improvements forecast at 6%, and the United States at 5%. The decline in the CO_2 intensity of electricity generation means that emissions savings via the electrification of transport, heating and industry will become even more substantial.

Wholesale electricity prices remain above pre-Covid levels in many countries

Wholesale electricity prices in many countries fell in 2023 from the record highs observed in 2022. This took place in tandem with declines in prices for energy commodities such as natural gas and coal. There are, however, regional differences. Wholesale electricity prices in Europe declined on average by more than 50% in 2023 from record levels in 2022. Despite this, prices in Europe were still roughly double 2019 levels, whereas US prices in 2023 were only about 15% higher than in 2019. Uncertainty about both the pace of France's nuclear recovery and natural gas prices are supporting higher futures prices in Europe for upcoming winters. The hydropower-dominated Nordics remain the only market in Europe with average wholesale electricity prices comparable to those in the United States and Australia. Wholesale prices in Japan and India also remained above 2019 levels in 2023.

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Growing weather impacts on power systems highlight the importance of investing in electricity security

Global hydropower generation declined in 2023 due to weather impacts such as droughts, below average rainfall and early snowmelts in numerous regions. Canada, China, Colombia, Costa Rica, India, Mexico, Türkiye, the United States, and Vietnam, along with other countries, all saw hydropower generation decline. The global hydropower capacity factor, a key measure of utilisation rate, fell to below 40%, the lowest value recorded in at least three decades. In certain countries, diminished hydropower output led to energy shortages, heightened reliance on fossil sources such as coal and gas, and raised concerns about the stability of electricity supply. The overall trend underscores the susceptibility of hydropower to weather patterns and the potential exposure of countries that rely heavily on hydro to generate electricity. Diversifying energy sources, building regional power interconnections and implementing strategies for resilient generation in the face of changing weather patterns will be increasingly important.

Extreme weather events triggered major power outages in 2023 in the United States and India. This underlined the need to boost resilience as weather impacts on power systems increase, with both supply and demand becoming more weather-dependent. Insufficient power capacity, fuel supply challenges and grid-related technical issues also continued to cause significant power shortages in many regions. The majority of these outages were observed in emerging economies such as Pakistan, Kenya and Nigeria, which are particularly affected by insufficient electricity supply, infrastructure problems and strained grids in the face of rising power demand. Expanded, stronger grids would not only ensure reliable electricity but also serve as a vital backbone for integrating renewables into power systems. Improving data collection, digitalisation and greater data transparency regarding outages is also essential to provide better insight into why faults occurred and to help develop preventative measures.

Specific operating measures and new markets for ensuring the stability of power systems are becoming more common. Countries with high shares of variable renewable generation are implementing mechanisms to ensure a steady power system frequency. Some regions are establishing minimum requirements for system inertia, a property typically provided by conventional generators with spinning rotors that helps enhance the power system's resilience during disturbances. Additionally, various countries including the United Kingdom, Ireland and Australia have been introducing markets and measures such as fast frequency response and similar services that stabilise the power system rapidly after disruptions. Battery storage systems can provide such services for grid stability while enhancing system flexibility, thus playing a crucial role in integrating renewable energy sources.

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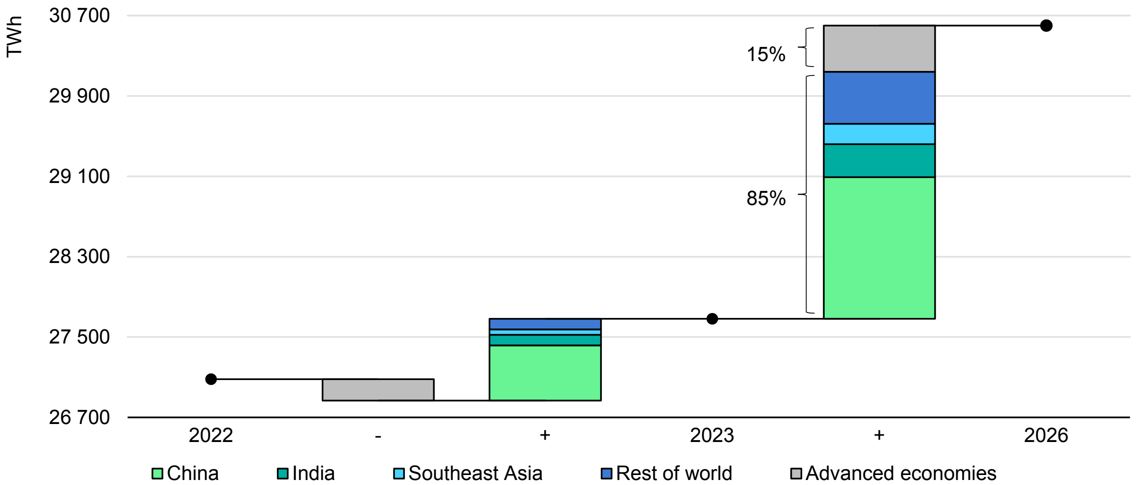
Global trends

Demand: Global electricity use posts strong growth to 2026

Emerging economies are the engines of global electricity demand growth

Global electricity demand grew by a relatively modest 2.2% in 2023, down from 2.4% in 2022. Growth, however, is on course to accelerate to a higher 3.4% in our 2024-2026 forecast period, with emerging markets continuing to dominate growing electricity demand, as they did in 2023. The far-ranging repercussions of the energy crisis continued throughout 2023, with elevated inflation levels, high interest rates and heavy debt burdens exerting downward pressure on economies around the world. Still, emerging market countries recorded strong growth in electricity demand. By contrast, most advanced economies posted declines amid the lacklustre macroeconomic environment as well as the weak industry and manufacturing sectors, despite continued electrification. Milder weather compared to the previous year also exerted downward pressure on electricity consumption in some regions, including the United States.

Year-on-year change in electricity demand by region, 2022-2026



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Note: Advanced economies grouping in this chart excludes Mexico and Türkiye.

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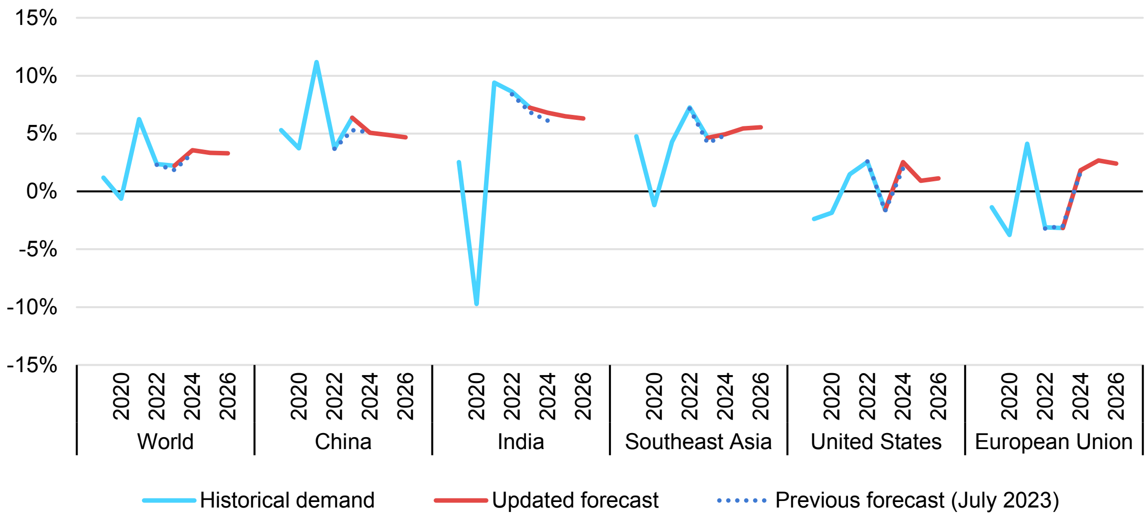
Strong growth in emerging economies combined with an anticipated recovery in industry and ongoing electrification of the residential and transportation sectors in many parts of the world will be the mainstays of increasing electricity over our outlook. An important new source of higher electricity consumption is coming from energy-intensive data centres, artificial intelligence (AI) and cryptocurrencies, which could double by 2026.

About 85% of the additional electricity through 2026 is set to come from outside advanced economies, mostly in People's Republic of China (hereafter, "China"), India and Southeast Asia. The International Monetary Fund (IMF) October 2023 outlook projects a gradual economic recovery for advanced economies, with the 2023 GDP growth rate of 1.5% followed by 1.4% in 2024 and an annual average of 1.8% in 2025-2026. By contrast, for emerging economies, the IMF projects sustained robust growth of an average annual 4%, or slightly higher at 4.1%, during 2024-2026, in line with the estimated 4% in 2023.

The share of electricity in final energy consumption is estimated at 20% in 2023, up from 18% in 2015. While there is progress, electrification of end uses needs to occur at a much faster pace to reach decarbonisation targets. In the IEA's Net Zero by 2050 Scenario (NZE Scenario), a pathway aligned with limiting global warming to 1.5 °C, the electricity share in final energy consumption nears 30% by 2030.

Year-on-year percent change in electricity demand in selected regions, 2019-2026



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China has the largest increase in electricity demand, while India sees the fastest growth

Electricity demand reflected diverging trends in 2023, with advanced economies recording significant declines, while emerging market countries, and especially China and India, recorded strong growth rates on rising demand for electricity spurred by economic activity. **China** posted growth of 6.4% in electricity demand in 2023, compared to the 3.7% year-on-year increase in 2022. Following the easing of stringent pandemic measures at end-2022, electricity demand growth accelerated from around 3% to over 5% year-on-year by H1 2023, and continued to rise further in H2 to close the year at over 6%. While construction-related industries such as glass and cement saw a slowdown in 2023, growth in Chinese electricity consumption was driven higher by the services and various industrial sectors, including manufacturing of PV modules, electric vehicles, and the processing of associated materials. The economy has shown some signs of rebalancing and is expected to grow at a slower pace in the coming years. As a result, we forecast electricity demand growth at 5.1% in 2024, before gradually easing to 4.9% in 2025 and 4.7% in 2026. Despite this slower pace of growth, China's increase in electricity demand of an estimated 1 400 TWh to 2026 is still more than 50% of current total annual electricity consumption of the European Union. Electricity consumption per capita in China already exceeded that of the European Union at the end of 2022. However, the per capita electricity consumption of households in China is still below the average for EU households.

Electricity demand in **India** rose by 7% in 2023 compared to last year's 8.6%. Continued rapid economic expansion and robust demand for space cooling were the main pillars of growth. After two consecutive years of strong gains, India's electricity consumption surpassed that of Japan and Korea combined at the end of 2023. Bolstered by a fast-growing economy and powered by increased electrification, we expect India's electricity demand to rise by an annual average of 6.5% over the 2024-2026 period. While China provides the largest share of demand growth in terms of volume, India posts the fastest growth rate out to 2026 among major economies. Following this, India will have added additional electricity demand roughly equivalent to that of the United Kingdom over the next three years.

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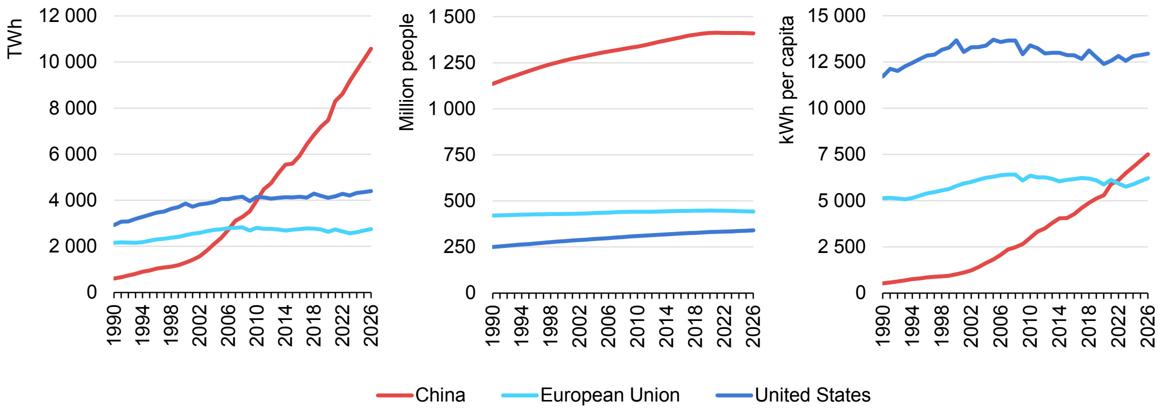
Total electricity demand (left), population (centre), and electricity consumption per capita (right) in China, European Union, and the United States, 1990-2026



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Notes: The figures for 2024-2026 are forecast values. Historical data and forecast for population are from World Bank (2022).

Electricity demand in the **United States**, the world's second largest consumer behind China, declined by 1.6% in 2023, after 2.6% growth in 2022. A major contributor to the downturn was the milder weather in 2023 compared to 2022. A slowdown in the manufacturing sector was also a factor, albeit with significantly less impact than the weather. While record high summer temperatures in Texas drove up cooling demand, overall summer weather was milder in 2023 compared to last year. Similarly, winter months were also warmer, with the lowest number of heating degree days recorded since 2012. We forecast a moderate rebound in demand of 2.5% in 2024, assuming normal weather conditions, followed by an average growth rate of 1% in 2025-2026 due to continued electrification and strong growth in the data centre sector. We expect more than one-third of the additional US electricity demand out to 2026 to come from the expanding data centres.

Electricity demand in **Japan** declined by 3.7% in 2023 compared to a 1% increase in 2022. Despite high temperatures boosting cooling demand in the summer, the slowdown in the manufacturing sector and continued energy saving measures exerted strong downwards pressure on electricity consumption. However, against a backdrop of an assumed gradual recovery in the manufacturing sector in 2024 and accelerating electrification of the transport and heating sectors over the outlook period, a modest rebound in electricity demand of 1.2% in 2024 is forecast, followed by an average annual growth rate of 0.2% in 2025-2026.

In the **European Union**, following a 3.1% decline in 2022, electricity demand fell by a further 3.2% in 2023. We anticipate a return to growth in 2024 of 1.8%, assuming a partial recovery in the industry sector given more moderate energy prices and expanding electrification of the transportation and heating sectors. EU electricity demand is forecast to grow on average by 2.5% annually during the

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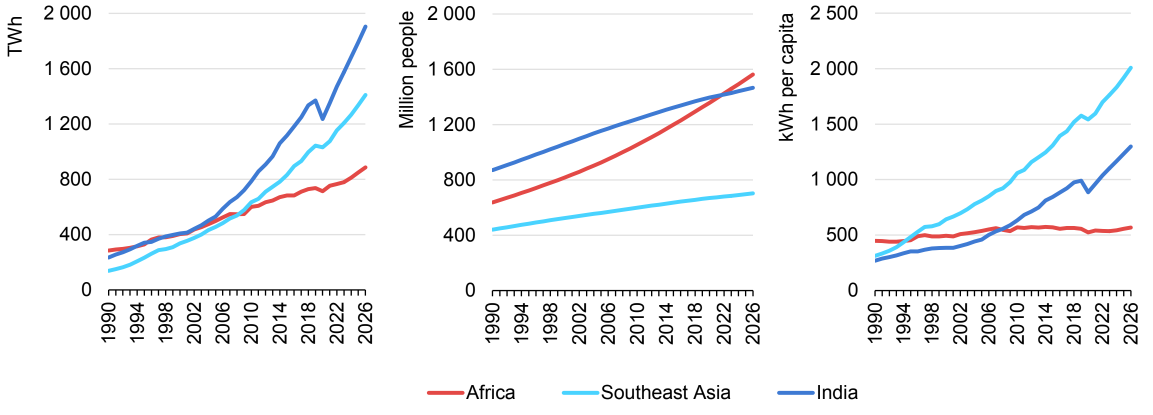
2025-2026 period, supported by an improved economic outlook. Nevertheless, following the record demand contraction in the European Union last year, uncertainties surround over how much of this decline is temporary and how much is structural.

Southeast Asia and India make strides in per capita electricity use, but Africa lags behind

In 1990, the average electricity consumption per person in Africa exceeded that of Southeast Asia by 40% and India by 65%. However, recent decades have witnessed a significant surge in electricity demand and supply in India and Southeast Asia, accompanied by rapid economic development and prosperity in these regions. Southeast Asia overtook Africa in per capita electricity consumption in 1995, and India achieved the same in 2008. Conversely, Africa's per capita electricity consumption has remained stagnant for more than three decades, with 2023 figures revealing it to be half that of India and 70% lower than in Southeast Asia. The 2023 per capita electricity consumption on the African continent is estimated at 530 kWh, while sub-Saharan Africa excluding South Africa averaged around 190 kWh. We expect per capita electricity consumption in Africa to recover to its 2010-2015 levels by the end of 2026 at the earliest.

Total electricity demand (left), population (centre), and electricity consumption per capita (right) in Africa, Southeast Asia, and India, 1990-2026



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Africa’s population is set to grow rapidly, making up one-fifth of the world’s population by 2030. This highlights the massive potential and need for additional electricity supply in this region. Our forecast for Africa for the period 2024-2026 anticipates an average annual growth in total electricity demand of 4%, more than double the mean growth rate observed over 2015-2023. Around 60% of this

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growth in demand is to be met by expanding renewables, the remaining mostly by natural gas. Renewable generation in Africa has grown on average by 5% in 2015-2023. We forecast an average of 10% growth in renewable generation out to 2026 in Africa, as deployment of renewables gathers pace. Nevertheless, In order to achieve the region's energy development and climate targets, energy investments will have to more than double from today's USD 90 billion by 2030, with almost two-thirds of this spending going towards clean energy.

As of 2023, 600 million people, or more than 40% of the African population lacked access to electricity, mostly in sub-Saharan Africa. A common solution to electricity access in Africa has been off-grid gasoline or diesel generators as they present low upfront costs in contrast to the cost of connection to the grid. However, their operating costs have significantly increased, especially since 2021 after oil prices soared. Additionally, since 2015 the adoption of decentralised modular solar home systems (SHS) has steadily increased. Countries like Ghana and Kenya increased their SHS capacity by more than twenty times from 2015 to 2019. SHS providers have enabled the system implementation through financial incentives such as a pay-as-you-go business model.

Spotlight: Navigating the uncertainties in the recovery of EU electricity demand

With consecutive declines of historic proportions in 2022 (-3.1%) and 2023 (-3.2%), electricity demand in the European Union has fallen to levels last seen two decades ago, predominantly due to lower consumption in the industrial sector amid the economic malaise. Our analysis shows that with a gradual recovery in the industrial sector, EU electricity demand would return to 2021 levels by 2026 at the earliest, with an average annual growth rate of 2.3%. The IMF October 2023 outlook projects GDP growth of the euro area for 2024 at 1.2%, indicating a slight recovery from the substantial slowdown in 2023 at 0.7% GDP growth that followed a robust 3.3% in 2022. Accordingly, the EU economy is expected to grow faster over 2025-2026, with an average annual growth rate of around 1.8%.

In addition to the gradual recovery in economic growth, strong drivers of electricity demand in the period to 2026 will come from electric vehicles, heat pumps and data centres, which combined are expected to account for half of the total demand gains. An estimated total of 9 million new battery electric vehicles and 11 million new heat pumps are expected to become operational by 2026 in the European Union, which will account for a large share of this stronger growth. Moreover, we forecast that electricity consumption from data centres in the European Union in 2026 will be 30% higher than 2023 levels, as new data facilities are commissioned amid increased digitalisation and AI computations. Ireland and Denmark alone make up 20% of the expected increase in data centre electricity demand to 2026.

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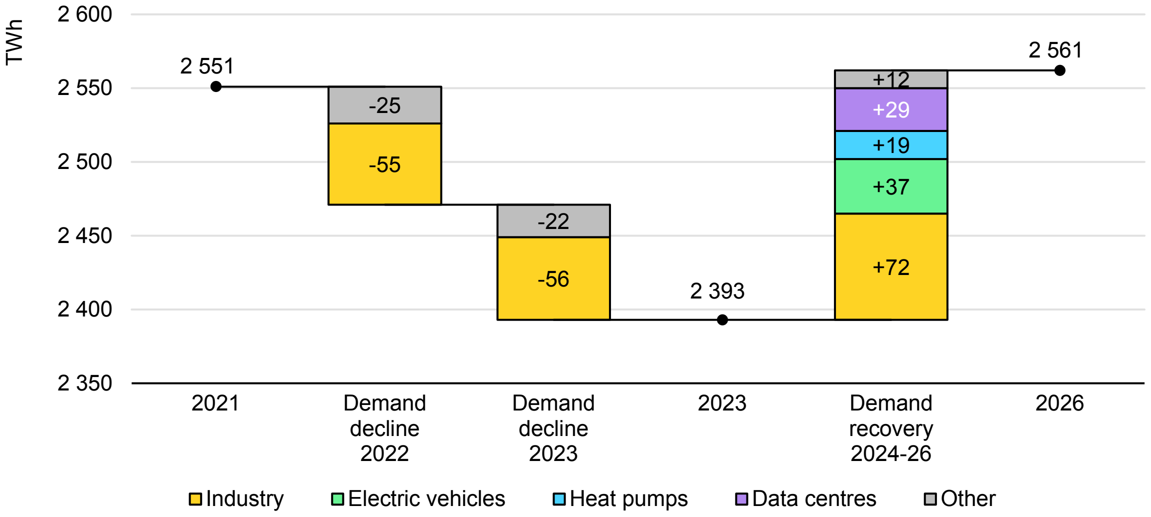
Estimated drivers of change in electricity demand in the European Union, 2021-2026



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Notes: Other includes the combined effect of changes in electricity demand in households, services and other sectors, including increases from EVs, heat pumps and data centres in 2022 and 2023. For 2024-2026 these are shown separately. In 2022, the net impact of weather on demand is estimated to have been a reduction of 13 TWh. In 2023, net weather impact is estimated to have accounted for a reduction of 7 TWh.

Industry was the main factor behind the decline in EU electricity demand in 2022 and 2023

Despite energy prices falling from their previous record highs, EU electricity demand further declined in 2023. Lower industrial electricity demand was the most important factor, as in the previous year. Following a 5.8% decline in 2022, we estimate electricity consumption in the EU industrial sector fell 6% year-on-year in 2023, with energy-intensive industries the hardest hit. Despite regional variations, the average European wholesale electricity price in 2023 was still more than double the 2019 level (see the Prices chapter for more analysis). This, combined with slower economic growth, lower consumer demand, weaker exports and the overhang of stocks from 2021 and 2022, depressed EU industrial electricity demand further.

The impact of milder weather on electricity consumption also weighed on demand, although to a much more limited extent. Overall, winter temperatures were higher and summer temperatures were lower compared to 2022, resulting in less space heating and cooling. About 0.3 percentage points of the 3.2% decline in EU electricity demand is attributable to weather, which means that the year-on-year decline would have been 2.9% without the influence of weather.

The six-month moving average for the EU wholesale electricity price was almost 45% lower in the second half of 2023 compared to the first half, stabilising around

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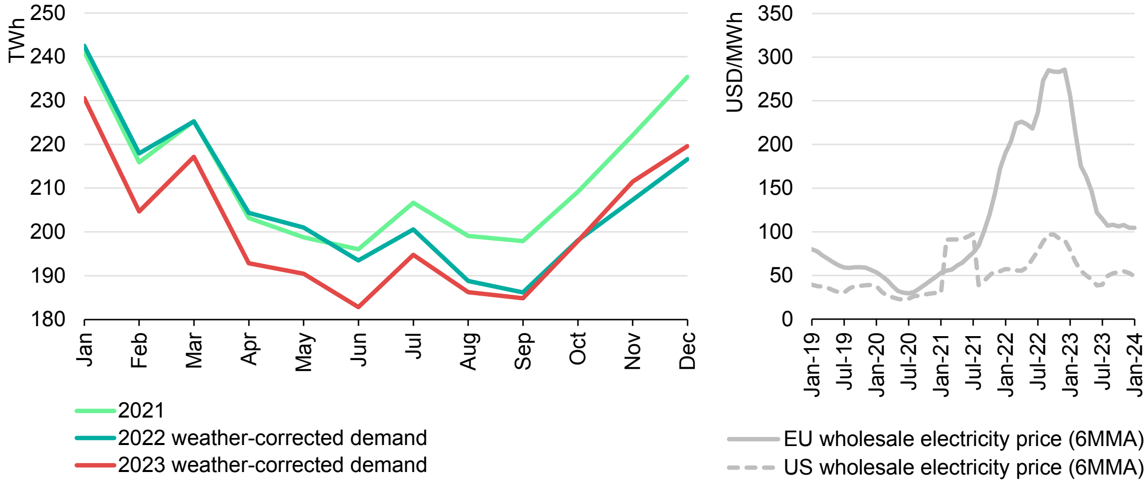
EUR 100/MWh in the fourth quarter. Similarly, the year-on-year fall in total electricity demand stopped from September onward and recovered slightly in November and December, after declines compared to 2022 had been recorded in every month up to that point.

Monthly EU electricity demand, 2021-2023 (left), and average wholesale electricity prices in the European Union and the United States, 2019-2023 (right),



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Notes: In the chart on the left, 2022 and 2023 demand is weather-corrected to the base year of 2021. This means what demand would have been in 2022 and 2023 if the weather was the same as in 2021. The 2021 demand profile corresponds to the realised net demand. In the chart on the right, the plotted average wholesale prices are 6-month moving averages (6MMA).
Source: IEA analysis based on data from Eurostat (2023) and EIA (2023).

Assuming energy prices remain relatively moderate and the economic outlook improves over the forecast period, we expect electricity demand in the industry sector to start recovering gradually from 2024 onward. Nevertheless, some permanent electricity demand destruction has already occurred, especially in energy-intensive chemical and primary metal industries, and there is still significant uncertainty about how much of the reductions of the last two years will be temporary or permanent.

There are signs of some permanent electricity demand destruction

Overall, production output and consequently the electricity demand of the energy-intensive industries such as aluminium, steel, paper and chemicals were lower in 2023 than in the previous year. Some production curtailments announced by energy-intensive industries following the sharp climb in prices in 2022 were temporary, as various facilities restarted and ramped up operations when energy prices started falling in 2023. However, many other plants remained shut down. Restarting a closed facility is generally costly. For example, reopening an

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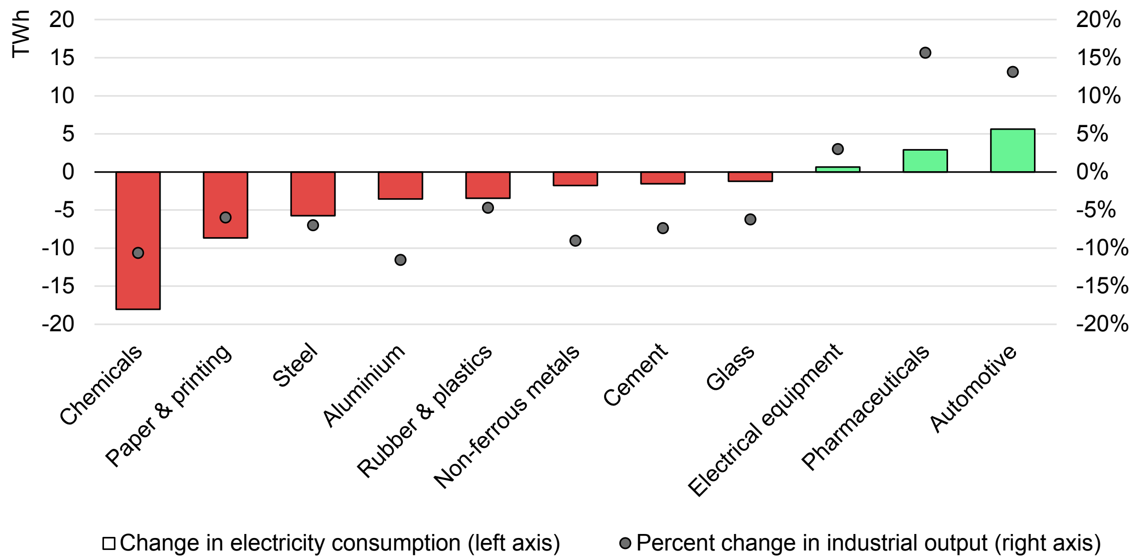
aluminium smelter can cost up to EUR 400 million (USD 394 million). Hence, it is likely some of the temporary shutdowns to date will be followed by permanent closures.

The **chemical** industry has been severely affected from elevated energy costs, with the risks of permanent closures compounded by reduced competitiveness as China dominates growth. Producers such as Yara, Dow, INEOS, Grupa Azoty, among many others, curtailed production of chemical products such as polyethylene, ammonia, urea, nitrates and NPK (nitrogen, phosphorus, and potassium) fertilisers. Large chemical producers such as BASF shut down plants in part due to high energy costs. This included the closure of caprolactam, ammonia, cyclohexanol, cyclohexanone, soda ash, toluene diisocyanate and precursor plants at its Ludwigshafen site, as well as fertiliser facilities. The site has an annual electricity consumption of around 6 TWh, and has plans to reduce their emissions by 5%. Assuming a similar 5% reduction in energy consumption, this amounts to 0.3 TWh of permanent electricity demand reductions.

Estimated year-on-year changes in industrial output and electricity consumption in selected industries in the European Union in 2023



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Source: IEA analysis based on data from Eurostat, Worldsteel, International Aluminium Institute and CEFIC.

The European primary **metal industry** was hit especially hard by soaring electricity prices due to the energy-intensive nature of the production process. For primary aluminium, for example, electricity costs generally make up about 40% of the cost of production. Considering the ongoing curtailments and announced shutdowns until end of 2023, our analysis shows the loss in EU annual electricity demand, cumulating the closures since 2020, to be about 23 TWh in the considered primary metal industries of aluminium, zinc, steel, and silicon.

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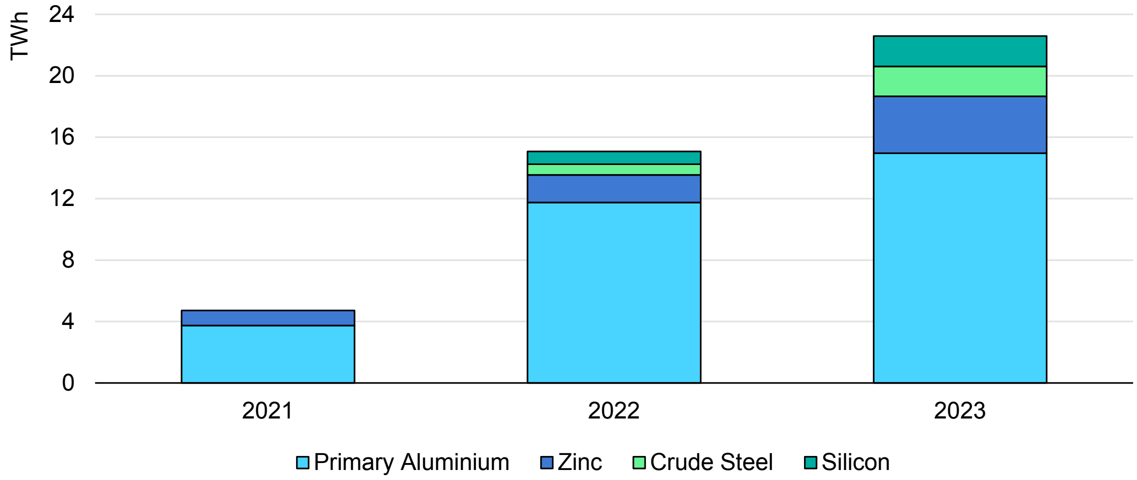
Estimated cumulative loss in annual electricity demand in selected primary metal industries in the European Union compared to 2020



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Notes: Estimates are based on announcements of permanent and indefinite plant closures, and production curtailments. The numbers are to be interpreted as the structural demand destruction due to production losses compared to the reference period 2020. Realised changes of demand in the year of closure can differ due to the exact timing of the closure within that year. Silicon electricity demand considers silicon metals, silicon manganese, polysilicon and silicon-based alloys.
Source: IEA analysis of company data, national statistics and news reports.

Around 30% of EU **primary aluminium** production capacity has been suspended since 2021, with the curtailments and closures adding up to a loss of about 1.1 Mt of annual production capacity by the end of 2023. This corresponds to an estimated loss of about 15 TWh of annual electricity demand. In 2023, several companies followed the temporary cuts in production with shutdowns. The temporary curtailment of Slovakia's Slovalco turned into a permanent shutdown in 2023. Germany's Speira, having halved its production in 2022, and announced in 2023 that it will stop production at its Rheinwerk (Germany) smelter. Similarly, Slovenia's Talum announced in 2023 that it will halt primary aluminium production, after having reduced output to 20% of capacity in 2022. Various other producers of primary aluminium such as Alcoa, Aldel, Alro, and Trimet also cut production.

Some producers also restarted production or are planning to do so. Liberty Aluminium ramped up the production of primary aluminium to full capacity in their Dunkirk (France) plant in early 2023, after cutting it by 20% in 2022. Alcoa announced that it will restart operations in 2024 after shutting down its primary aluminium production in San Ciprian (Spain) at the end of 2021 due to high energy costs. An agreement was reached to restart production through a long-term wind power purchase agreement (PPA) that powers 75% of its production capacity.

There is also an observable trend in Europe towards shifting operations to recycled aluminium production, which is less energy-intensive. In April 2023, Speira completed the acquisition of Real Alloy Europe, which was announced in

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February 2022, doubling its aluminium recycling capacity with the addition of 350 kt. Romania's Alro extended its aluminium recycling capacity following the commissioning of its new recycling facility with an annual capacity of 60 kt in September 2023.

Three **zinc** smelting factories shut down in Germany, Italy and the Netherlands, equivalent to 580 kt of production capacity, and two in Belgium and France reduced production by 50% each. These reductions in zinc production correspond to an estimated yearly electricity demand loss of almost 4 TWh. Shutdowns and production reductions in **silicon** and silicon-based alloys from the plants of Ferroglobe in Spain and France are estimated to similarly account for a loss of annual electricity demand of almost 2 TWh. The **steel** sector lost almost 4 Mt of capacity, equivalent to an estimated 2 TWh of electricity demand, with Lech steelworks shutting down completely in Germany and ArcelorMittal's blast furnaces in France idling.

Amid elevated energy costs, flexible operation is becoming increasingly more important for energy-intensive industries. ArcelorMittal reacted to the rise in electricity costs by taking advantage of the flexibility of their system; stopping during an electricity price peak and resuming after the peak had passed. Other producers such as Salzgitter chose to continue operations at its steel plant in Peine using the flexibility of their facilities to shift production to lower cost hours, thereby partially mitigating the adverse effects of the increased energy costs.

High energy prices also pose a challenge for small and medium-sized companies

Many large energy-intensive industries across the European Union are often exempted from various taxes and fees related to electricity and are also partially compensated for the indirect costs resulting from the EU Emissions Trading System (EU-ETS). By contrast, small and medium-sized industries generally face higher electricity prices. A survey in Germany showed that during the peak of the crisis in 2022, many medium-sized companies reported high energy costs as an existential challenge. The rate at which industrial companies in the European Union are declaring bankruptcy showed an increasing trend in 2023. While new industry-related business registrations have posted steady growth over the period Q1 2022-Q2 2023, averaging 4.4% per quarter, the number of industrial businesses declaring bankruptcy increased at an even higher rate of 10% over the same period.

High energy costs for small and medium-sized companies are particularly problematic if they are also facing international competition, as relatively higher EU energy costs decrease their competitiveness. A survey conducted in 2023 by the German Chamber of Industry and Commerce found that one-third of the

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country's companies that were considering investing abroad cited concerns about high energy cost as a disadvantage. For example, the manufacturer of traditional Christmas sweets Lambertz is considering withdrawing its production operations in Germany, stating that its international customers are reportedly unable to accept the rising prices. The glass manufacturer Heinz-Glass, which supplies bottles for the international perfume industry, has recently indefinitely postponed its plans to increase production capacities, citing concerns over high energy cost in the future.

Outside the energy-intensive sectors, some smaller businesses were also strongly hit by soaring energy bills, often without the financial buffer that large companies tend to have. Particularly affected, for example, are bakeries, where businesses scrambled to adjust operations for energy saving or decided to file for insolvency under the pressure of rising electricity prices. Many countries, such as France, Germany, Poland and Spain, introduced measures to dampen the negative effect on local businesses. On a European level, emergency interventions included a revenue cap of inframarginal producers at EUR 180/MWh and redistribution of excess profits in the oil, gas, coal and refinery sectors.

European metal and chemical industries are likely to remain vulnerable to energy price shocks

The degree of vulnerability in energy-intensive commodity industries from increasing energy prices varies significantly. While some industries can tolerate elevated energy costs, other sectors are more dependent on cheap energy inputs. Our analysis shows that chemicals, steel, and aluminium are more exposed to increasing energy cost. Despite energy prices stabilising in 2023, the metal and chemical industries remain vulnerable, with margins expected to stay at low levels until 2025. While other industries may have a more positive outlook, increasing uncertainty and expectations about future price increases may still negatively impact business conditions for industry in Europe.

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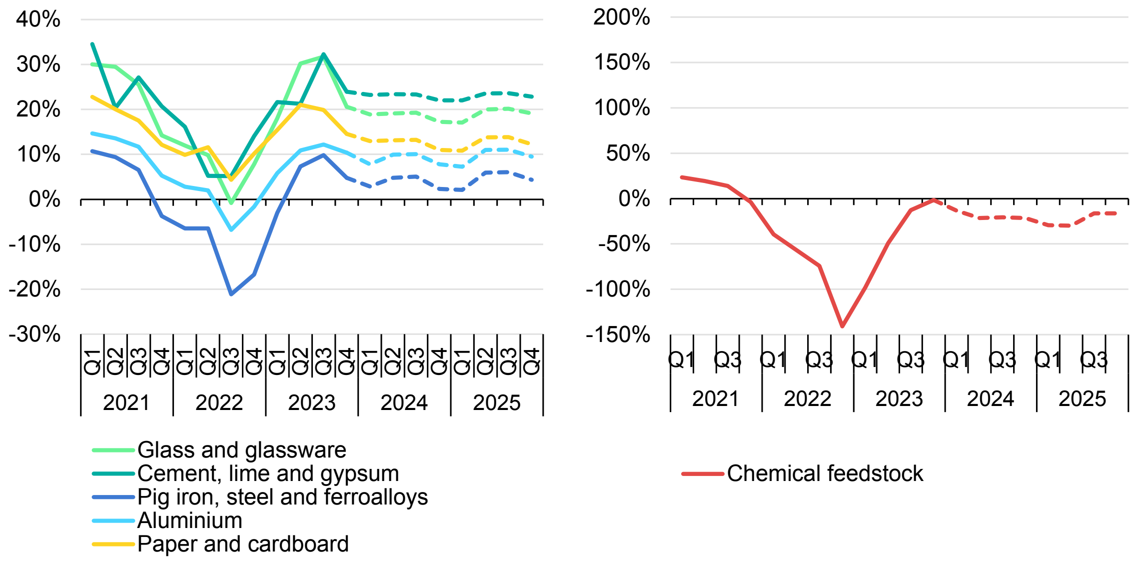
Estimated quarterly net value added of selected industries in Germany, 2021-2025



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Notes: Chemical feedstock includes basic organic and inorganic chemicals, fertilisers and nitrogen products, primary rubber and plastics, industrial gases, and pigments and colourings. The analysis uses data on German firms from 2019 to calculate the initial profit margins, aggregated by sector. These are extrapolated using EUROSTAT indices for production volume and producer price indices on a sectoral level. Assuming a constant energy intensity of production over time, historical and futures price data on energy carriers are used to simulate the margins over time. Considering the pass-through of cost in the future, futures prices of the produced commodity are used when available (i.e. for steel and aluminium). The analysis also excludes ex-post compensation payments, subsidies or any other government interventions. Prices are calculated using a 3-month moving average.

Source: IEA analysis based on data from Eurostat and Destatis.

How much electricity does the European Union import in the form of energy-intensive goods?

The issue of reduced production of energy-intensive goods in the European Union amid high energy prices has contributed to an increase in imports in these sectors, which was particularly observable in 2022. This raises the question of how much electricity is not consumed in the European Union but is shifted to other regions and imported from there indirectly in the form of energy-intensive goods.

Our analysis shows that over 160 TWh of electricity – corresponding to 6% of EU electricity demand – was indirectly imported in 2022 into the European Union in the form of energy-intensive goods made up by chemicals, primary aluminium, crude steel, paper pulp, and cement. After an estimated 8% year-on-year increase in 2022, 2023 is expected to record a decline of 4% in indirect imports of electricity in the form of the energy-intensive goods, which can be attributed to the slowdown in EU manufacturing, weaker demand and overhang of inventories. Nevertheless, 2023 imports are still estimated to be 4% higher than the 2021 levels. This means that, in the years 2022 and 2023 combined, an additional 18 TWh of electricity was imported compared to 2021 levels in the form of energy-intensive goods considered in our analysis, mostly due to higher primary aluminium imports.

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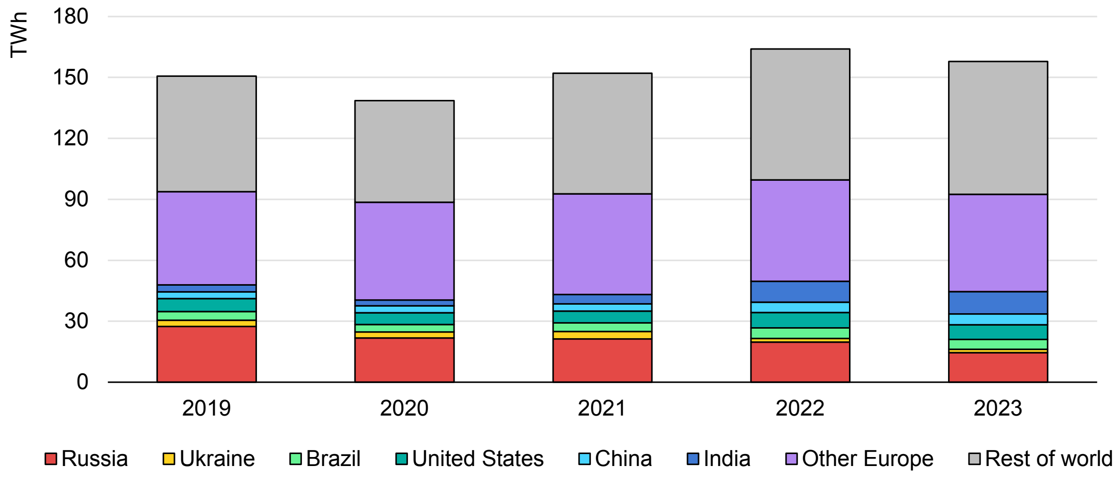
Indirect electricity imports in the form of energy-intensive goods (chemicals, primary aluminium, crude steel, paper pulp, and cement) to the European Union by country of origin, 2019-2023



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Notes: The indirect electricity imports of selected energy-intensive goods include chemicals, primary aluminium, crude steel, paper pulp and cement. Indirect electricity imports in the form of energy-intensive goods are estimated as the electricity required to manufacture the imported product in the European Union based on the electricity intensity of production values in the European Union. The 2023 values are estimated based on Q1-Q3 2023 data and analysis of latest market trends.
Source: IEA analysis based on data from EU trade since 1999 by SITC and Eurostat (2023).

The largest cumulative increases in energy-intensive imports since 2021 have been in primary aluminium. In 2022 and 2023 combined, there was an additional 20 TWh of indirect electricity imports, compared to 2021 levels. Around half of this came from higher imports from India, which was followed by United Arab Emirates. Chemicals was another sector which saw growth in imports in 2022, with about 2 TWh more indirect electricity imported compared to 2021, mainly from the United States and China. But the imports of chemicals declined in 2023 amid slower economic activity, more than offsetting this increase. Pulp and cement imports similarly saw increases in 2022, but were more than offset by significant declines in 2023.

There have been also changes with respect to where these energy-intensive products came from. For example, in order to substitute the loss of crude steel imports from Ukraine following the Russian invasion, imports from China, Brazil, India, and other countries increased in 2022.

Sanction-hit Russia has seen a sharp drop in exports to the European Union in the energy-intensive industries. The share of Russia in the indirect electricity imports from these energy-intensive goods is estimated to have decreased from 18% in 2019 and 14% in 2021, to 9% in 2023. As sanctions entered into force gradually over the course of 2023, Russia was still one of the largest sources of

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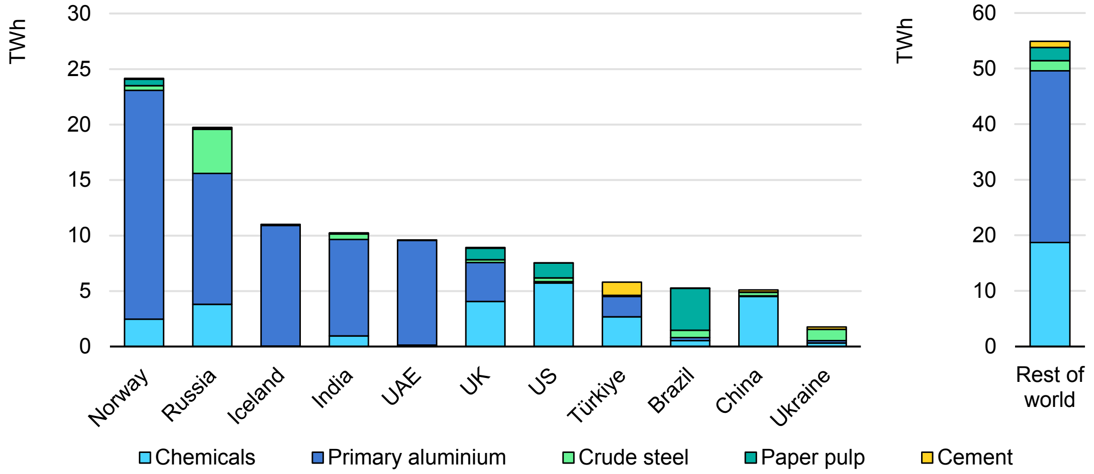
indirect electricity imports to the European Union in the form of energy-intensive goods in 2023, largely due to substantial amounts of steel imports, followed by primary aluminium and chemicals.

Estimated indirect electricity imports in the form of energy-intensive goods to the European Union by sector and country of origin, 2022



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Note: Indirect electricity imports in the form of energy-intensive goods are calculated as the electricity required to manufacture the imported product in the European Union, based on the electricity intensity of EU production values.
Source: IEA analysis based on data from Eurostat (2023), EU trade since 1999 by SITC.

Russia's share in the imports of these energy-intensive goods is expected to decrease further in the future, as sanctions are rigorously applied. However, other products such as primary aluminium are currently not sanctioned. Even though there are sanctions on individual aluminium products, primary aluminium remains unsanctioned since it is considered a strategic raw material by the European Union. Additionally, Russian aluminium is still strongly integrated within European supply chains. However, there have been calls within Europe's aluminium industry group to lobby for EU sanctions on Russian aluminium.

EU sanctions on Russia related to energy-intensive goods

Sector	Date of adoption	Sanction
Steel	15 March 2022	The European Union adopted Council Regulation (EU) 2022/428 imposing an import ban on iron and steel products originating from Russia (flat-rolled products, bars, rods, wire, tubes, pipes etc.)
	23 June 2023	As part of the eleventh EU sanctions package, importers of iron and steel must prove that inputs used in their goods have not originated in Russia. However, these sanctions are implemented in phases coming into force in September 2023.

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Sector	Date of adoption	Sanction
Cement	8 April 2022	Imports of cement from Russia are banned as part of a fifth set of economic and individual sanctions
Paper pulp	6 October 2022	Plastics, paper and wood pulp imports from Russia are banned as part of an eighth set of economic and individual sanctions.
Chemicals	6 October 2022	Imports of chemical products such as basic petrochemicals, inorganic chemicals, intermediates, plastics, fertilisers and specialties are now banned. These include methanol, phosphates, potash, NPK, nitrates, hydrochloric acid, nitric acid, phosphoric acid, sulfuric acid and others.
Aluminium	8 April 2022	Imports of flat-rolled aluminium products above 0.2 mm such as plates, sheets or strip from Russia are banned as part of the fifth set of sanctions.
	18 December 2023	As part of the twelfth EU sanctions package, imports of aluminium wires, foil, tubes and pipes from Russia were banned.

Carbon policy and EU energy-intensive industries

Next to overall competitiveness influenced by energy prices, EU carbon policy will additionally play a large role in determining the future of the energy-intensive industries in Europe. Relying to a large extent on price-based policies, the EU-ETS will soon be accompanied by a Carbon Border Adjustment Mechanism (CBAM) at the centre of its climate policy. Allowance prices have been rising over the last few years, exceeding EUR 100/t CO_2 in February 2023 for the first time, before falling and averaging about EUR 85/t CO_2 in the second half of the year. In addition, progressing decarbonisation will ease the burden accordingly as companies invest in reducing the carbon intensity of production. Other countries outside the European Union have significantly lower carbon prices and/or rely on subsidy-based programmes (such as the United States with the Inflation Reduction Act of 2022), or have no effective policies targeting CO_2 emissions.

Additionally, the European Union uses a range of measures to counter potential negative effects on the competitiveness and carbon leakage of industry. After providing free allowances to energy-intensive industries in the first years of the EU-ETS, the CBAM will be phased in, pricing embedded carbon on EU imports for key sectors, including cement, aluminium, steel and fertilisers. This can aid competitiveness in the domestic market and shield against import pressure. However, EU firms largely relying on exports will still need to compete in international markets, where other firms might face less stringent carbon pricing policies. Partially addressing this, electricity compensation schemes allow member states to provide state aid for a limited time up until 2030, to offset increases in electricity cost associated with the EU-ETS (see the Prices chapter for more details.)

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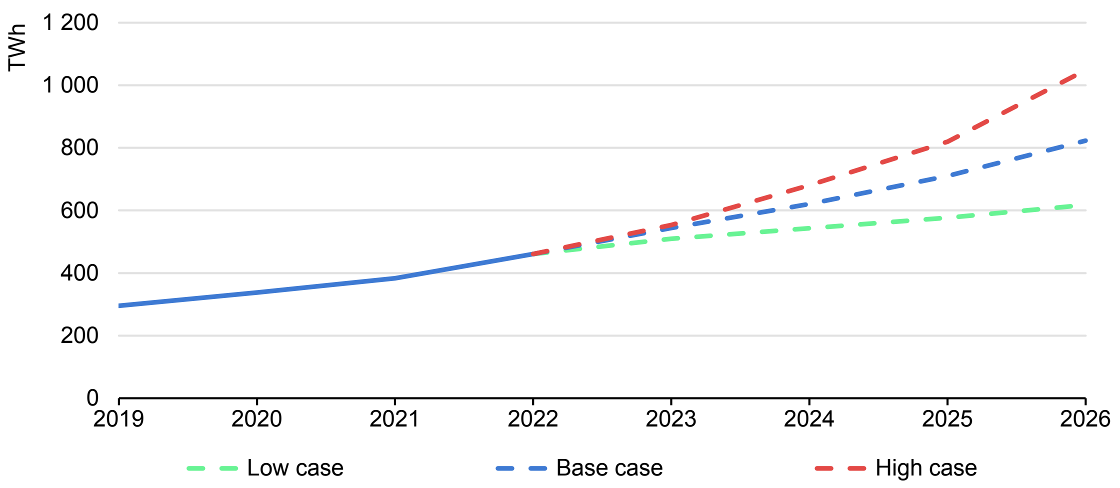
Global electricity demand from data centres could double towards 2026

We estimate that data centres, cryptocurrencies, and artificial intelligence (AI) consumed about 460 TWh of electricity worldwide in 2022, almost 2% of total global electricity demand. Data centres are a critical part of the infrastructure that supports digitalisation along with the electricity infrastructure that powers them. The ever-growing quantity of digital data requires an expansion and evolution of data centres to process and store it. Electricity demand in data centres is mainly from two processes, with computing accounting for 40% of electricity demand of a data centre. Cooling requirements to achieve stable processing efficiency similarly makes up about another 40%. The remaining 20% comes from other associated IT equipment.

Future trends of the data centre sector are complex to navigate, as technological advancements and digital services evolve rapidly. Depending on the pace of deployment, range of efficiency improvements as well as artificial intelligence and cryptocurrency trends, we expect global electricity consumption of data centres, cryptocurrencies and artificial intelligence to range between 620-1 050 TWh in 2026, with our base case for demand at just over 800 TWh – up from 460 TWh in 2022. This corresponds to an additional 160 TWh up to 590 TWh of electricity demand in 2026 compared to 2022, roughly equivalent to adding at least one Sweden or at most one Germany.

Global electricity demand from data centres, AI, and cryptocurrencies, 2019-2026



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Notes: Includes traditional data centres, dedicated AI data centres, and cryptocurrency consumption; excludes demand from data transmission networks. The base case scenario has been used in the overall forecast in this report. Low and high case scenarios reflect the uncertainties in the pace of deployment and efficiency gains amid future technological developments.

Sources: Joule (2023), de Vries, The growing energy footprint of AI; CCRI Indices (carbon-ratings.com); The Guardian, Use of AI to reduce data centre energy use; Motors in data centres; The Royal Society, The future of computing beyond Moore's Law; Ireland Central Statistics Office, Data Centres electricity consumption 2022; and Danish Energy Agency, Denmark's energy and climate outlook 2018.

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Data centres are significant drivers of electricity demand growth in many regions

There are currently more than 8 000 data centres globally, with about 33% of these located in the United States, 16% in Europe and close to 10% in China. US data centre electricity consumption is expected to grow at a rapid pace in the coming years, increasing from around 200 TWh in 2022 (~4% of US electricity demand), to almost 260 TWh in 2026 to account for 6% of total electricity demand. Growth will be driven by increased adoption of 5G networks and cloud-based services, as well as competitive state tax incentives.

China's State Grid Energy Research Institute expects electricity demand in the country's data centre sector to double to 400 TWh by 2030, compared to 2020. We forecast electricity consumption from data centres in China to reach around 300 TWh by 2026. Regulations are being updated to promote sustainable practices in current and future data centres to align them with decarbonisation strategies. A major source of data centre growth is expected to come from the rapid expansion of 5G networks and the Internet of Things (IoT).

In the European Union, data centre electricity consumption is estimated at slightly below 100 TWh in 2022, almost 4% of total EU electricity demand. Around 1 240 data centres were operating within Europe in 2022, with the majority concentrated in the financial centres of Frankfurt, London, Amsterdam, Paris, and Dublin. With a significant number of additional data centres planned, as well as new deployments that can be expected to be realised over the coming years, we forecast that electricity consumption in the data centre sector in the European Union will reach almost 150 TWh by 2026.

Almost one-third of electricity demand in Ireland could come from data centres by 2026

In Europe, the data centre market in Ireland is developing rapidly as their electricity consumption grows along with new policies and initiatives. Electricity demand from data centres in **Ireland** was 5.3 TWh in 2022, representing 17% of the country's total electricity consumed. That is equivalent to the amount of electricity consumed by urban residential buildings. At this pace, in a high case scenario, Ireland's data centres might double their electricity consumption by 2026, and with AI applications penetrating the market at a fast rate, the sector could reach a share of 32% of the country's total electricity demand in 2026 if most of the approved projects are able to be connected to the system. This assumes that at the same time efficiency gains in other sectors continue to take place.

Ireland's stock of data centres, currently at 82, is expected to grow by 65% in the coming years, with 14 data centres under construction and 40 approved to start

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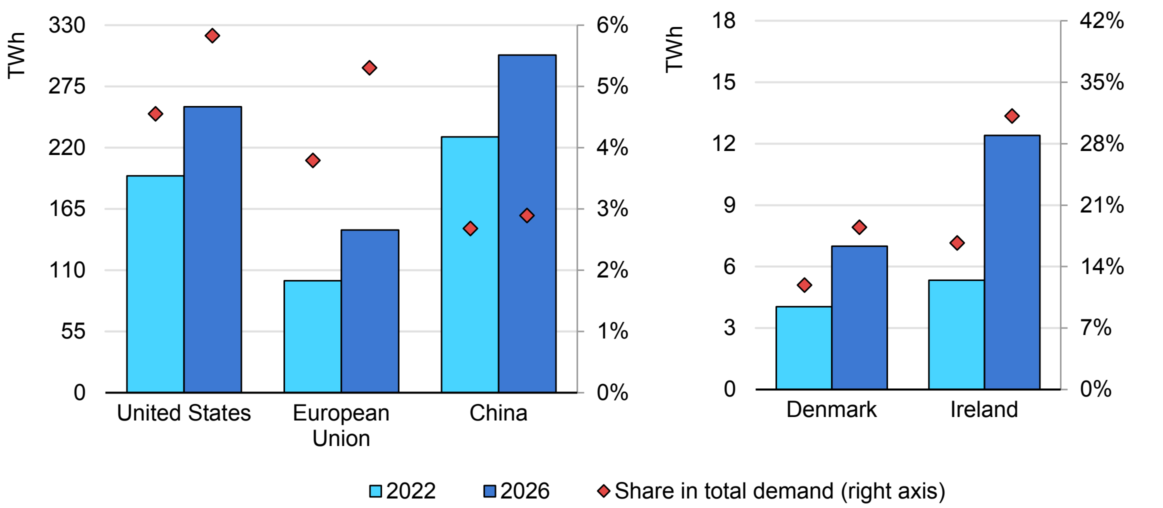
the building phase. Ireland has one of the lowest corporate tax rates in the European Union (12.5%), which is an advantage for the sector's expansion in the country. By contrast, European OECD countries' average corporate tax rate is 21.5%.

The rapid expansion of the data centre sector and the elevated electricity demand can pose challenges for the electricity system. To safeguard the system's stability and reliability, Ireland's Commission for Regulation of Utilities published in late 2021 its decision on the new requirements applicable to new and ongoing data centre grid connection applications with three assessment criteria to determine if the connection offer can be made. First, the location of the data centre with respect to whether they are within a constrained region of the electricity system. Second, the ability of the data centre to bring onsite dispatchable generation and/or storage equivalent, at least, to their demand. Third, the ability of the data centre to provide flexibility in their demand by reducing it when requested by a system operator. For the third clause, data centre operators that offer their servers for hire will have to update their contracts to reflect the new regulations. These requirements showcase the local government's inclination to grant connections to those operators that can make efficient use of the grid and incorporate renewable energy sources with a view of decarbonisation targets.

Estimated data centre electricity consumption and its share in total electricity demand in selected regions in 2022 and 2026



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Sources: IEA, Data Centres and Data Transmission Networks; Lawrence Berkeley National Laboratory, United Stated Data Center Energy Usage Report; Ireland Central Statistics Office, Data Centres Metered Electricity Consumption 2022; Danish Energy Agency, Denmark's Energy and Climate Outlook 2018; China's State Council, Green data centres in focus; European Commission, Energy-efficient Cloud Computing Technologies and Policies for an Eco-friendly Cloud Market; Joule (2023), Alex de Vries, The growing energy footprint of artificial intelligence; and Crypto Carbon Ratings Institute, Indices.

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Denmark currently hosts 34 data centres, half of them located in Copenhagen. As in Ireland, Denmark's total electricity demand is forecast to grow mainly due to the data centre sector's expansion, which is expected to consume 6 TWh by 2026, reaching just under 20% of the country's electricity demand. Denmark is the hub for a new pan-European initiative, Net Zero Innovation Hub for Data Centers. The hub offers a space for collaboration between suppliers, operators and governments to enable progress towards the sector's innovation and decarbonisation while meeting increasing regulatory demands.

Data centres in **Nordic** countries – such as Sweden, Norway, and Finland – benefit from lower electricity costs. This is attributed to lower cooling demand due to their colder weather, and to lower electricity prices in comparison to other major data centre hubs, such as Germany, France and the Netherlands. The largest actor amongst Nordic countries is Sweden, with 60 data centres, and half of them in Stockholm. In August 2023, plans for a nuclear-powered data centre were announced utilising small modular reactors (SMR) technology on the east coast of Sweden, with a commissioning date envisaged for 2030. Given decarbonisation targets, Sweden and Norway may further increase their participation in the data centre market since almost all of their electricity is generated from low-carbon sources.

In the United States, the largest data centre hubs are located in California, Texas and Virginia. In the case of Virginia, their economy was dominated in 2021 by the data centre sector expansion, attracting 62% of all of the state's new investments and providing more than 5 000 new jobs. Northern Virginia is the largest data centre market in the country, collecting USD 1 billion in local tax revenues per year, with growth trending higher as companies, such as Amazon's planned USD 35 billion expansion by 2040, continue to increase their investment in the state. New legislation is aimed at tightening regulations on data centre developments, including zoning rules, mandatory environment and resource impact assessments, as well as guidelines on water usage. In US northeastern states, the regional transmission organisation PJM expects data centres to increasingly drive electricity demand, forecasting a rise in summer peak load from 151 GW in 2024 to 178 GW by 2034.

Artificial intelligence and cryptocurrencies are additional sources of electricity demand growth

Market trends, including the fast incorporation of AI into software programming across a variety of sectors, increase the overall electricity demand of data centres. Search tools like Google could see a tenfold increase of their electricity demand in the case of fully implementing AI in it. When comparing the average electricity demand of a typical Google search (0.3 Wh of electricity) to OpenAI's ChatGPT

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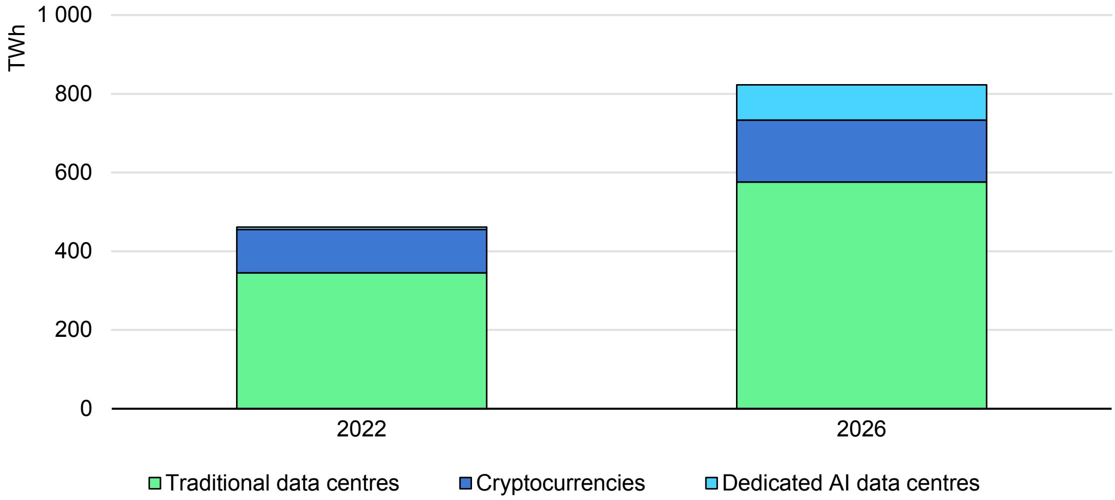
(2.9 Wh per request), and considering 9 billion searches daily, this would require almost 10 TWh of additional electricity in a year.

AI electricity demand can be forecast more comprehensively based on the amount of AI servers that are estimated to be sold in the future and their rated power. The AI server market is currently dominated by tech firm NVIDIA, with an estimated 95% market share. In 2023, NVIDIA shipped 100 000 units that consume an average of 7.3 TWh of electricity annually. By 2026, the AI industry is expected to have grown exponentially to consume at least ten times its demand in 2023.

Estimated electricity demand from traditional data centres, dedicated AI data centres and cryptocurrencies, 2022 and 2026, base case



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Note: Data centre electricity demand excludes consumption from data network centres.
Sources: IEA forecast based on data and projections from Data Centres and Data Transmission Networks; Joule (2023), Alex de Vries, The growing energy footprint of artificial intelligence; Crypto Carbon Ratings Institute, Indices; Ireland Central Statistics Office, Data Centres Metered Electricity Consumption 2022; and Danish Energy Agency, Denmark's Energy and Climate Outlook 2018.

In 2022, cryptocurrencies consumed about 110 TWh of electricity, accounting for 0.4% of the global annual electricity demand, as much as the Netherland's total electricity consumption. In our base case, we anticipate that the electricity consumption of cryptocurrencies will increase by more than 40%, to around 160 TWh by 2026. Nevertheless, uncertainties remain for the pace of acceleration in cryptocurrency adoption and technology efficiency improvements. Ethereum, the second largest cryptocurrency by market cap, reduced its electricity demand by an amazing 99% in 2022 by changing its mining mechanism. By contrast, Bitcoin is estimated to have consumed 120 TWh by 2023, contributing to a total cryptocurrency electricity demand of 130 TWh. Challenges in reducing electricity consumption remain, as energy savings can be offset by increases in other energy

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consuming operations, such as other cryptocurrencies, even as some become more efficient.

Efficiency improvements and regulations will be crucial in restraining data centre energy consumption

The revised Energy Efficiency Directive from the European Commission includes regulations applicable to the European data centre sector, promoting more transparency and accountability to enhance electricity demand management. Starting from 2024, operators have mandatory reporting obligations for the energy use and emissions from their data centres, and large-scale data centres are required to have waste heat recovery applications, when technically and economically feasible, while meeting climate neutrality by 2030. An earlier EU regulation, applicable since 2020, sets efficiency standards for data centres enabling better control over their environmental impact. A self-regulatory European initiative created in 2021, called the Climate Neutral Data Centre Pact, sets targets to achieve climate neutrality in the sector by 2030. More than 60 data centre operators have signed on to the pact, including large operators like Equinix, Digital Realty and Cyrus One.

In the United States, the Energy Act of 2020 requires the federal government to conduct studies on the energy and water use of data centres, to create applicable energy efficiency metrics and good practices that promote efficiency, along with public reporting of historical data centre energy and water usage. The Department of Energy (DOE) is supporting the local production of semiconductors and is funding the development of more efficient semiconductors over the next two decades. More efficient semiconductors reduce cooling requirements, thus supporting the decarbonisation of the sector. At a state level, regulators in Virginia and Oregon have already imposed requirements for better sustainability practices and carbon emissions reductions.

Chinese regulators will require all data centres acquired by public organisations to improve their energy efficiency and be entirely powered by renewable energy by 2032, starting with a 5% share mandate for renewables in 2023.

New fields of research can help increase efficiency and reduce energy consumption in data centres

The primary drivers of data centre electricity demand are the cooling systems and the servers themselves, with each typically accounting for 40% of the total consumption. The remaining 20% is consumed by the power supply system, storage devices and communication equipment. The adoption of high-efficiency cooling systems has the potential to reduce electricity demand in data centres by 10%. Other cooling research shows that a 20% reduction in consumption can be

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achieved when operating with direct-to-chip water cooling and specific low viscous fluids to cool all other components. Machine learning can help reduce the

electricity demand of servers by optimizing their adaptability to different operating scenarios. Google reported using its DeepMind AI to reduce the electricity demand of their data centre cooling systems by 40%.

In the long term, replacing supercomputers with quantum computers could reduce electricity demand of the sector if the transition is supported by efficient cooling systems. Quantum computers deliver more and faster processing power than supercomputers while consuming less energy, but they need to be cooled to temperatures near absolute zero (-273°C) while supercomputers can operate at 21°C.

Data centres are evolving towards more sustainable and efficient operations, including transitioning to Hyperscale Data Centres, which can run large-scale operations without a significant increase in electricity consumption. This transition is also financially attractive, with the global market for Hyperscale Data Centres projected to double in size by 2026 compared to 2023, reaching a value of USD 212 billion.

Another promising field of research for decarbonising data centre operations involves time and location shifting of electricity demand. Software developments can allow operators to temporarily shift power loads with carbon-aware models that relocate data centre workloads to regions with lower carbon intensity at selected times. Simultaneously, such methodology has shown the probability of increasing the operational affordability by reducing costs of consuming low-emissions energy around the clock by up to 34%. Results of this methodology combined with other energy efficiency measures in place and on-site low-emission energy production have demonstrated that data centres can achieve a 64% share of carbon-free energy in their total electricity consumption, according to Google's 2023 Environmental Report.

Rising self-consumption in distributed systems and data collection challenges

As part of the energy transition, distributed generation has been increasing in many parts of the world. This is most notably reflected in rising rooftop solar PV installations and growing amounts of self-consumption from behind-the-meter solar PV. By 2022, self-consumption from distributed solar PV generation accounted for about 2% of total electricity demand in Italy. In countries such as Germany, Spain, Brazil and Japan this share is estimated to be around 1% of total electricity demand in 2022. However, an accelerating trend in Spain and Brazil can be observed.

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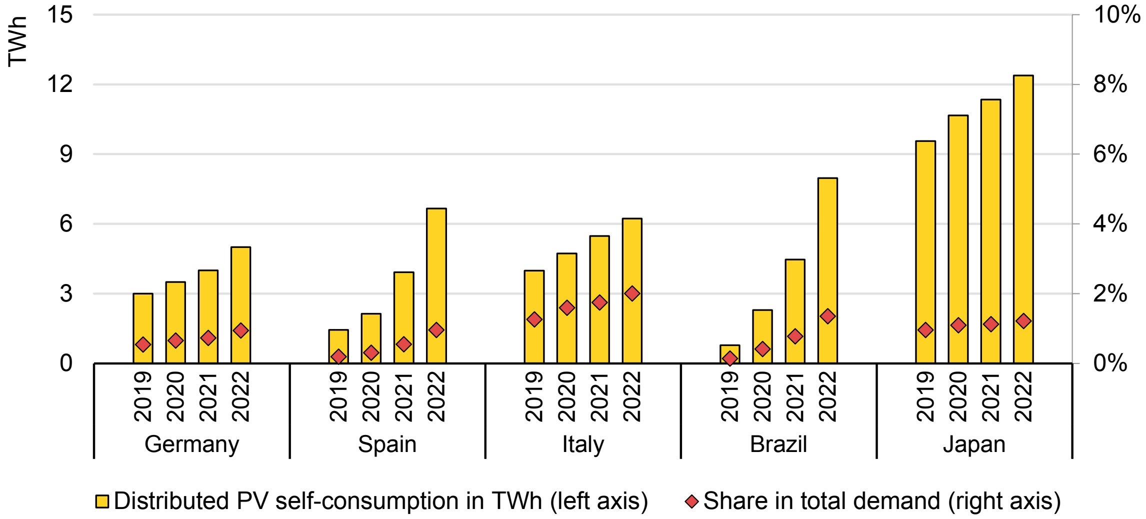
Estimated electricity self-consumption in distributed systems and its share in total electricity demand in selected countries, 2019-2022



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Source: IEA estimates based on data and information from various sources; Federal Network Agency (Germany), Bundesnetzagentur; Federal Ministry of Economics and Climate Protection (Germany), BMWK; Strom-Report, Photovoltaic in Germany; APPA (Spain), Self-consumption yearly report; IEA, Photovoltaic Power Systems Programme; Terna, (Italy); EPE (Brazil), Brazilian distributed generation.

Self-consumption is set to increase as more distributed resources are deployed in the context of the energy transition. Improved availability of distributed generation and self-consumption data will be increasingly important for accurate demand forecasts, peak load projections and grid planning. Depending on how self-consumption is accompanied by deployment of domestic storage systems, increased reliance on self-consumption can also have a bearing on flexibility estimations for system balancing operations. Therefore, in addition to forecasts and planning, a complete data set on distributed generation and consumption can give valuable insights into the potential for local flexibility solutions to mitigate intermittency challenges in power systems increasingly based on renewable generation.

Improved data exchange between distribution system operators (DSOs) and transmission system operators (TSOs) can contribute to a more comprehensive accounting of self-consumption. Regarding individual consumption data, collected data must be handled with a certain degree of confidentiality. Data privacy protection policies on the topic have been implemented and are continuously adapted to emerging changes. However, these policies need to be designed in such a way that they do not create an additional obstacle for data utilisation. New EU rules adopted in June 2023, for example, enhance this process. These amendments are aimed at improving interoperability between customers, utilities and eligible third parties that wish to access smart metering data while protecting

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consumers. The new rules allow stakeholders to access historical smart meter data from 2019 onwards, including near-real-time data.

Smart meter roll-out on the way for improved data collection

Global smart meter investments doubled in 2022 compared to 2015, with the number of smart meters exceeding 1 billion worldwide. China accounts for more than half of the total figure, followed by the European Union with 16% and the United States with a share of 13%. Smart meter penetration varies significantly among countries and regions, with use in 80% of US households. An estimated 70% EU consumers have a smart meter, and this share is expected to rise to 77% by 2024. In Latin America, approximately 10% of electricity consumers have smart meters, with 70% of this share in Brazil and Mexico. India aims to replace 250 million conventional meters by 2026 and counts close to 8 million smart meters as of 2023. Lagged smart-meter roll out in several regions has been experienced due to budget constraints, complex procedures, and a general consumer concern on data privacy.

Smart meters not only enable better and more detailed data collection, which can be used for an improved assessment of self-consumption, among other things, but can also enable considerable cost savings. For example, in 2018 alone, with an installation cost of EUR 180-200, smart meters in the European Union have reportedly allowed yearly savings of EUR 280 per metering point on average among the member states, which are based on direct and indirect benefits for consumers. Direct consumer benefits derive from an observed behavioural change in energy consumption triggered by the awareness of the granular data from smart meters. Additionally, timely information about dynamic tariffs motivates consumers to shift their energy consumption to times when is most economically convenient. Indirect benefits are enabled by an improvement on the utility's operations, for example, by remote management of the metering system.

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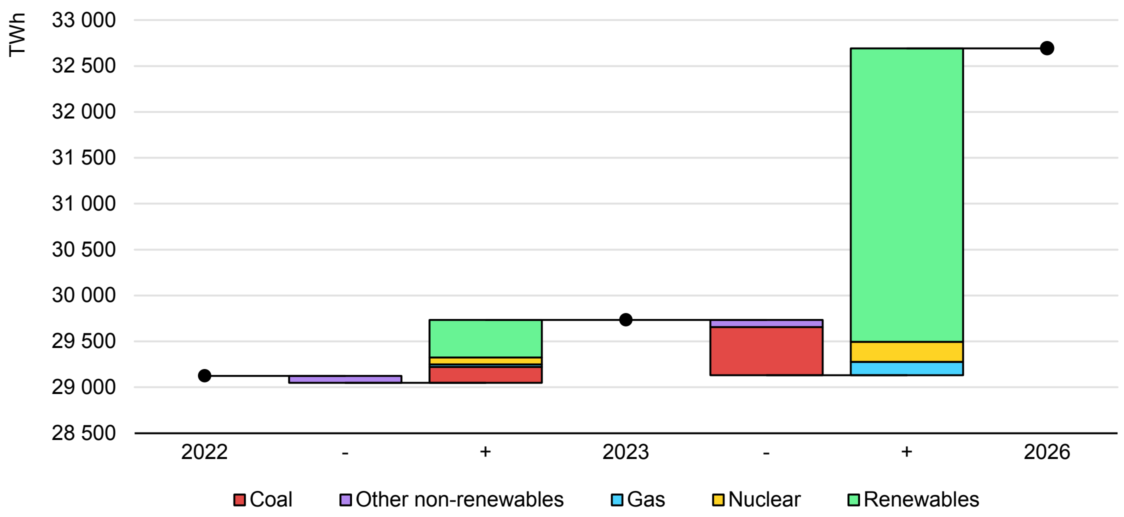
Supply: Clean electricity to meet all additional demand out to 2026

Renewables overtake coal as the largest source of global electricity supply in 2025

Our forecast period out to 2026 is characterised by three turning points with regard to low-carbon electricity sources. First, renewables are expected to generate more than one-third of world's electricity in 2025, overtaking coal as the largest source of supply. Second, low-carbon sources – renewables and nuclear together – are expected to account for 46% of the world's electricity generation by the end of 2026, rapidly approaching the halfway mark, up from 39% in 2023. And finally, on a global scale, low-carbon generation is set to meet all the additional demand growth towards 2026.

In 2023, growth in renewable power generation was relatively subdued, recording an increase of 5% compared to 8% in 2022, and was below the 2016-2022 average of 6.5%. This was predominantly due to low hydropower output in various regions due to droughts, especially in China. Assuming the return to normal hydropower conditions, we expect stronger year-on-year gains in renewable generation, with a 14% surge in 2024 over the drought-stricken 2023, followed by an annual average of 9% in 2025-2026.

Changes in global electricity generation, 2022-2026



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Note: Other non-renewables includes oil, waste and other non-renewable energy sources.

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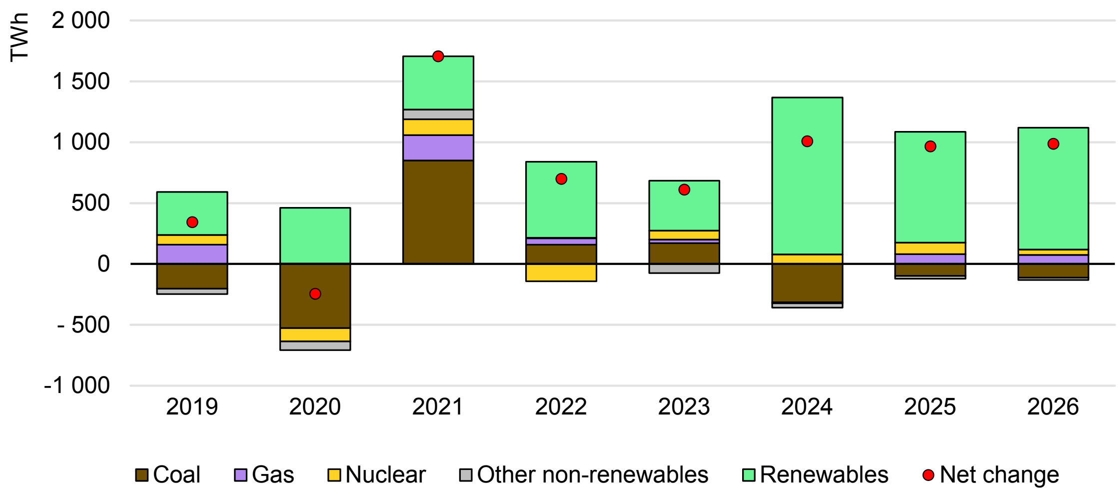
Global nuclear generation is expected to reach a new historical high in 2025, exceeding the previous 2021 record. After rising by 2.7% in 2023, we forecast nuclear generation to grow on average by about 3% over the period 2024-2026. This is supported by the continued recovery in French nuclear output, restarts in Japan, and new plants coming online in many parts of the world, half of them in China and India alone.

Year-on-year global change in electricity generation by source, 2019-2026



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Notes: Other non-renewables includes oil, waste and other non-renewable energy sources. The figures for 2024-2026 are forecast values.

Over the forecast period, coal's share in global electricity generation is set to drop to below one-third from 36% in 2023, marking another significant milestone. Coal-fired generation is expected to have peaked in 2023, with 1.6% year-on-year growth, after which it is set to post a decline of 3% in 2024, assuming a recovery in hydropower generation from the drought-induced low levels of 2023. This is forecast to be followed by a slow structural decline of around 1% on average in 2025-2026 under normal weather conditions. By contrast, following an increase of 0.5% in 2023, global gas-fired generation is expected to continue to rise at an average annual growth rate of less than 1% out to 2026. This will be supported by coal-to-gas switching in various regions, with additional LNG supply becoming available from 2025 onward. As clean electricity supply continues to expand rapidly, the share of fossil fuels in global generation is forecast to contract from 61% in 2023 to 54% in 2026. This is the first time fossil share in electricity generation will dip below 60% and decline at a pace never seen before according to the IEA records dating back more than five decades.

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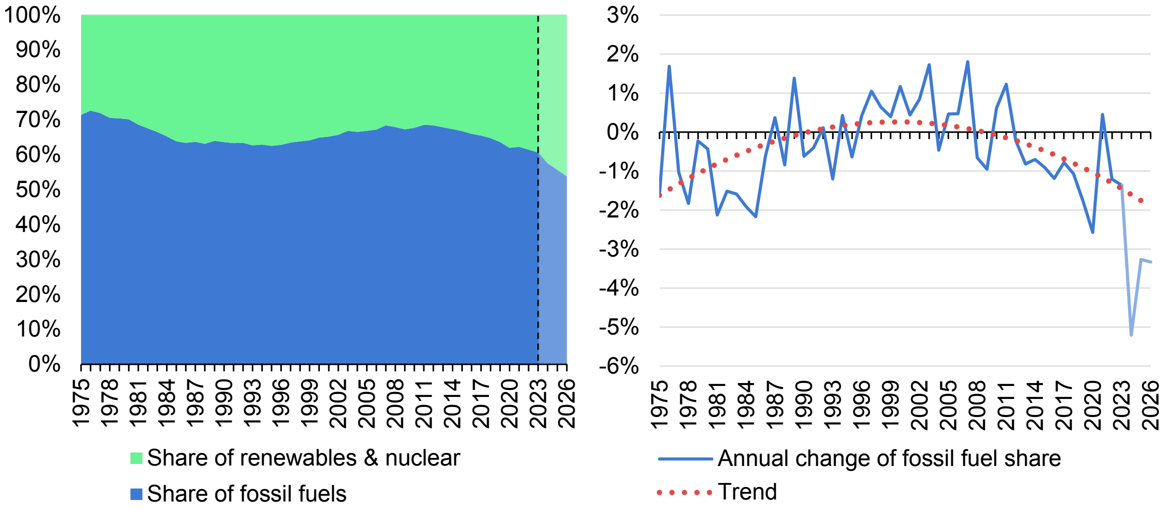
Evolution of the shares of low-emissions sources vs. fossil fuels in global electricity generation (left), and the annual change of fossil fuel share (right), 1975-2026



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Coal constrained by renewables in China, but not in other parts of Asia

As highlighted in IEA's *Renewables 2023* report, **China** commissioned in 2023 as much solar PV capacity as the entire world did in 2022, while its wind power capacity additions also grew by 66% year-on-year. The strong expansion trend of renewables is expected to result in renewable generation growing by around 20% in 2024, assuming a recovery in hydropower, and 13% on average in 2025-2026, covering all the additional Chinese demand growth and suppressing coal-fired output. It should be noted that the weather impact, such as the reduced hydropower due to droughts as observed in recent years, can cause an uptick in Chinese coal-fired generation in individual years. However, the overall trend of coal-fired supply being restrained and replaced by strong growth in renewable energy sources (RES) is expected to remain largely stable.

Given **India**'s rapid increase in demand for electricity, coal-fired power generation is expected to rise by an average 2.5% annually in 2024-2026. At the same time, renewable generation will accelerate, with an average annual growth rate of 13% over the period.

Southeast Asia is another region with new coal-fired capacities coming online amid significant demand growth. Coal-fired generation is set to increase each year on average about 4% out to 2026. Renewables are expected to grow at a higher average 7% rate and gas-fired output at about 5%

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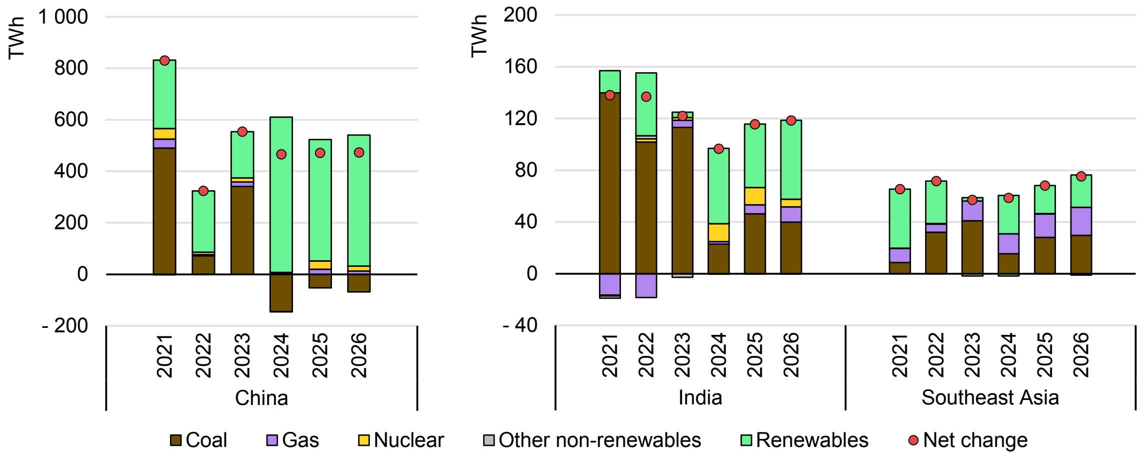
In **Japan**, coal-fired generation is expected to decline annually on average by 3% and in **Korea** by 3% over our outlook period amid increased nuclear and renewable generation. In other parts of Asia, such as **Bangladesh** and **Pakistan**, new coal plants are coming online, with coal-fired generation forecast to record average annual growth rates of 18% and 6%, respectively, from 2024 to 2026.

Year-on-year change in electricity generation by source in Asia, 2021-2026



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Note: Other non-renewables includes oil, waste and other non-renewable energy sources.

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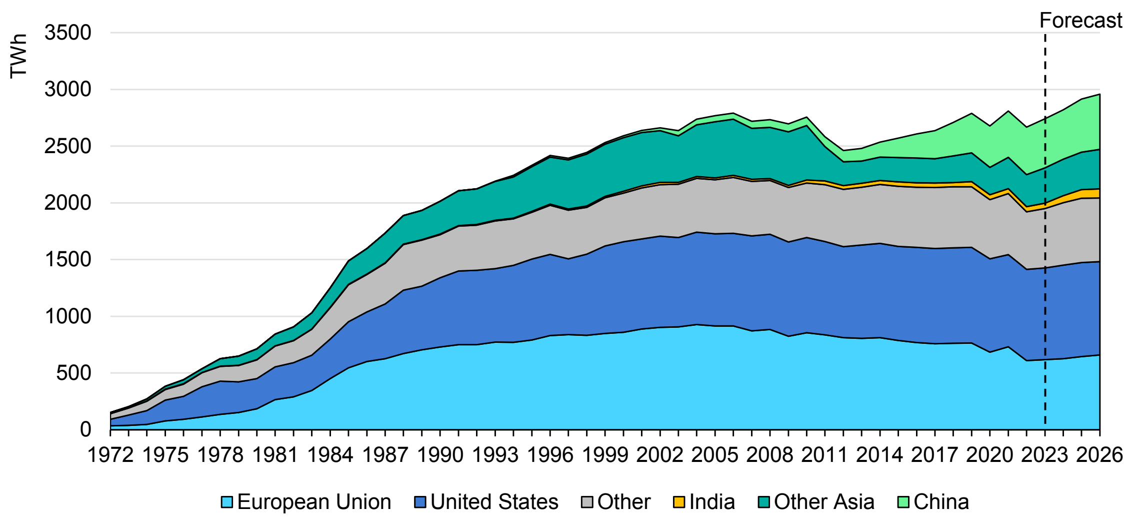
Spotlight: Nuclear generation will reach a new record high by 2025

Between 2024 and 2026, an additional 29 GW of new nuclear capacity is expected to come online globally, more than half of them in China and India. With new plants starting commercial operation in various regions, as well as French nuclear recovery and expected restarts in Japan, we forecast global nuclear generation will be almost 10% higher in 2026 compared to 2023. In 2025, global electricity generation from nuclear energy will have exceeded its previous record level in 2021.

In 2022 and 2023 many countries placed the phasing in or expansion of nuclear power at the centre of their strategies to reach climate policy objectives, sparking a significant revival of global interest in nuclear energy. The IEA's updated Net Zero Roadmap shows nuclear energy more than doubling by 2050, complementing renewable deployment, and easing the pressure on critical mineral supply. With a minority of European countries currently planning to phase out nuclear energy, many emerging and a number of advanced economies are planning to phase in or expand nuclear energy generation. Based on the number of nuclear power plants that are currently under construction and new ones that are being planned, the growth in nuclear power is so far mainly in Asia.

Evolution of nuclear power generation by region, 1972-2026



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Note: The 2026 forecast is based on projects currently under construction and expected to be operational by the end of the period.

At COP28, over 20 countries signed a joint declaration to triple nuclear power capacity by 2050. Globally, that would mean an addition of 740 GW of nuclear

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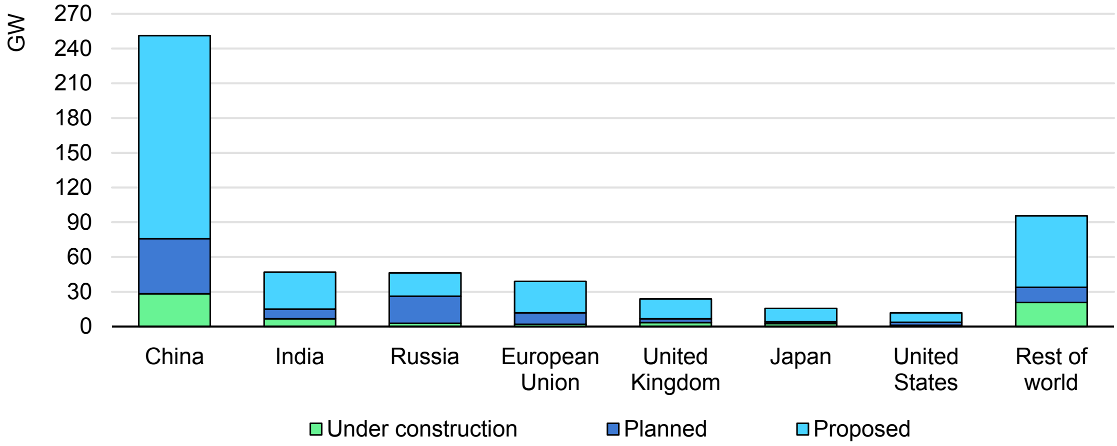
capacity to the current stock of 370 GW. The World Nuclear Association estimates that, as of November 2023, 68 GW was under construction, with a further 109 GW currently planned and 353 GW proposed. In addition to the reactors currently under construction, even if all these planned and proposed projects are realised, reaching the goal of the declaration would require an additional 210 GW to reach the announced objective by 2050.

Nuclear power capacity under construction, planned or proposed as of November 2023



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Notes: We use the definitions employed by the World Nuclear Association. Planned projects include ones that are approved, and funding is committed and available. The timing for commencement of operation is considered likely within 15 years. Proposed projects include those where the site and scale are specified, but the timing and approval remains uncertain.
Source: IEA analysis based on data from World Nuclear Association.

Asia remains the epicentre of growth in nuclear power

Asia's share in global nuclear generation is expected to reach 30% in 2026. Based on reactors under construction with expected completion up until 2026, Asia is set to surpass North America as the region with the largest installed capacity. Nuclear power has seen particularly strong growth in China over the last decade, with capacity additions of about 37 GW. This has resulted in China's share of global nuclear generation rising from 5% in 2014 to about 16% in 2023.

China continues to lead in global nuclear capacity additions, with 27 GW currently under construction. In its 14th Five-Year Plan, China is aiming for total installed capacity of 70 GW by 2025. The country's long-term commitment to nuclear power is further evidenced by its strategy to become increasingly self-reliant for its fuel cycle. Currently, China runs domestic mining operations with the capacity to cover around 15% of its yearly uranium demand. Having announced large domestic resources of 107 kt of uranium, China aims to source one-third of its uranium through domestic resources and equity stakes in mining operations in Africa.

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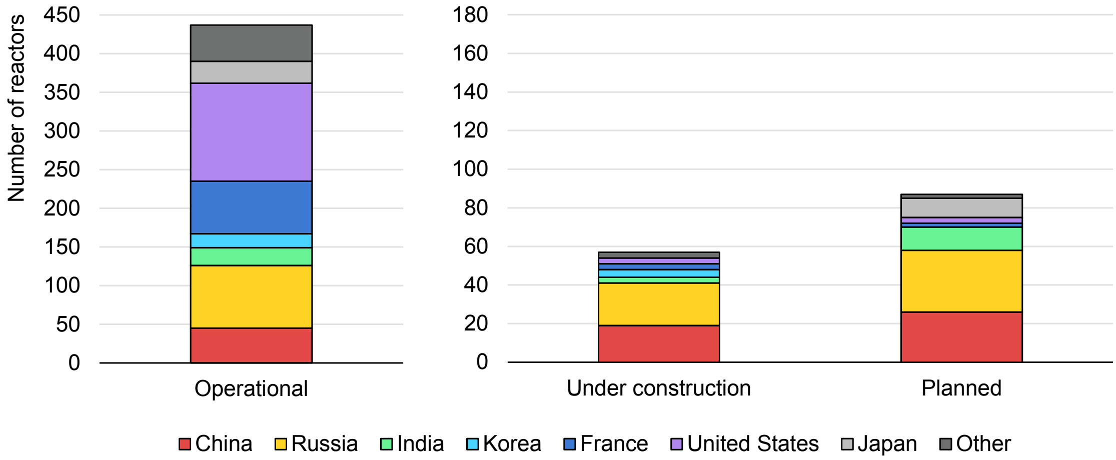
Given these developments, technological leadership in nuclear power is shifting towards China and Russia. The technology providers for 70% of the reactors currently under construction were China and Russia. In addition, China started commercial operation of its first fourth-generation reactor at the Shidaowan plant in December 2023, a 200 MW unit with a high-temperature gas-cooled reactor using a modular design. There are ultimately ten similar units planned at the site.

Technology providers of currently operational reactors (left) and of reactors that are currently under construction or in planning (right)



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Notes: Operational reactors in this figure also include the suspended reactors in Japan. Planned reactors include projects that are approved, and funding is committed and available.
Source: IEA analysis based on in-house research and data from IAEA PRIS database (accessed January 2024).

Contributing to large capacity additions in Asia, **India** announced in 2022 plans to triple its nuclear capacity by 2032, which corresponds to capacity additions of almost 13 GW, with 6 GW currently under construction. Bangladesh, with strong financial and technical support from Russia, currently has its first nuclear power plant under construction at the Rooppur site, where it recently received its first fuel shipment and is officially scheduled to begin commercial operations in 2024.

Japan is set to continue its revival of nuclear energy as public opinion starts to favour the restart of nuclear reactors for the first time since the Fukushima incident. The current plans indicate a steady increase in operating capacity through 2024-2026, and the eventual goal for nuclear to account for 20% of the energy mix by 2030. Specifically, the Shimane Unit 2 reactor is planned to restart in August 2024, while the target to complete necessary safety adjustments at the Onagawa Unit 2 is also set for 2024. Further restarts, such as Tokai 2 and Shika 2, scheduled for 2025 and 2026, have been delayed but remain on the agenda as a central pillar of Japan's strategy to meet its emission reduction targets.

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Renewed interest in nuclear in Europe and Americas, but significant delays in ongoing projects raise concerns

In Europe, the political landscape for the deployment of nuclear power is evolving. Germany has phased out its nuclear capacities, and Spain is still aiming for a phase out starting in 2027. Eleven member states in the European Union launched an alliance in February 2023 to co-operate on nuclear energy under the leadership of France, which grew to 14 members by its third meeting in May 2023. The goal of the alliance is to add 50 GW of nuclear capacity by 2050, which means a 50% increase in the installed nuclear power capacity in the European Union. The alliance also aims for nuclear to be treated equally to renewables in EU energy and climate policies. In line with that, in December 2023, the EU Council followed the European Parliament in voting to include nuclear energy as a strategic element to reach climate neutrality.

In 2022, France announced plans to construct six new European Pressurised Reactors (EPR). Before the parliament debate on new energy strategy in January 2024, the French Energy Minister reaffirmed plans to pursue an additional eight reactors with a combined capacity of 13 GW, planned for construction after 2026. In parallel, it is proceeding with a large-scale effort to extend the operations of its existing fleet, whose average lifetime is 37 years. The Netherlands, rescinding an earlier phase-out decision, declared nuclear energy as critical for its climate policy targets and announced in 2023 that it started negotiations for the construction of two new reactors by 2035. The new reactors are intended to meet 10% of Dutch electricity demand. Sweden also adopted a new regulation in 2023 to allow the construction of additional nuclear power plants. The Swedish government confirmed its commitment to nuclear power when it announced plans in November 2023 for the construction of two new conventional reactors by 2035 and ten new reactors, including SMRs, by 2045. In addition, Sweden's parliament passed additional legislation that allows, in principle, for more reactors than the ten reactors slated to be built by 2045. While not announcing any new capacity additions, Belgium has stated that a deal has been reached for the planned lifetime extension by ten years of its two newest reactors, Doel 4 and Tihange 3. With a combined capacity of 2 GW, they account for 35% of Belgium's current nuclear capacity.

In addition, Finland in 2023 announced a life-time extension of its Loviisa power plant, and started commercial operations of its largest reactor Olkiluoto 3. Slovenia announced an additional 20 years of operation for the existing reactor at the Krško Nuclear Station and reaffirmed its commitment to add a second block. Bulgaria is implementing its new nuclear strategy with plans to add four new reactors by 2053 with the construction of 2.3 GW additional capacity at its Kozloduy site. Poland has made further steps in implementing its nuclear programme with an eventual capacity goal of 6 to 9 GW by 2040. The permit for the construction of its first

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nuclear plant in Pomerania was granted in July 2023, and construction is set to start in 2026. The second reactor recently gained approval in November 2023, where two units are expected to supply 22 TWh annually from 2035 onwards.

Ukraine continues its efforts to expand its nuclear capacity without reliance on Russia. In June 2022, Ukrainian energy provider Energoatom signed an agreement to extend the number of planned reactors provided by Westinghouse from five to nine. Further, in January 2023, the Cabinet approved plans for construction of two new reactors, Khmelnitsky 5 and 6, which are expected to be connected to the grid by 2030 and 2032, respectively.

Policy agendas on nuclear energy of selected countries

Phase in	First considerations	Phase out
Bangladesh, Egypt, Poland, Türkiye, Uganda	Albania, Algeria, Azerbaijan, Estonia, Ethiopia, Ghana, Indonesia, Jordan, Kazakhstan, Kenya, Laos, Latvia, Lithuania, Morocco, Nigeria, Philippines, Rwanda, Saudi Arabia, Serbia, Sri Lanka, Sudan, Thailand, Uzbekistan	Belgium (after lifetime extension of two reactors in the existing fleet), Germany, Spain

Expansion	Keeping steady
Brazil, Bulgaria, Canada, China, Czechia, Hungary, India, the Netherlands, Pakistan, Romania, Russia, Slovakia, Slovenia, Korea, Sweden, UAE, Ukraine, United Kingdom, Argentina	Belarus, Finland, France, Iran, Japan, Switzerland

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Sources: World Nuclear Association and news reports.

In the United States, reactors with 37 GW of capacity initially had operating licences which will expire between 2030 and 2040. Under the subsequent licence renewal programme, the Nuclear Regulatory Commission is currently considering lifetime extensions for operating reactors from 60 to 80 years. Around 6 GW of capacity extensions have already been approved, with another 10 GW under review or expected to apply. Still, a further 21 GW of nuclear capacity, accounting for almost 23% of the capacity in operation, is, as of now, expected to suspend operations between 2030 and 2040. The replacement of this capacity will be a major challenge for the US nuclear sector. An estimated 17 GW of capacity is currently planned or proposed. However, only 2.5 GW at the Turkey Point site in Florida, including the new reactors Units 6 and 7, are estimated by the World Nuclear Association to start commercial operations before 2030, compared to scheduled retirements of 6.5 GW. Citing security of supply concerns during extreme weather events, California's utilities regulator has granted a five-year extension to the Diablo Canyon Power plant with a capacity 2.3 GW in December 2023, with the new licenses now running to 2029 and 2030 for the two reactors.

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In Canada, 1.2 GW of capacity is planned to come online by 2036 at the Darlington site. In addition, the province of Ontario has announced plans to start pre-development for the addition of 4.8 GW of capacity. A major construction project in South America is ongoing in Brazil, where the extension of the ANGRA site is delayed by almost four years, now scheduled for 2027 after initial plans for commercial readiness by 2023. Argentina plans to add a reactor to its Atucha site in co-operation with China.

Construction risk of nuclear projects remains the largest hurdle for financing

Globally, nuclear construction projects that started between 2010 and 2020 had an average delay of around three years, which amounted to an additional 50% increase on top of the initially planned construction time. China had an average delay of just over two years, while the global average, excluding Chinese projects, is three and a half years, with some projects up to eight years behind schedule. While the issue of delays in construction is currently a major global concern, the delays in Europe and the United States exceed what is observed in other parts of the world, with China especially posting significantly fewer delays.

The first reactor of the newest US nuclear power plant, Vogtle 3, went into commercial operation in 2023, with the second Vogtle 4 unit expected to follow in early 2024. The plant construction took twice as long as expected. After construction commenced in 2009, the two units were initially scheduled to start operations in 2016 and 2017. However, with Vogtle-3 only connected to the grid in late 2023 and Vogtle-4 now scheduled for early 2024, the construction took 14 years to complete, double the initial time frame, resulting in a cost overshoot of USD 17 billion of an initial budget of USD 14 billion.

France's newest reactor in Flamanville, now scheduled to deliver its first electricity in 2024, was initially planned to be finished in 2016, and based on the most recent cost estimates it is now more than quadruple the initial budget. In Hinkley Point C, a joint project between the French EDF and Chinese CGN, the Chinese firm announced a freeze in payments in December 2023 after cost overruns reached a level that allowed the Chinese firm to refuse participation in the additional cost. EDF affirmed the project will be completed nonetheless, taking on the financial burden.

Through cutting construction times and delays, and with the extensive experience of the construction of multiple plants in recent years, China is able to build nuclear power plants at significantly lower cost and with minimal delays compared to the United States and the European Union.

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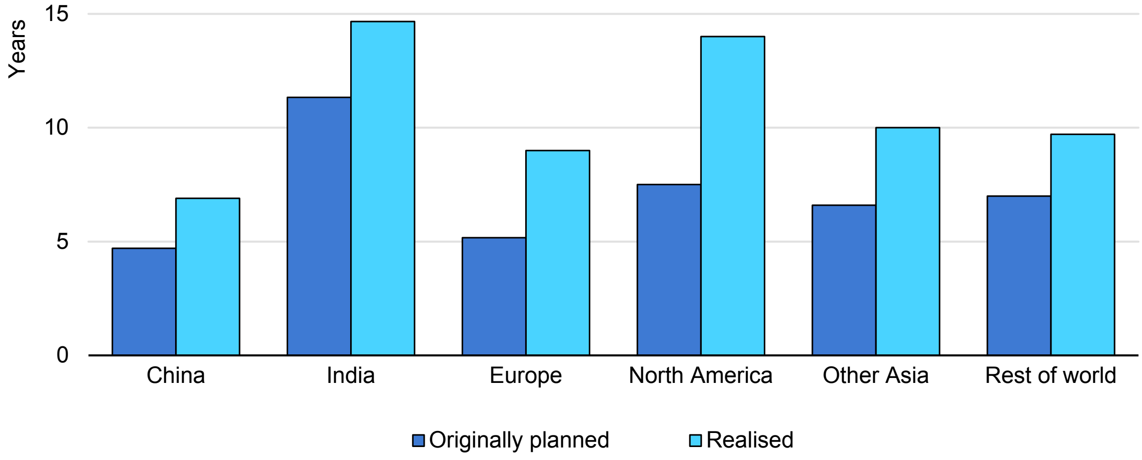
Average planned vs. realized construction time of nuclear power projects with construction starts after 2007 in selected regions



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Notes: Realised counts the year when the plant went online. We include the most recent estimates of expected grid connection for ongoing projects that started before 2020. The projects still ongoing that have delays include Carem25, Rooppur-1, Rooppur-2, Angra-3, Fangchenggang-4, Zhangzhou-1, Zhangzhou-2, Flamanville-3, Hinkley Point C-1, Hinkley Point C-2, Kakrapar-4, Rajasthan-7, Rajasthan-8, Ohma, Akkuyu-1, Akkuyu-2.
Source: IEA analysis of the individual nuclear power projects.

The financing of nuclear projects involves high upfront capital costs, which amortise over long-time periods. This means that the profitability of a project is highly sensitive to construction risks and the cost of capital. With higher interest rates, construction delays can become even more costly through the increased value of time. The bulk of the risk is associated with the construction phase. Once a nuclear power plant is commissioned, the steady sale of electricity and the low share of fuel cost in total costs make it a low-risk asset, although some risks in relation to technical issues and maintenance, and a stable fuel supply remain. However, during the construction phase, technical issues, shortages of qualified staff, supply-chain disruptions or complex interactions with regulators can significantly lengthen construction times and escalate cost. Those instances could particularly raise the risk of interim interest payments due during the construction phase, which can jeopardize the financial viability of an ongoing project.

Reducing construction risk can significantly bring down the cost of capital, which are a major cost factor for nuclear projects. While construction risk is inherent in all capital-intensive projects, there are best practices for project owners to minimise their exposure. Most importantly, complete and comprehensive design and planning should be completed before any construction begins. Further, high standards for documentation as well as integrated planning of interconnected dependencies are essential. Structural factors, such as supply-chain disruptions and skilled labour shortages need to be considered, and their potential impacts planned for. Pooling demand in a consortium to ensure future revenue streams

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through committed order books, as well as standardising projects, can further bring down risk, secure supply chain developments and facilitate learning curves.

State involvement as a potential option to help reduce the cost of capital

In addition to reducing construction risk, improving financing conditions will be important for the deployment of nuclear capacities. Whereas well-structured projects with creditworthy operators are a must, additional measures can be employed to manage the cost of capital. Especially in the case of incomplete financial markets, government interventions such as contracts for difference (CFDs), guarantees or market design measures can be economically justified. However, the risk of over-subsidising nuclear energy through these government-backed instruments can also be a concern.

In practice, financing issues have been addressed in various ways. One major approach is through the involvement of state actors. Projects can be directly funded through state financing, which is how a majority of nuclear projects are financed, for instance, in China. India only recently considered allowing private minority stakes in nuclear operations, with all operating plants financed through government funds. Governments can also step in as guarantors to bring down capital cost, which was the stated objective of the US government when providing guarantees for the financing of Vogtle 3 and 4. Similarly, Sweden, in light of its announcements to expand its nuclear capacity, has already offered loan guarantees for the construction of the newly planned nuclear sites.

State actors interested in selling technology can also provide vendor financing, as done by Russia for the construction of Rooppur nuclear reactor in Bangladesh or the El-Dabaa plant in Egypt, where the country both sold its technology and provided financing instruments. Public support by ratepayers and the British government has recently been introduced in the United Kingdom, where the Regulated Asset Base model, originally intended for other parts of infrastructure, allows nuclear operators to reduce upfront capital requirements, which are divided among the different steps and revenue is already generated during the construction phase. This helps to cover parts of the capital requirement through applying surcharges to electricity consumers upfront to fund planning and construction phases in real time. An additional UK government support package (GSP) would be triggered if construction cost overruns exceed a certain level.

By providing stable frameworks for the energy sector in general and electricity market design in particular, governments can remove parts of the operating risk exposure of nuclear power plants. While not removing the construction risk as the largest source of uncertainty, instruments stabilising revenue expectations, backed by state actors, can further help reduce cost of capital. Typical measures

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include PPA, as implemented for the Akkuyu nuclear plant in Türkiye or CFDs agreements with a set strike price for sold electricity, as agreed on for the new Hinkley Point C reactor in the United Kingdom. Geopolitical energy strategies and limited options to diversify risks on financial markets can justify government interventions.

Dedicated institutions with focused expertise and pooled capital can also be beneficial. Within this context, the International Bank for Nuclear Infrastructure (IBNI) intends to provide a wide range of financial and advisory services for the development of nuclear projects in its member states. According to its representatives, they expect 20-30 countries to sign the joint declaration for the establishment of the institution between December 2023 and the Nuclear Energy Summit in Brussels in March 2024.

Green taxonomies can play a role in financing of nuclear energy but remain a political discussion. In July 2023, following the United Kingdom, China and Korea, the European parliament voted to include nuclear energy transitionally as a green power source into its new sustainability taxonomy. However, more than half of the world's major private banks have excluded nuclear energy from their green financing frameworks. In response, the declaration to triple nuclear energy by 2050, launched at the COP28, includes a statement urging financial institutions to include nuclear energy into their energy lending policies.

SMR deployment is still at a small scale and is not without challenges, but R&D is picking up

A new generation of SMR is intended to address some of the financing challenges of nuclear capacity by employing modular reactors, which might offer serial factory production, so that the final product can be shipped to the site. The smaller project size helps to facilitate the financing of projects as the capital requirements for any single project are decreased. Serial production would reduce construction risk on the side of the operator. Whilst the average capital cost per MW is likely to be similar, the cost uncertainty of SMR is estimated to be significantly lower than that of large reactors, where especially tail risks are strongly reduced.

There are a range of technologies with different use-cases being developed and operated, ranging from microreactors with capacities below 10 MW and large reactors of up to 400 MW. Currently, according to the International Atomic Energy Agency (IAEA), there are only two countries operating SMRs, China and Russia. Whilst Russia is running an installation with 70 MW capacity, China recently started commercial operations of the first unit at the Shidaowan site with a capacity of 200 MW. The two countries combined currently have an additional 425 MW under construction. In addition, Argentina is planning to connect its test reactor Carem25 in 2027. The OECD Nuclear Energy Agency (NEA) estimates global

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SMR capacity to reach 21 GW by 2035. Beyond 2040 there could be a large expansion of this technology if the goals of efficient production and low-risk installations can be realised. The OECD Nuclear Energy Agency's SMR Dashboard provides a comprehensive overview of current developments in SMRs.

The discontinuation of the NuScale SMR project set to deploy the first VOYGR SMR in Idaho (US) was notable in 2023. After failing to meet target subscription levels for future power output, and citing escalating cost, operator Utah Associated Municipal Power Systems (UAMPS) and NuScale agreed to terminate the project, scheduled to start operations in 2029. The project plan included six 77 MW modules. Initially, the costs were estimated at USD 58/MWh in 2020, however by 2023 these projections had ballooned to USD 119/MWh due to increased material and equipment cost. In December 2023, a lawsuit was filed against NuScale by investors, accusing the company of actively withholding information about the financial issues of the now cancelled project from its investors. The outcome and influence on the financial viability of NuScale remains unclear at the time of writing this report. This event underlined the difficulties and vulnerabilities of pilot SMR projects, raising concerns about the future of them. However, NuScale has affirmed its continual commitment to its design and stated that other projects in the United States, as well as in Romania and Korea, are still being developed. As of November 2023, NuScale holds the US-model SMR design approved by the NRC.

Despite the uncertainty surrounding the pace of mass deployment, there is a wide interest amongst numerous countries for the development of SMR as a technology. In December 2023, Holtec International announced plans to add two of its SMR-300 units to the existing Palisades site in Michigan, with commissioning expected in the mid-2030s. Canada has also affirmed its plans to rely on SMR technology as a central part of its energy strategy. Specifically, the province of Ontario plans to deploy four units of the 300 MW Hitachi BWRX from GE Hitachi Nuclear Energy at its Darlington site. Further, additional units have been proposed by New Brunswick Power at Point Lepreau and public funding is provided to prepare the deployment of Hitachi BWRX units in Saskatchewan. In addition, in December 2023, Poland announced its intent to deploy 24 300 MW Hitachi BWRX units at six locations.

In addition, there are currently over 85 designs and concepts being developed by firms and operators in over 20 countries, including all major nuclear powers, such as China, the United States and Russia. In addition, France has recently announced the investment of USD 1 billion for the development of commercially viable SMRs until 2030 as a central part of its re-enhanced nuclear strategy, and in July 2023 confirmed co-operation with India to advance SMR technology. At the summit of G7 leaders in May 2023, a consortium from Japan, Korea and the United States announced the funding of an SMR for deployment in Romania.

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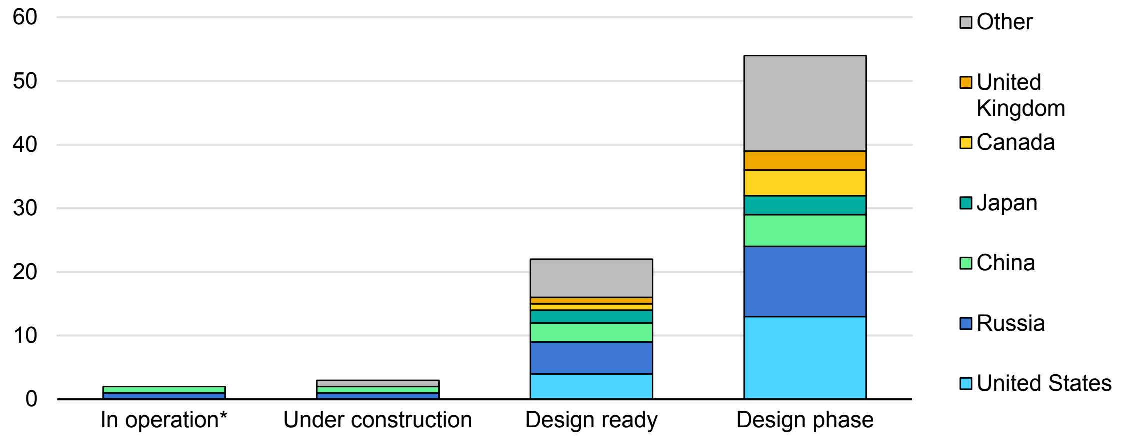
Further, in November 2023, the European Commission announced an Industrial Alliance to facilitate the development and deployment of SMRs in early 2024. At COP28, the United States announced a range of financial instruments through its Export-Import Bank to support the export of SMR technology.

Number of ongoing SMR projects by country and status



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Notes: The IAEA counts Japan's HTTR test-reactor in Ōarai as an additional SMR in operation. Based on newer definitions on modularity, we exclude it from the statistic.
Source: IEA analysis based on own research and data from IAEA.

The largest players in developing new technologies are the United States, China and Russia, accounting for more than half of projects in the design phase. In Europe, there are currently 13 ongoing projects at varying stages of the design process, including in the United Kingdom, France, Denmark, the Czech Republic, Netherlands, Sweden and Italy.

For SMRs, cogeneration or high temperature steam for industrial use are also being explored. All units currently operating or under construction have a capacity between 30-300 MW. China is operating a gas-cooled SMR, and also has water-cooled models under construction. Russia already runs a water-cooled unit and in addition is currently building a Fast-Neutron Spectrum reactor of the type Brest-OD-300 at the Seversk site. A considerable number of projects being developed are micro-reactors. Those are easily transportable and flexible units, and thus suited for use in remote areas, for the electrification of industrial complexes, research stations or military sites. The United States and Russia run more than half of the ongoing research projects for micro-reactors, with Japan's Mitsubishi Heavy Industries also announcing plans to have a micro-reactor with a capacity of 0.5 MW commercialised by 2030.

Accommodating the need for flexibility in energy systems, new SMR models are designed to provide more flexibility than current Generation III+ reactors. This

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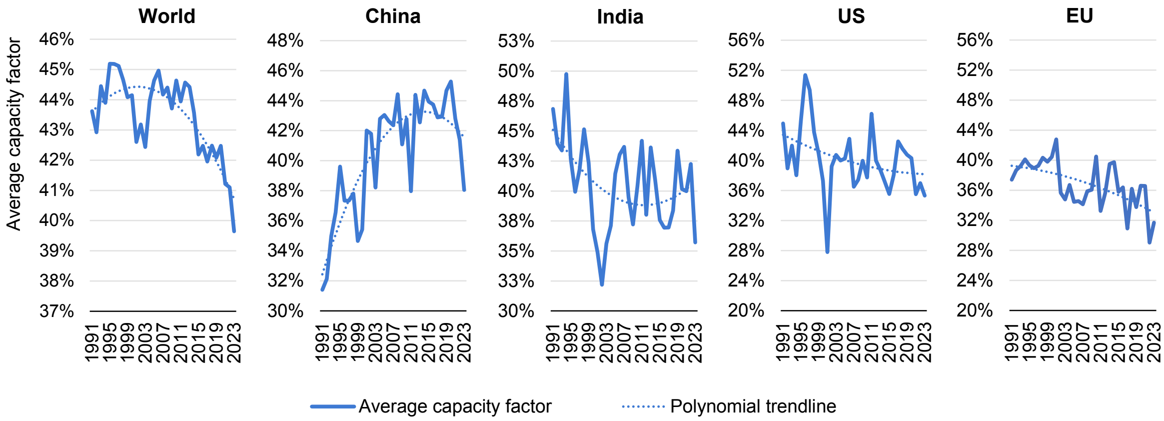
feature is advertised by both manufacturers, energy providers and international agencies. Other concepts combine SMRs with storage, such as a co-operation of TerraPower and GE Hitachi Nuclear Energy that aims to provide flexibility by combining a nuclear reactor with a thermal storage technology, which enables boosting the system output by over 40% during peak hours.

Hydropower generation was reduced in 2023 in numerous regions due to weather impact

A common trend across multiple regions in 2023 was the significant reduction in hydropower generation due to weather impact, particularly droughts, below average rainfall and early snowmelt. As a result, global hydropower generation decreased by more than 2% in 2023 compared to year earlier. The global average hydropower capacity factor is estimated to have fallen to below 40%. This is the lowest value recorded since at least three decades and is well below the 2015-2022 average of 42% and the average for 2004-2014 of 44%.

Canada, China, Colombia, Costa Rica, India, Mexico, Türkiye, the United States, and Viet Nam, among other countries, all experienced varying degrees of reduction in hydropower generation. In some countries the reduced hydropower output resulted in energy shortages, increased reliance on alternative sources such as coal and thermal power, and concerns about electricity supply stability. The consequences varied, including power shortages, the need for additional thermal power procurement and higher CO_2 emissions.

Annual hydropower capacity factors in selected regions, 1991-2023



Notes: The analysis includes reservoir and run-of-river type hydropower plants; excludes pumped hydro storage plants.

In Asia, hydropower generation in China decreased by 5.6% due to severe droughts, contributing to a 6.2% increase in coal-fired generation. India faced challenges with a 15% drop in hydropower, which led to power shortages. To

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ensure uninterrupted power supply, the government mandated blending 6% of imported coal with domestic coal until March 2024. Vietnam faced a power crisis due to a drought-induced hydropower shortage and the country had to significantly increase coal-fired generation and electricity imports.

Hydropower output in the United States declined by 4.4% due to rapid spring snowmelt, impacting around 50% of the country's hydropower capacity. Canada, where hydro accounts for over half of its electricity supply, similarly saw a 7% reduction in hydropower due to a mild winter affecting snowmelt. Multi-year droughts in Mexico led to a 40% decrease in hydropower generation in 2023, prompting operational alerts. El Niño Southern Oscillation impacts threatened Colombia's hydropower generation, which constitutes about 70% of the country's annual electricity production. The El Niño phenomenon led to similarly lower hydropower output in Costa Rica in 2023, resulting in thermal generation contributing more than 5% to the electricity mix.

The European Union recovered from the 20% drop in hydropower generation in 2022, as output increased by 16%. However, Türkiye experienced a 4.5% decline in 2023 due to an extended drought, following a recovery in hydropower in 2022.

The overall trend highlights the susceptibility of hydropower to weather patterns. Countries who are particularly hydropower-dependent can especially become adversely affected by weather-related disruptions to hydro availability. Diversifying energy sources, increasing interconnections and implementing strategies for improved security of supply in the face of changing weather patterns will be increasingly important.

The supply chain of gas turbines is geographically concentrated in different ways

The utilisation rates of gas-fired power plants in many regions are set to decline as they are utilised more flexibly with increasing wind and solar PV share in the generation mix. At the same time, as electricity demand continues to grow, new gas-fired power plants are being built to meet peak demand and provide dispatchable capacity.

In the IEA's World Energy Outlook 2023, the Stated Policies Scenario (STEPS) sees global installed capacity of gas-fired power plants in 2030 10% higher than in 2022, equivalent to about 200 GW of capacity additions. This compares to capacity additions of approximately 240 GW between 2015 and 2022 and shows there will be continued demand for gas turbines worldwide, eventually expected to be hydrogen-powered in the IEA's NZE Scenario. For example, Germany, aiming to largely rely on renewable generation for its energy transition, is planning

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to operate 23.8 GW of hydrogen power plants by 2035, with tenders expected to be auctioned by 2026.

In expectation of these developments, major players are phasing in commercial hydrogen-ready turbines. In 2023, Siemens successfully operated a modified gas turbine with 100% hydrogen. Kawasaki Heavy Industries in 2023 commercialised a 1.8 MW hydrogen turbine. GE also has turbines with 100% hydrogen-firing capacity, and plans to provide utility-scale power plants fully based on hydrogen by 2030. It is also possible that turbines are powered by other renewable gases. Mitsubishi Heavy Industries is developing an ammonia-powered turbine, planned for commercialisation by 2025.

Natural gas-fired turbines and hydrogen-ready gas turbines are technologically advanced systems that require a high level of expertise in the design and production phase. Consequently, only a handful of developers dominate the gas turbine market. In addition, the manufacture of gas turbines requires several critical minerals, the production of which are highly concentrated geographically. Geographic and market concentration in global supply chains of energy technologies can pose potential challenges that need to be considered by governments and relevant stakeholders, which recent IEA work on PV supply chains has analysed in-depth.

Companies from North America and Europe dominate the production of gas turbines

Turbine technology developers are highly concentrated, with the largest three companies operating globally holding over 85% of the market share by revenue in 2021. GE Energy has a global market share of slightly over 45%, with Siemens Energy and Mitsubishi Power controlling 22% and 19%, respectively. Looking at the geographical distribution of the companies' headquarters, gas turbine manufacturers are highly concentrated outside Asia. Firms with their corporate parent located in the United States hold over 50% of the global gas turbine market.

These companies also have production facilities outside their home base. For example, in addition to its main US production facility in Greenville, North Carolina, GE operates a manufacturing centre in Birr, Switzerland. Siemens, whilst maintaining large manufacturing capabilities at its historic plant in Berlin, also operates facilities in Finspång, Sweden, as well as North Carolina in the United States. Notably, the company operates the largest manufacturing facility for gas turbines in the Middle East at its Siemens Dammam Energy Hub in Saudi Arabia, where the first "Made in KSA" gas turbine was assembled in 2016.

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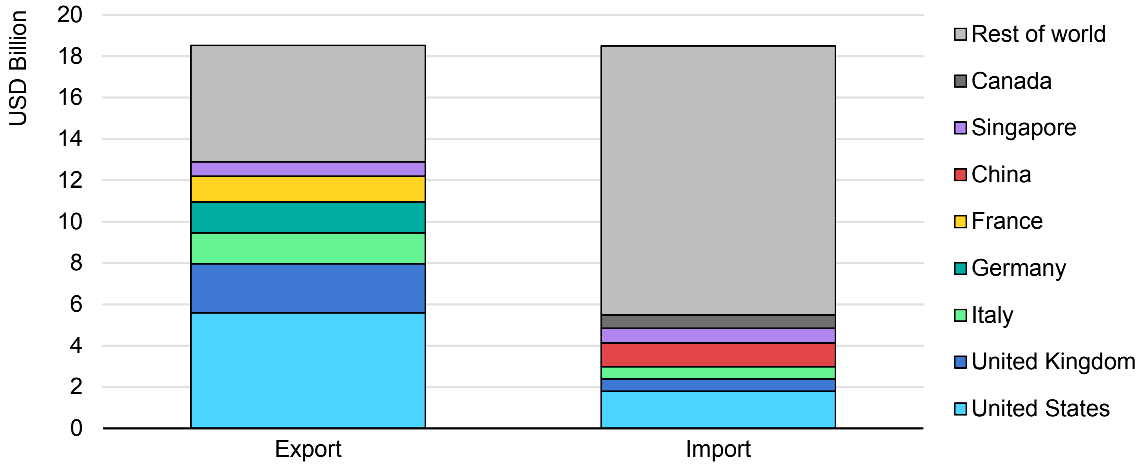
Exporters and importers of gas turbines in terms of trade volume by country, cumulative 2019-2021



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Notes: The analysis is based on export and import data from the Centre d'études prospectives et d'informations internationales (CEPII), and considers the trade of gas turbines exceeding 5 MW, and aggregate by country.
Source: CEPII, BACI bilateral trade flow dataset.

The dominance of those three players, however, is not going unchallenged. Manufacturers in China, such as Harbin Turbine Company and Dongfang Electric Corp, and in Russia Power Machines, have recently connected their first heavy-duty gas turbines. The Russian company has announced plans to build eight 170 MW turbines annually by 2025, with the eventual goal of a production capacity of 12 turbines per year.

The top six countries exporting gas turbines accounted for 70% of global exports between 2019-2021 in terms of trade volume (USD billion), with the United States the leader with a 30% share. The largest importer in terms of trade volume was also the United States, with a share of 10%, followed by China with 6%. The market concentration in importers is much lower, with the top six countries accounting for 30% of global imports.

Mining of essential critical minerals for gas turbines is highly concentrated in a few emerging economies

For gas turbines, the principal material requirements are low alloy steel as well as heat-resistant nickel-based super alloys for the turbine blades. The most relevant critical minerals used in the steel mixes are molybdenum, manganese, chromite, nickel, cobalt and rhenium. Putting the absolute mined amounts into perspective, the magnitude of these minerals is small compared to commodities such as iron ore. While in 2022, 2 600 Mt of iron ore, 22 Mt of copper and 20 Mt of manganese were mined globally, the amount of nickel mined was only 3.2 Mt, molybdenum

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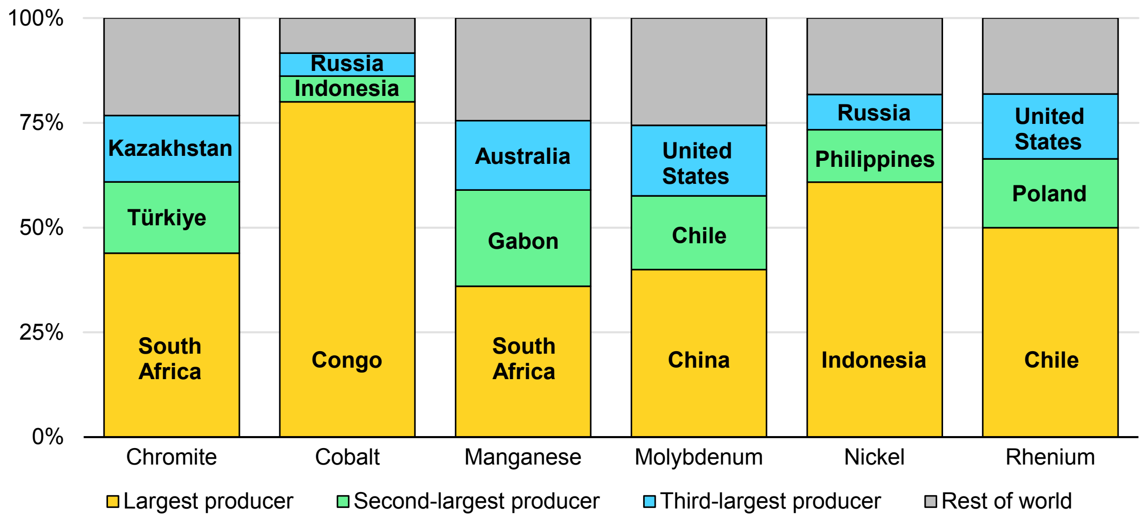
and cobalt were mined in the magnitude of 255 kt and 200 kt, respectively, and rhenium mining amounted to only 58 t globally.

A study from the Fraunhofer Institute for Solar Energy Systems (ISE), estimates the material requirements by 2050 for a 385 MW Siemens Gas Turbine include precious metals of 247 kg/MW of high-alloy steel and 137 kg/MW of low-alloy steel. Further, the turbine requires almost 900 g/MW of copper. This translates, among others, into just under 45 kg/MW of chromite, 25 kg/MW of cobalt, around 2.5 kg/MW of nickel, 2.8 kg/MW of manganese, and about 1.7 kg/MW of molybdenum.

Recently, the global concentration of mining and processing of critical minerals has taken a prominent place in global discussions about the energy transition. The quantity of materials required for turbines is unlikely to be a significant user of the global demand for these materials, though they are used in multiple other engineering, chemical and medical applications. Nevertheless, it is important to understand the industry's dependence on the mineral supply chains to identify potential dependencies on concentrated or single suppliers. Supply disruptions affecting any of the major suppliers due to natural disasters or geopolitical tensions may lead to disruptions in the gas turbine industry supply chain.

Share of global mining by region for selected critical minerals essential to gas turbine production, 2022



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Source: IEA analysis based on data from United States Geological Survey, National Minerals Information Center

The mining of the required minerals is highly concentrated in some countries. An estimated 40% of global molybdenum mining takes place in China and similarly more than 40% of world's chromite is mined in South Africa. The global landscape is even more concentrated for nickel, cobalt and rhenium. Indonesia is mining over 50% of global nickel, and the Democratic Republic of the Congo (hereafter,

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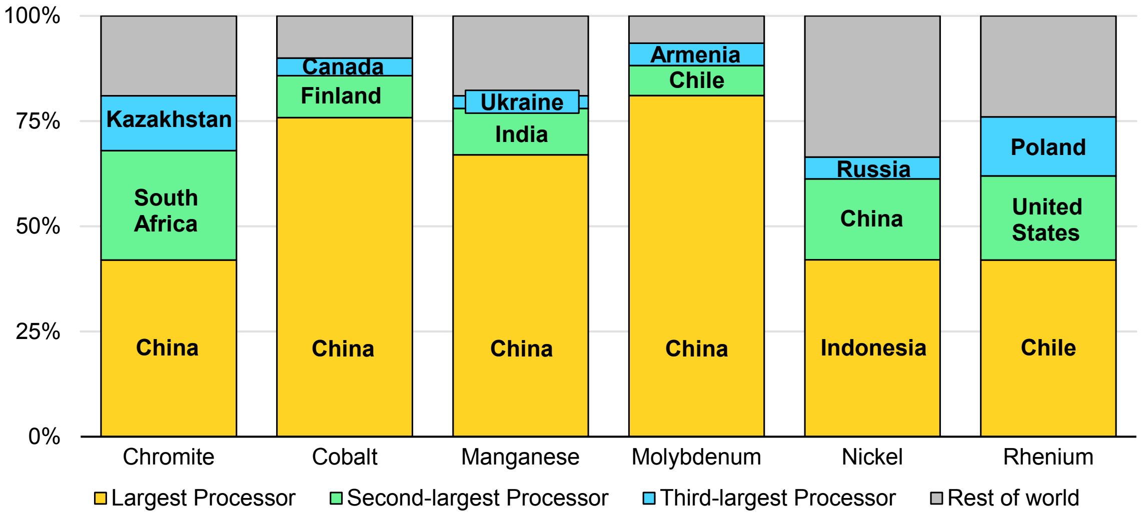
"Congo") produces 70% of the global cobalt supplies. The vast majority of Congolese cobalt mines are owned and operated by Chinese firms. Chile alone mines half of global rhenium. Two other major miners of rhenium are Poland and the United States, each having a share of about 16% of total production.

The global distribution of processing of those minerals is equally concentrated. Similar to mining, the largest players account for over 40% in each case, with the top three accounting for over 75% of global processing (except nickel with slightly over 65%). Notably, China holds an even stronger position in the processing step as compared to global mining. China dominates the global processing of two of the minerals required for the alloys in turbines, accounting for over 75% of both cobalt and molybdenum processing, and 67% of global manganese processing. Cobalt mined in Chinese-owned mines in Congo is largely processed in China. Further, China plays a significant role in the processing of chromite and nickel, thereby being an integral player in the supply chain of four out of five minerals critical for the gas turbine industry.

Share of global processing by region for selected critical minerals essential to gas turbine production, 2022



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Sources: IEA analysis based on data from European Commission, Raw Materials Information System (RMIS), IEA Critical Minerals Review 2023.

It is important to emphasize that recycling of turbine materials can greatly reduce the dependence of the industry on global mining of those minerals. Given the expected rise in demand through accelerating renewables deployment, recycling materials from old power equipment can be an attractive option to partially mitigate robust increases in demand. Following the successful recycling of a jet engine gas turbine in 2016, there are many firms specialising in the recycling and recovery of precious metals from used turbines at the end of their operational lifetime.

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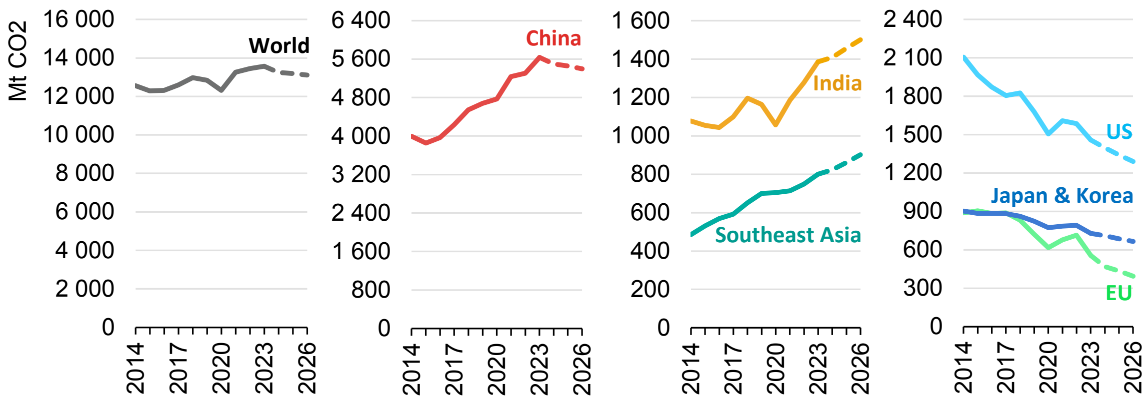
Emissions: CO_2 from electricity sector entering a structural decline

China accounts for half of the decline in global power generation emissions to 2026

After a strong rebound of almost 8% in 2021, global emissions from electricity generation rose 1.4% in 2022. Similarly, emissions increased by 1% in 2023, which is an upward revision from our previous July forecast. Fossil-fired power generation decreased in many regions in 2023, particularly in the United States and the European Union. At the same time, on a global scale, fossil-fired output remained resilient amid reduced hydropower because of reasons such as droughts, below-normal rainfall, and low water availability due to early snowmelt. China, India, Viet nam, United States, Canada, Türkiye and Mexico, among others, were impacted by reduced hydropower generation. A strong increase in coal-fired output in China and India, driven by reduced hydropower and strong electricity demand growth, prevented a decline in global emissions in the electricity sector. Nevertheless, coal in China is expected to enter a slow but structural decline due to a significant increase in renewables deployment and the rebalancing of the economy. We expect global electricity sector emissions to fall 2.4% in 2024, followed by 0.5% declines of 0.5% in 2025-2026. While extreme weather, economic shocks and government policies could cause upticks in individual years, the overall trend is expected to remain stable.

CO_2 emissions from electricity generation in selected regions, 2014-2026



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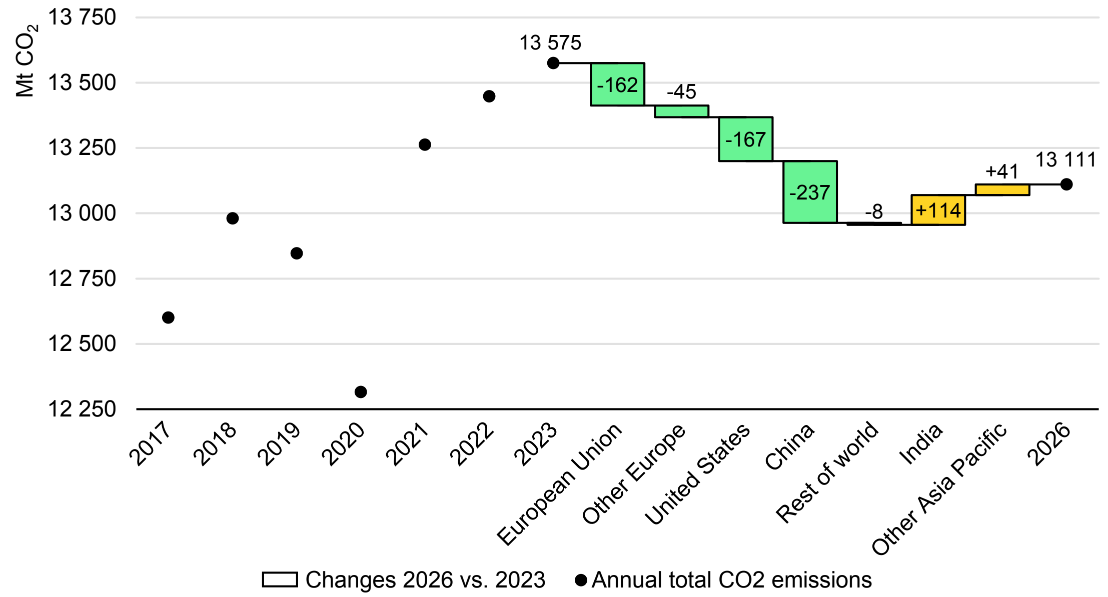
China, the United States and European Union lead declines in power sector emissions

Global emissions from electricity generation are forecast to fall by more than 2% in 2024, followed by smaller declines of about 0.5% in both 2025 and 2026. The large contraction in emissions in 2024 assumes average weather conditions and that hydropower in **China** recovers from the drought-induced lows of the last three years, displacing coal and resulting in a 2.4% decline in China's emissions from electricity generation. Followed by rapid renewables deployment and moderate demand growth, emissions in China are expected to decline by 1% per year on average in 2025-2026, falling back to 2022 levels. China is set to account for almost half of the total decline in global emissions from power generation from 2024 to 2026.

US power sector emissions are expected to decline on average by 4% over the 2024-2026 period, led by the ongoing switch from coal to gas, and rapid growth of renewables. The country will account for one-quarter of the reductions in global power sector emissions, followed by the **European Union** at one-fifth of the total. EU annual reductions are forecast at an average 11% in 2024-2026.

Over the outlook period, growth in electricity sector emissions is expected to come primarily from India, Southeast Asia, and other emerging economies. The continued growth in coal-fired generation in India and Southeast Asia, combined with rising gas-fired output in the Middle East, will put upward pressure on global emissions. Nevertheless, these increases in emissions are not enough to offset large decreases expected in China, the United States and the European Union.

Forecasted changes in global CO_2 emissions from electricity generation, 2026 vs. 2023



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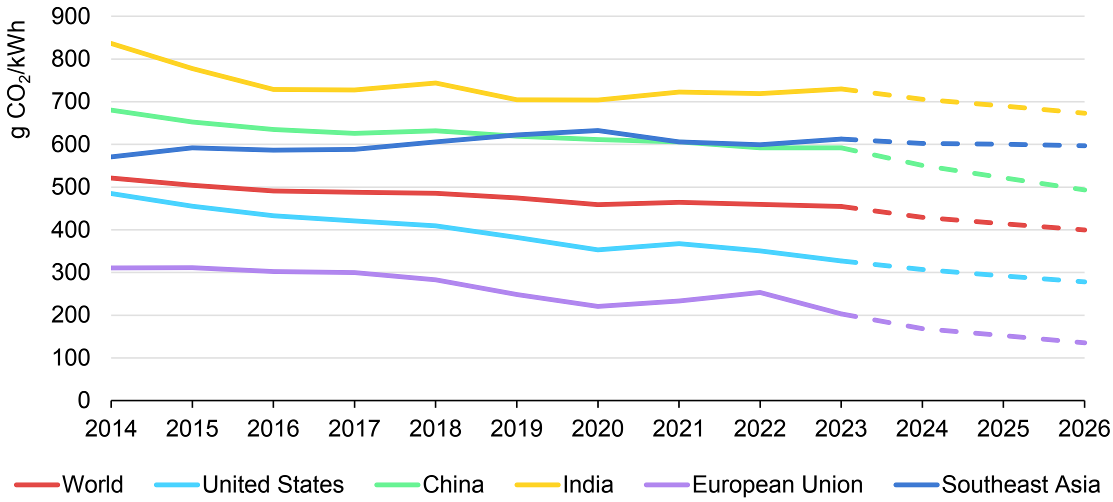
Emission intensity of the power sector to fall at an unprecedented rate

As global emissions from power generation enter a structural decline, its CO_2 intensity is forecast to improve, by falling at an unprecedented average annual 4% over the 2024-2026 period, double the 2% rate of decline observed in 2015-2019. After a decline of 1% in 2023, global CO_2 intensity is forecast to tumble by almost 6% in 2024, which assumes a recovery in hydropower generation in China. This will be followed by an average annual decline of 3.5% in the 2025-2026 period, as the share of low-carbon sources (renewables and nuclear) in total supply continue to increase. Global CO_2 intensity is expected to fall from 455 g CO_2/kWh in 2023 to 400 g CO_2/kWh in 2026.

The European Union is set to have the highest rate of relative decline out to 2026, at an average 13% per year, in emission intensity among the major energy consuming regions, followed by China (6%) and the United States (5%). By 2026, CO_2 intensity of power generation in China is expected to fall to US levels from 2014. Over the outlook period, India is also forecast to record a decline of 3% on average annually as the share of low-carbon sources increases. By contrast, emission intensity in Southeast Asia is expected to remain stable.

CO_2 intensity of electricity generation in selected regions, 2014-2026



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

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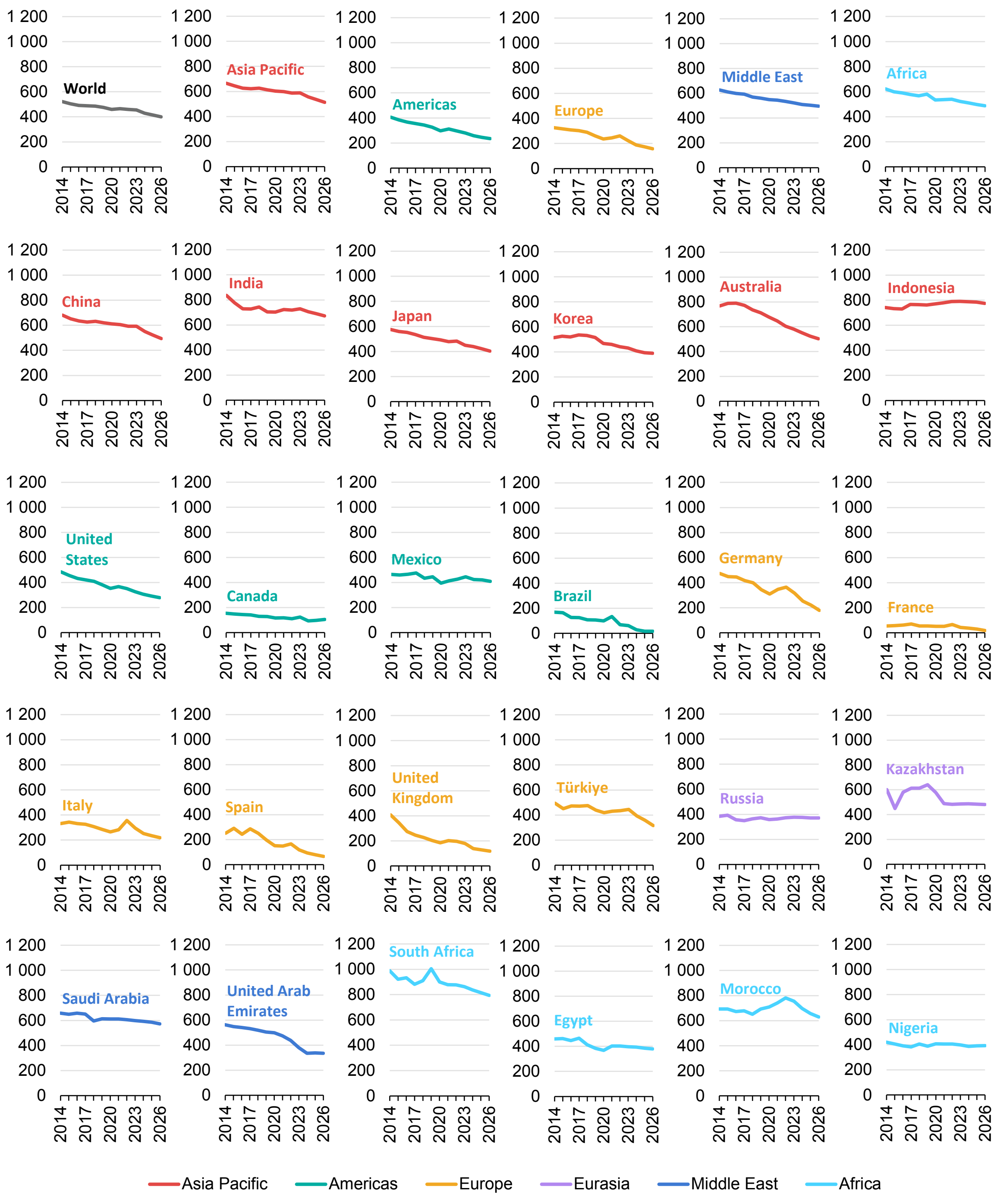
CO_2 intensity of electricity generation in the world, by selected countries and regions ($g\ CO_2/kWh$), 2014-2026



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Notes: The CO_2 intensity is calculated as total CO_2 emissions divided by total generation. The figures for 2024-2026 are forecast values.

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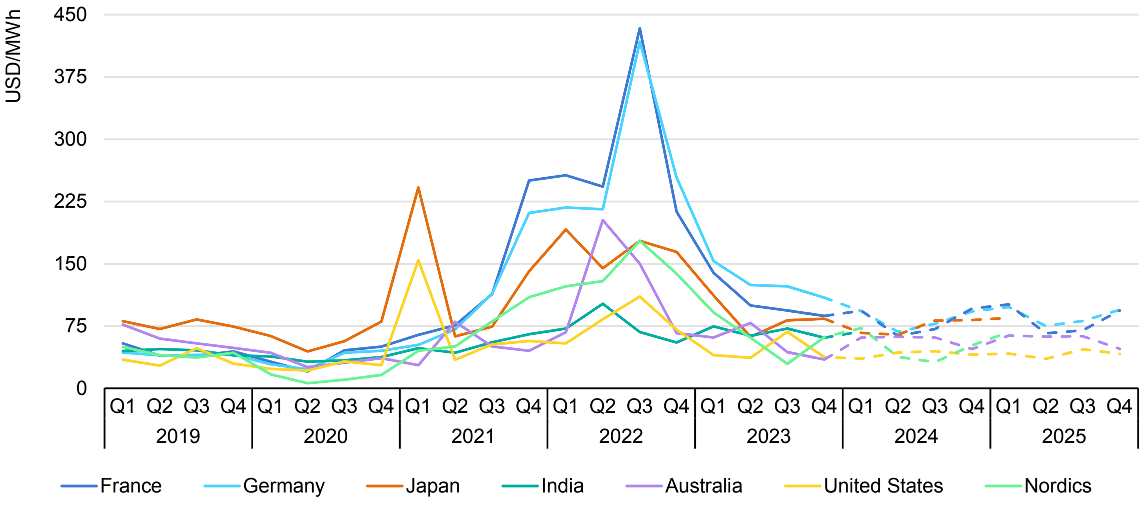
Prices: Wholesale electricity prices fall from record highs

Electricity prices in many regions still remain above pre-pandemic levels

Wholesale electricity prices in many countries fell in 2023 from the record highs observed in 2022. The moderation in energy commodity prices, such as gas and coal, led wholesale electricity prices lower, particularly in Asia and Europe. The year-on-year reduced demand in Europe also added downward pressure on prices. Despite this, prices in these regions still remain significantly higher than pre-Covid levels. Futures prices also show varying trends among countries, reflecting different seasonal supply and demand fundamentals.

Quarterly average wholesale prices for selected regions, 2019-2025



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Notes: Continuous lines show historical data and dashed lines refer to forward prices. Prices for Australia and the United States are calculated as the demand-weighted average of available prices in their regional markets. For the Nordics region, the Nord Pool system price is used for historical prices and EEX Nordics futures are used for forward prices.

Sources: IEA analysis based on data from French transmission system operator RTE (France) accessed via the ENTSO-E Transparency Platform; German regulator Bundesnetzagentur, SMARD.de; AEMO, Aggregated price and demand data; EIA Short-Term Energy Outlook January 2024; IEX, Area Prices; EEX, Power Futures; ASX, 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: 19 January 2024.

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Wholesale electricity prices declined in tandem with lower natural gas costs in many regions

After peaking at an average USD 80/MWh in 2022, wholesale electricity prices in the **United States** fell 40% in 2023, to an average USD 46/MWh. The lower level reflected the 60% plunge in natural gas prices from their 2022 highs. The other factor was milder weather in both the winter and summer of 2023 versus the previous year. For 2024 the average US wholesale price outlook remains stable, slightly lower than a year ago, at around USD 40/MWh. This is about 15% higher than the 2019 average and remains the lowest wholesale electricity price among the markets considered in our analysis.

In **Australia**, wholesale prices averaged AUD 82/MWh (USD 55/MWh) in 2023, down more than 50% from their 2022 highs and 10% below the 2019 average. In Q1 2023, wholesale electricity prices were zero or negative 12% of the time, largely due to record renewable generation contributing to the lowest Q1 operational demand in the National Electricity Market (NEM) regions since 2005, according to the Australian Energy Market Operator (AEMO). At the same time, electricity from gas-fired generation, which typically is the most costly, reached its lowest Q1 level since 2005. In Q3 2023, record-setting renewable generation output pushed down average wholesale electricity prices by more than two-thirds, doubled the occurrence of zero or negative wholesale prices (19%) and reduced total emissions by 11% year-on-year, AEMO reported. Our analysis for South Australia – where VRE share reached 75% shows that hourly prices were negative about 25% of the time in 2023, up from 19% in 2022. This highlights the need for additional system flexibility in the form of more price-reactive demand and supply, as well as additional storage. Futures contracts for delivery in 2024 traded at an average AUD 90/MWh (USD 58/MWh), 10% higher than in 2023.

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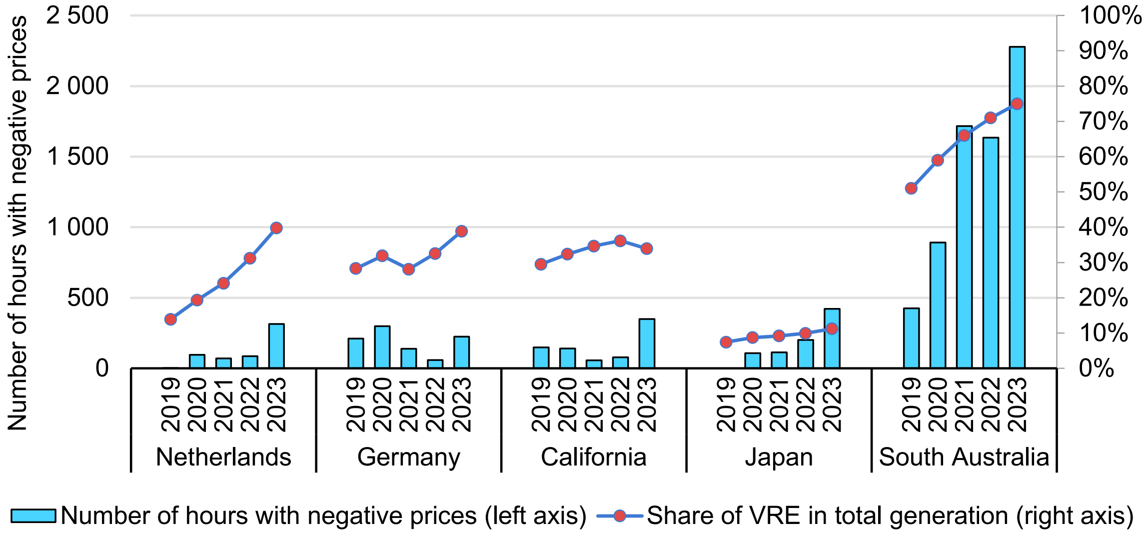
Number of hours with negative wholesale electricity prices and share of variable renewable energy in total electricity generation in selected regions, 2019-2023



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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.

In contrast to the United States and Australia, the 2023 average **European** price at around EUR 105/MWh (USD115/MWh) was still about double the 2019 level of EUR 54/MWh (USD 50/MWh). This was despite wholesale electricity prices in Europe falling on average by more than 50% in 2023 from the record 2022 highs. In the summer of 2023, the European electricity markets were characterised by negative wholesale prices amid strong solar output against low electricity demand. A similar episode of negative prices also occurred in late December when strong wind generation accompanied low electricity demand during the holiday season. In 2023, the number of hours with negative wholesale electricity prices more than quadrupled in countries such as Germany and the Netherlands compared to the previous year. In 2023, prices were below zero in Germany almost 3% of the time, and in the Netherlands almost 4%.

Like many other European markets, the **Nordics** also saw record wholesale price levels in 2022, as the cheaper hydropower-driven power exports to neighbouring European markets added upward pressure on domestic wholesale prices. In line with the moderation of European wholesale markets, prices in the Nordics fell by 60% in 2023, with the Nord Pool spot price averaging EUR 57/MWh (USD 61/MWh). Futures for the Nordics market indicate similar price levels, which makes it the only wholesale market in Europe to have comparable prices levels to

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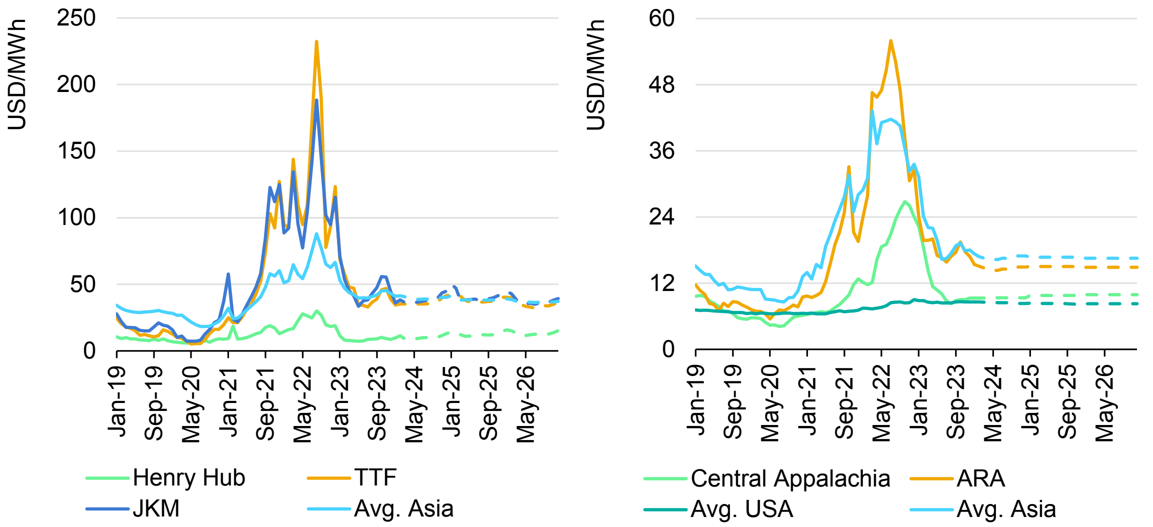
those in the United States and Australia. Nevertheless, regional differences within the Nordics market exist, with southern Scandinavia generally facing higher prices than the northern parts.

Prices for natural gas (left) and coal (right) in selected markets, 2019-2026



Note: 2024-2026 prices are based on available forward prices as of January 2024. Natural gas prices TTF; coal prices CIF ARA; Asia natural gas prices reflect estimated LNG import prices, including via oil-indexed LNG contracts and spot procurements; coal prices are Japan marker prices.
Sources: EIA (2023), STEO, January 2024.

Uncertainty around the French nuclear recovery and weather outlook to prop up winter prices in Europe

French wholesale prices in 2023 declined year-on-year by more than 60%. The gradual recovery of the French nuclear fleet from the record-low availability levels in 2022, combined with falling prices of energy commodities, drove wholesale electricity prices down. At an average of EUR 97/MWh (USD 105/MWh), French wholesale prices in 2023 were about 18% lower than in Germany. In July 2023, French futures contracts for delivery in Q1 2024 cost almost double the German futures for the same period. This price premium gradually disappeared as the French nuclear power plant operator EDF confirmed that it expects the country's nuclear power plant fleet to continue its steady recovery. Developments regarding the maintenance schedule of the French nuclear fleet will continue to have a strong impact on the futures prices.

German wholesale electricity prices averaged EUR 118/MWh (USD 127/MWh) in 2023 and were 55% lower compared to 2022. Nevertheless, prices were still above pre-Covid levels and are on average almost three times higher than the 2019 level. The uncertainty surrounding the availability of French nuclear plants is also reflected in the German prices, as it influences the supply patterns via

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electricity imports and exports. In addition to this, weather-induced price volatility can affect the near-term outlook, with the potential of colder than normal winter weather pushing up the prices of natural gas.

Wholesale prices in Japan and India remain elevated above 2019 levels

Wholesale electricity prices in **Japan** fell about 50% in 2023 compared to 2022, to an average of JPY 11 930/MWh (USD 85/MWh). In addition to lower prices for energy commodities, Japan's power market in 2023 was characterised by overall lower electricity demand and a stable supply situation, despite higher temperatures that drove cooling consumption during its hottest summer in recorded history. Reportedly there is limited concern for a tight supply-demand outlook for the winter of 2023/24, which is reflected in the stable trend of futures prices.

India remains the only market that did not post a substantial drop in wholesale electricity prices in 2023. Prices fell 4% in 2023 to INR 5 540/MWh (USD 68/MWh), but were still almost double those in 2019. The tight supply situation due to strong demand growth kept prices elevated. The price cap of INR 10 000/MWh continued to be implemented to protect the interests of buyers. Further, a high price segment was introduced to cover costly power generation technologies (gas and imported coal), but has seen low and intermittent buyer presence.

What does energy-intensive industry pay for electricity across the world?

Following the rise in wholesale electricity prices through 2021-2022, many regions saw increases in electricity costs in the industry sector. European industry, in particular, faced high costs compared to other regions. While electricity prices for large energy-intensive consumers were generally higher in Europe before the energy crisis in 2019, for example, than in the United States, they were still at comparable levels. In addition, in 2022 European prices increased substantially. Countries strongly relying on gas or coal were particularly exposed to price hikes, with prices in Germany about three times as high as the US prices, and those in Italy about five times as high. Average final electricity prices for the large energy-intensive industry in the European Union are expected to decline in 2023 based on Eurostat data, following the peak in 2022. Exact levels nevertheless depend on the electricity procurement strategies followed by industries (e.g. share of spot vs. long-term procurement) as well as country-specific measures.

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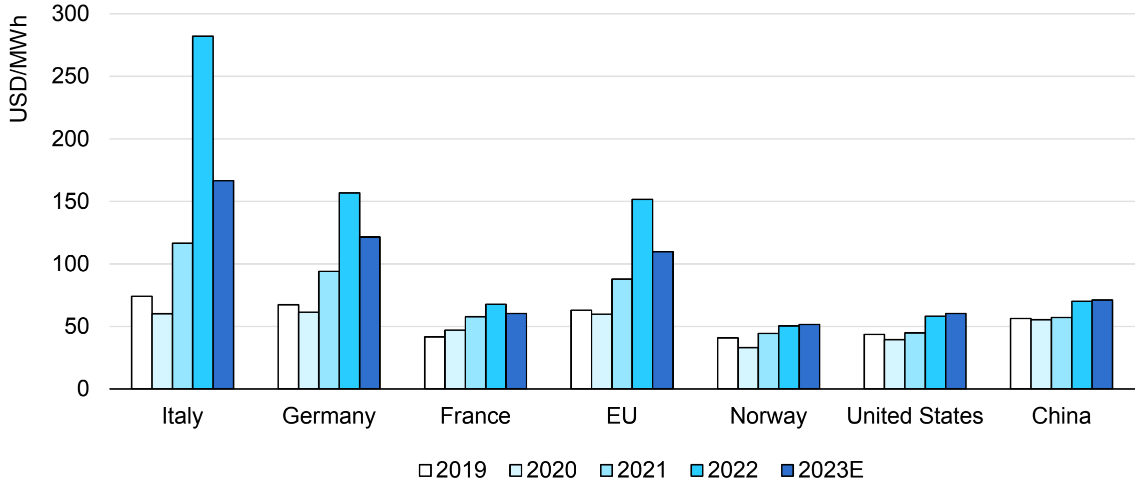
Estimated final electricity price for large industrial customers in energy-intensive industries, 2019-2023



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Notes: The analysis considers electricity costs of industries with greater than 150 GWh of annual electricity consumption for the European countries, based on Eurostat data. Electricity price compensation included for countries that participate in EU-ETS. For the calculation of the maximum possible state aid for electricity price compensation in European countries, the analysis assumes that the specific product has an electricity consumption benchmark of 0.8 and that the company in question receives the maximum possible state aid once this benchmark is incorporated into the maximum aid calculation. The prices for the US and China are indicative of the average reported prices; individual industries depending on their energy consumption levels and where they are located can face different prices.

Sources: IEA analysis based on IEA end-use prices database; data from Eurostat (2023); Official Journal of the European Union (2021), Southeastern U.S. Industrial Rate Survey; Brubaker & Associates (2023); Shanghai Metals Market (2023); Intercontinental Exchange (2023), EUA Futures (Accessed November 2023).

In France, the amount of nuclear power sold by French state-owned utility EDF to alternative suppliers at the regulated price of EUR 42/MWh under the ARENH law decreased from 120 TWh in 2022 to 100 TWh in 2023, which added upward pressure on prices. Expiring at the end of 2025, the ARENH scheme will be succeeded by a new agreement between EDF and the French government. It stipulates that all of EDF's nuclear generation is targeted towards an intended average price of EUR 70/MWh. The agreement aims to achieve this with a mechanism to redistribute excess profits of EDF back to consumers, where 50% of any additional revenue generated above EUR 78-80/MWh (with the exact price still to be determined at the time of writing of this report) would be redistributed, and 90% of all revenues exceeding a price of EUR 110/MWh. These thresholds are regularly renegotiated. The agreement remains subject to approval by the European Commission.

In China, prices were relatively stable in 2023 compared to 2022, although some provinces within China rolled back or cancelled discounted electricity prices for the industry. A reform of the electricity pricing systems further end the preferential treatment of heavy industries, setting equal rates based on voltage levels for all commercial and industry users. However, price increases can be expected in 2024, as the Chinese government announced steps to liberalise industry power

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prices. This allowed power producers to charge market prices to industry consumers starting in October 2023, resulting in a price increase of up to 20% for some industry consumers. Continuing this development, starting in January 2024, coal power plants will receive guaranteed payments based on the installed capacity, financed by a surcharge to industrial and end-use consumers. Russia also announced price increases for its power exports to China in late 2023, putting further upward pressure on prices going forward.

Final cost of electricity for energy-intensive industries in Europe also depends on indirect ETS compensation

Large industrial consumers are often fully or partially exempt from taxes and levies. Furthermore, carbon costs arising from the EU-ETS can be compensated through state aid and this must be considered in the final electricity price to accurately assess the competitiveness of energy-intensive industry in Europe.

There are several factors that go into calculating the maximum state aid that a plant may apply for each year, relating to the carbon price burden in electricity consumption. The European Commission specifies the calculation of the implicit carbon price burden through electricity use on a product-region level by multiplying defined product-specific electricity consumption efficiency benchmarks, regional carbon intensities of power production and the European Union Allowance (EUA) forward price from the previous year. The efficiency benchmark per product is the electricity consumption per tonne of output for a given product when using the most electricity-efficient method of production. Every plant can apply for payable aid based on its calculated implicit carbon price burden and realised production volume. Since 2019, an aid intensity of 0.75 is specified, meaning the payable support amounts to a maximum of 75% of the calculated price burden. All aid schemes related to the mitigation of the carbon price burden on electricity must be phased out by 2030, as specified on the most recent guidelines of the European Commission on State aid measures in the context of the EU-ETS.

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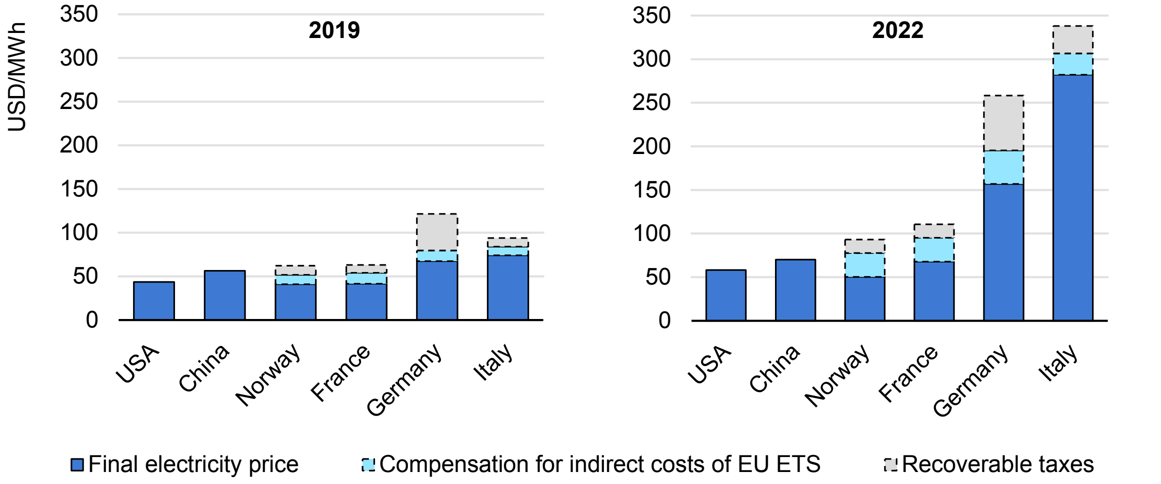
Electricity price for large industrial customers in energy-intensive industries in 2019 (left) and 2022 (right) in selected countries



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Notes: The analysis considers electricity costs of industries with greater than 150 GWh of annual electricity consumption for the considered European countries, based on Eurostat data. Electricity price compensation included for countries that participate in EU ETS. For the calculation of the maximum possible state aid for electricity price compensation in European countries, the analysis assumes that the specific product has an electricity consumption benchmark of 0.8 and that the company in question receives the maximum possible state aid once this benchmark is incorporated into the maximum aid calculation. The final US electricity price is based off the final electricity for industry in Texas. The final electricity price for China is based off the final electricity for industry in Inner Mongolia.

Sources: IEA analysis based on data from Electricity prices components for non-household consumers; Eurostat (2023), Communication from the Commission supplementing the Guidelines on certain State aid measures in the context of the system for greenhouse gas emission allowance trading post-2021; Official Journal of the European Union (2021), Southeastern U.S. Industrial Rate Survey; Brubaker & Associates (2023), Will the Cancellation of Preferential Power Tariff in Inner Mongolia Impact New Energy Market?; Shanghai Metals Market.(2023). EUA Futures; Intercontinental Exchange (2023).

The future of electricity prices for European industries

Policy changes may further influence the final electricity cost of energy-intensive industry. Germany temporarily introduced a price guarantee, where firms receive 70% of their historical demand at a set price of EUR 130/MWh (plus taxes and levies), applicable to users with a demand exceeding 30 MW per year. More long-term measures were approved in early November 2023, with the stated objective for energy-intensive businesses to remain competitive and to prevent industries in the country from relocating abroad. The new measures include a practical exemption from the power tax for all industry, reducing it from approximately EUR 15.3/MWh to EUR 0.5/MWh for the years 2024 and 2025. In addition, after subsidising grid levies with EUR 13 billion in 2023, the government declared in November 2023 that it will spend another EUR 5 billion to stabilise grid levies within that period.

However, later in November 2023, the German Supreme Court ruled that the extra spending of the government in the energy crisis was inconsistent with the constitutional cap on public debt, forcing the government to renegotiate its budget for 2024, which includes the spending for the long-term support measures that

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were agreed earlier in 2023. In response, the finance ministry has temporarily halted the approval of any new commitments for the use of the funds dedicated in part to the electricity price relief measures. As the payments for the price guarantees for parts of the power and gas consumption of the energy-intensive industry have been approved prior, they will continue to flow. However, they will be phased out four months earlier than initially planned, at the beginning of 2024.

The renegotiated budget, agreed in December 2023, reaffirmed the continuation of the major parts of the initially agreed long-term energy price relief measures, such as the strong reduction of the power tax for energy intensive industry as well as the compensation for power cost increases due to the EU-ETS. Still, the new budget included the cancellation of the EUR 5 billion public investment to stabilise grid network charges, initially announced in 2023.

Concerns about the financial burden associated with supporting energy-intensive industry are being raised in other countries as well. Norway, having implemented a floor price for compensation for companies for CO_2 costs above USD 19.07/t, is looking to increase the floor price further in the next national budget.

A reform of the electricity market with the goal to protect both businesses and consumers against soaring prices within the European Union has been agreed upon between the Council and the Parliament in December 2023. The proposal now needs to be formally adopted by both parties to enter into force. One central measure discussed is defining two-way contracts for difference as the central allowed support measure for new installations using technologies included in the green taxonomy. If the market price is above a pre-agreed strike price, the excess revenues are distributed to consumers, while if the market prices are below a pre-agreed strike price, then the difference is reimbursed to the generator. The aim is to help increase the deployment of renewables by providing a guaranteed return on investment as well as more predictable pricing. The underlying spot market model is largely preserved, however capacity remuneration schemes are explicitly mentioned as playing an integral role in the future electricity market. More detailed information on additional content and negotiations process of the reform is provided in the Europe Section of the Regional Focus part of this report.

Household electricity prices and affordability

Since the onset of the global energy crisis, households across the world have seen an increase in the retail electricity prices affecting their affordability. Retail electricity prices in the United States have increased by a 5% yearly average from 2019 to 2023. By contrast, prices in the United Kingdom, adjusted for purchasing power parity (PPP), have increased by 19% in the past year and doubled since 2019. Norway saw record-high electricity prices in 2022. The hydropower-based country suffered a reduction in its reservoirs which, in combination with the

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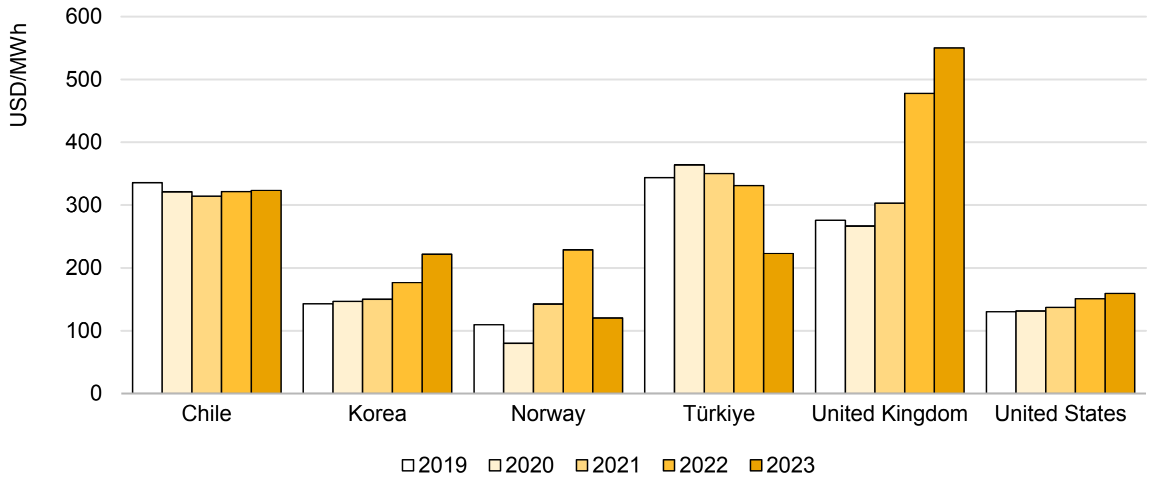
ongoing European energy crisis, created the surge. By 2023, prices were reduced by around NOK 1 000 compared to the previous year, nevertheless remaining 70% higher compared to 2019 levels.

Average household electricity prices in USD/MWh in purchasing power parity (PPP), 2019-2023



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Note: Residential electricity prices include taxes and have been converted from local currencies to USD/MWh (PPP) using PPP conversion rates provided by the IMF PPP database. 2023 value is the average of Q1-Q3 2023 for all the countries except Chile, which is based on Q1-Q2 2023 average. The countries shown here are chosen due to data availability for 2023 as the time of publication of this report.
Sources: IEA electricity prices database, IMF, PPP database.

To protect households against soaring prices, governments used mostly temporary measures in the form of tax exemptions and price regulation mechanisms. In Chile, the government intervened and froze tariffs for consumers starting in 2019, thereby leaving the prices largely unchanged during the energy crisis. The United Kingdom put into effect a new two-year supportive measure from October 2022 applicable to all households, setting a price cap that saves average consumers around GBP 1 000 per year. Norway introduced measures to support household consumers in December 2021, including a support scheme where consumers are rebated half of the difference between their payable electricity price and a reference price of NOK 70/MWh (USD 81/MWh) for their electricity consumption. Nevertheless, prices in 2022 exceeded 2021 levels. Norway's government is considering setting supplementary taxes on electricity exports to improve control over domestic prices.

In the European Union, the emergency interventions helped to partially decouple the development of household prices and the price consumers had to pay. The combined support measures are estimated to have reduced average retail prices in the European Union in 2023 by almost 20%, based on data from VaasaETT.

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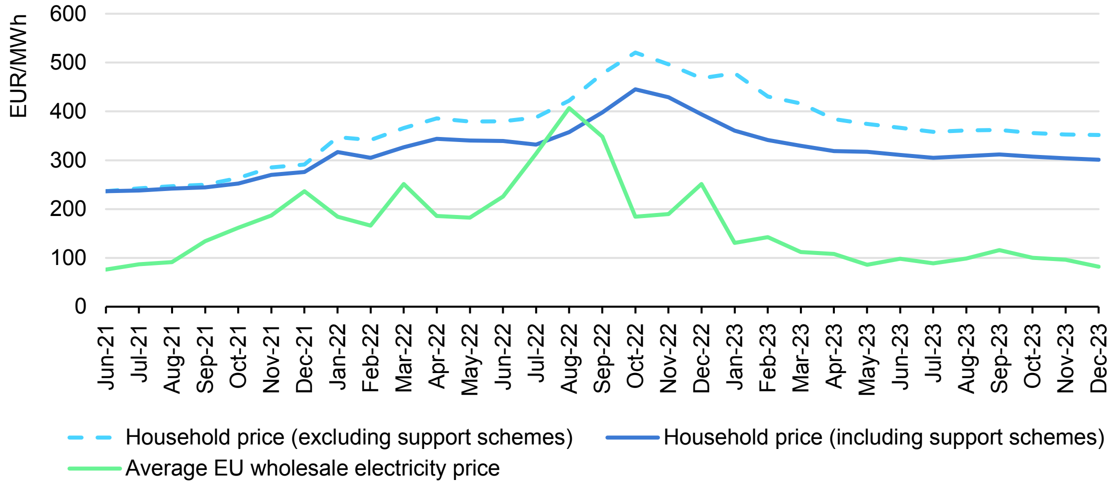
The recent EU market design reform aims to include multiple measures to tackle soaring consumer prices in the longer term, without relying on strong market interventions by governments except in exceptional circumstances.

Country level measures played a large role in shaping the final consumer price. Measures throughout included exemptions from taxes and levies, direct support payments and subsidies, price brakes and reductions in VAT. The magnitude of support measures across EU countries in 2023 varied. In Poland, the government introduced a Solidarity Shield that fixed electricity prices. As a consequence, consumer costs were cut by about 60% in 2023. This was one of the most substantial relief measures observed in the European Union, along with Romania's price caps by almost 50% in the same year. On the other hand, in Finland, Belgium and Germany, the relief in power prices in 2023 through public support measures only amounted to 4-5%.

Representative household prices in the European Union including and excluding support measures, from June 2021 to December 2023



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Note: The household price analysis focuses on general measures affecting typical consumers and selected capital cities which have applied such measures during the period analysed. Household prices consider new tariff offers, which are weighted by electricity demand. Average wholesale price is also demand-weighted for the same countries.
Source: Based on data and analysis provided by VaasaETT (2023), © 2023 VaasaETT Ltd.

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Reliability: Monitoring electricity security remains essential

As electrification gathers pace and both the demand and supply of electricity become increasingly weather-dependent, electricity security and reliability are becoming more important than ever. Many power systems around the world continue to face adequacy issues during heightened electricity demand in periods of extreme cold or heat, alongside increasing weather-induced outages and disruptions in power supply availabilities. Every year, extreme weather events cause largescale power outages in many regions. Insufficient power capacity as well as fuel supply issues due to elevated energy costs continue to plague a significant number of emerging economies. In such a world, it is of paramount importance to monitor the secure operation of electricity systems and keep track of the measures implemented in this context. Against this backdrop, commencing with this year's *Electricity 2024* report, we have included our monitoring and tracking of the global developments in electricity security and reliability as a dedicated chapter.

Specific measures and markets for system inertia are becoming common

As power systems decarbonise, there is a growing need to explicitly procure the services to ensure stable power system operation that conventional generation fleets have in the past provided by default alongside their electricity production. To meet this requirement, countries with high variable renewable generation are increasingly introducing mechanisms to maintain control over power system inertia to keep a steady frequency as the share of conventional generation sources declines.

In this respect, some regions have started setting minimum requirements for system inertia, typically provided by conventional generators with spinning rotors that help the power system ride through disturbances such as faults. A number of countries are also introducing markets for services like fast frequency response (FFR) that help stabilise the power system rapidly after disturbances and may help reduce inertia requirements. Such services like the FFR typically function within a time frame of few seconds or less, making batteries an ideal technology choice due to their fast response times.

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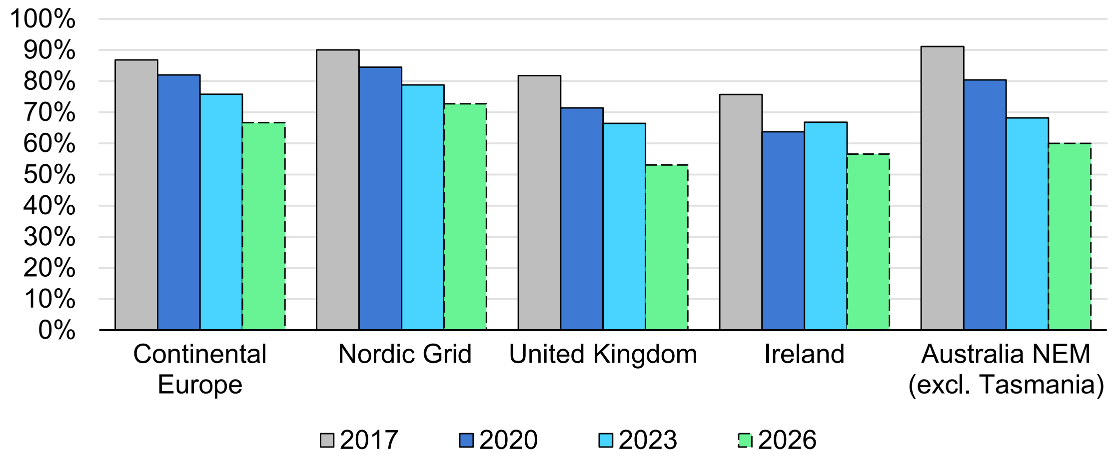
Share of non-VRE sources in total electricity generation in selected synchronous areas, 2017-2026



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Note: 2026 figures are forecast values.

In the **Nordics**, a fast frequency reserve was implemented in May 2020 to address low-inertia scenarios. The required volume of fast frequency reserves is contingent on the prevailing inertia within the power system and the scale of the reference incident. Procurement of this fast frequency reserve by the TSOs occurs in national markets, with market parameters varying among Nordic countries.

The **United Kingdom** mandates that the power system must maintain a minimum inertia level, which has been reevaluated annually since 2021, and currently stands at 120 GVAs. Dynamic Frequency Containment (DC) gained increasing significance due to the imperative of counter rapid frequency fluctuations from low inertia. This fast-acting post-fault service is designed to maintain the frequency within the statutory range of +/-0.5 Hz in the event of sudden demand or loss of generation.

Australia assesses the inertia requirements of each of its regions on a regular basis. In October 2023, the AEMO launched two new fast frequency response market ancillary services under the existing Frequency Control Ancillary Services (FCAS) arrangements. These are "very fast raise" and "very fast lower", each responding within a one-second time frame upon activation. In addition, the Australian Energy Market Commission (AEMC) proposed a rule change on 2 March 2023 to introduce an ancillary service spot market for inertia within the National Electricity Market (NEM).

Ireland also implemented a fast frequency response service in 2018, as part of the DS3 programme (Deliver a Secure Sustainable Electricity System). This service is characterised by the delivery of megawatts within a time frame ranging from 0.15 to 10 seconds. As fast frequency response services do not directly

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substitute for inertia, Ireland has a dedicated service aimed at providing inertia response. Its SIR (Synchronous Inertia Response) service is defined as the kinetic energy of a centrally dispatched generating unit multiplied by the SIR factor. This service has varying requirements depending on whether it is a synchronous generator or a hybrid synchronous compensator-flywheel. The service provider receives payment for each MW of SIR available volume for the providing unit in each trading period when synchronised.

In **Germany**, regulator BNetzA was consulted in 2023 on a market-supported procurement model for inertia services. The current proposal considers a fixed premium payment to be paid to providers of inertia. The fixed price would be set by the transmission system operators (TSOs) and may differ among different regions throughout the system. The 2021 coalition agreement stipulated the development of a roadmap for system stability under the lead of the Federal Ministry for Economic Affairs and Climate Action (BMWK). The roadmap was published in December 2023, with a discussion paper on grid frequency also made available, which focuses on potential measures for providing system inertia, complementary methods such as fast frequency control among other types of mechanisms, and the associated challenges. In parallel, a discussion paper on voltage and another one on resonance stability, angular stability and short-circuit current were also published.

In the **United States,** since 2016 ERCOT's control room has been monitoring inertia levels, and operators have been taking actions to increase critical inertia above 100 GWs when needed. In 2020, the North American Electric Reliability Corporation (NERC) underscored the critical importance of faster frequency response to address the decline in inertia, especially in smaller interconnections within North America, such as Texas and Quebec interconnections. In October 2022, the ERCOT system underwent updates to implement changes associated with the Fast Frequency Response Advancement Project.

Extreme weather events caused large-scale power outages in 2023

Extreme weather events triggered major power outages across multiple regions in 2023. Severe storms caused large-scale power supply interruptions in a number of countries, highlighting the need to increase resiliency against the growing weather impact on power systems.

In the **United States** an ice storm resulted in a major power outage for 400 000 consumers in late January. The Texan power public company, Austin Energy, replaced the exposed 101 distribution poles and 52 transformers which were under trees and ice. The gradual power restoration was delayed for ten days due to the challenging weather conditions. One month later, Michigan saw one of its

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worst ice storms, leaving 800 000 customers without power after electricity lines were destroyed by fallen trees. More than half of the customers had their electricity restored after one day but others had to wait a week. During April, an ice storm left 1.3 million households without power in Quebec, Canada. Fallen trees took down many power lines while gradual recovery of power required the replacement of 50 km of power lines and 440 transformers over six days.

To prepare for future events, utilities identified the damaged infrastructure due to fallen trees and heavy snow as the root cause of their recent outages and developed action plans to address them. Shielding the assets against harsh ice storms includes mainly burying power lines and tree trimming programmes. Detroit-based utility DTE Energy reportedly spent USD 200 million replacing electric equipment and line posts to recover from the ice storm and will invest USD 9 billion on its 5-year weather-resilience plan. The investment cost is to be reflected in consumers' electricity bills linked to a rise of up to 3% of their current expenses.

In June, US southern and Gulf Coast states faced severe thunderstorms, tornadoes and heavy rain. More than 600 000 households and businesses lost electricity service for at least two days in four states due to damaged infrastructure. Among the states, Texas managed to restore service for 300 000 users after two days. The utility serving most of the affected consumers, SWEPCO, repaired fallen transmission lines, approximately 60 transmission and distribution substations and replaced 114 transformers.

Storms in the US northeastern region in December 2023 resulted in major power outages for 400 000 customers in Maine, over 260 000 in Massachusetts and many more in the other four surrounding states. Strong winds and severe floods broke electricity poles and damaged transformers. Most of the power was reestablished after the second day.

Western **France** and the **UK's** southern region were hit by windstorm "Ciarán" in November, leaving more than 1.2 million consumers without power for one day, while approximately 36 000 households had their electricity reestablished after one week. In France, distribution company Enedis is currently working on a modernisation plan to improve their network's climate resilience and adaptation to low-carbon sources of electricity. The plan targets new underground networks, replacement of exposed lines with tougher or underground cables, and new substations by 2050.

The state of Gujarat in **India** was hit by Cyclone Biparjoy in June. The tropical cyclone caused power outages and severe damages to the electricity network valued at INR 10 billion in power lines, transformers and other equipment along the transmission and distribution infrastructure. Power was gradually restored after a week. A second cyclone, Michaung, hit India in December in the southeast

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state of Andhra Pradesh. Several districts were flooded and power supply was interrupted for a week in another case of damaged infrastructure. India's distribution system operator (DSO) BESCOM in the state of Karnataka scheduled daily outages for maintenance work during December. Power cuts at an average duration of six hours to carry out maintenance in an alternating routine affected eight districts with a total of population of 20 million people.

Supply and grid issues led to major outages mostly in emerging and developing countries

In 2023, adequacy problems, fuel supply challenges and grid-related technical issues continued to cause major power shortages in many regions. The majority of the large-scale power outages stemming from these causes were observed in emerging economies, which are particularly affected by a shortfall of electricity supply, infrastructure problems, and strained grids in the face of rising electricity demand.

One of the major blackouts of 2023 occurred on 23 January in **Pakistan**, resulting from overloaded transmission lines, causing a voltage drop. Simultaneously, the northern region grappled with reduced power generation due to plant operating issues. These combined factors led to an uncontrollable power swing that resulted in a nationwide blackout affecting 220 million people for over 12 hours. Notably, this marked the second occurrence within a year, with a prior incident on 13 October 2022 causing a complete blackout in the south and a partial blackout in the north, resulting in a loss of over 8 000 MW.

After analysis of the early January incident was conducted, a set of 18 recommendations were made by Pakistan's National Electric Power Regulatory Authority (NEPRA). The list highlighted that modern equipment installation is required to detect oscillations instability and improvement of the HVDC and VAR compensation systems is needed to avoid operational failures and ensure the correct operation of the black start facilities to achieve timely power restoration. This new list adds to the ongoing implementations of the actions recommended from the late 2022 blackout, including the performance assessment of aged transmission lines before connecting to new power plants.

On 25 August 2023, **Kenya** experienced a major power outage, impacting over 50 million people, with power being restored nearly 24 hours later. The cause of this outage remains uncertain. This incident marked Kenya's fifth nationwide blackout in the past four years and is noted as one of the longest on record. Kenyans saw another nationwide outage early December. The event lasted less than a day but it was the third major blackout in four months. In response to the worsening situation, the national power company, Kenya Power, scheduled power

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interruptions throughout December as a load shedding strategy while allowing for maintenance and modernisation of the infrastructure.

Nigeria endured a nationwide blackout lasting approximately ten hours on 14 September 2023. The grid collapsed due to a fire on a major transmission line. The country has grappled with recurrent power failures, totalling 46 grid collapses between 2017 and 2023. Nigeria's grid continues to face issues due to aged infrastructure and vandalism.

Power cuts occurred in **Egypt** during the summer and late 2023 due to a combination of gas shortages and increased energy consumption amid high temperature overloading the grid. A national daily load shedding strategy was in place since July 2023, with scheduled power outages lasting up to two hours. From November on, power outages have been reduced to one-hour duration.

A major blackout struck **Brazil** on 15 August 2023, lasting six hours and affecting over 29 million people due to a voltage drop from a transmission line failure. The blackout's primary cause was equipment malfunction in the state of Ceara, which underperformed compared to predictions in mathematical models and simulations. Operador Nacional do Sistema Elétrico (ONS) pointed out that the issue was not related to the type of power source.

In Quebec, **Canada** 490 000 buildings lost electricity service for several hours in April due to a maintenance incident deriving from a loss of production from a turbine at a 5 GW hydropower plant. In southern **France**, a two-hour power outage affected 260 000 households due to a system overload in October. RTE, the grid operator, reported this overload as an exceptional technical failure without major consequences.

Outages and routine power cut offs since 2022 have been occurring in major cities and surrounding provinces of the interconnected countries of **Kazakhstan**, **Kyrgyzstan** and **Uzbekistan** due to grid imbalances, e.g. system overloads. During 2023, controlled frequent black outs with a duration of up to five hours have been in place in western Kazakhstan while regional authorities prepared a priority power supply strategy. The oil and gas exporting Kazakhstan has been recently seeking to modernise its ageing power grid infrastructure after gas exports have been interrupted by domestic energy crises.

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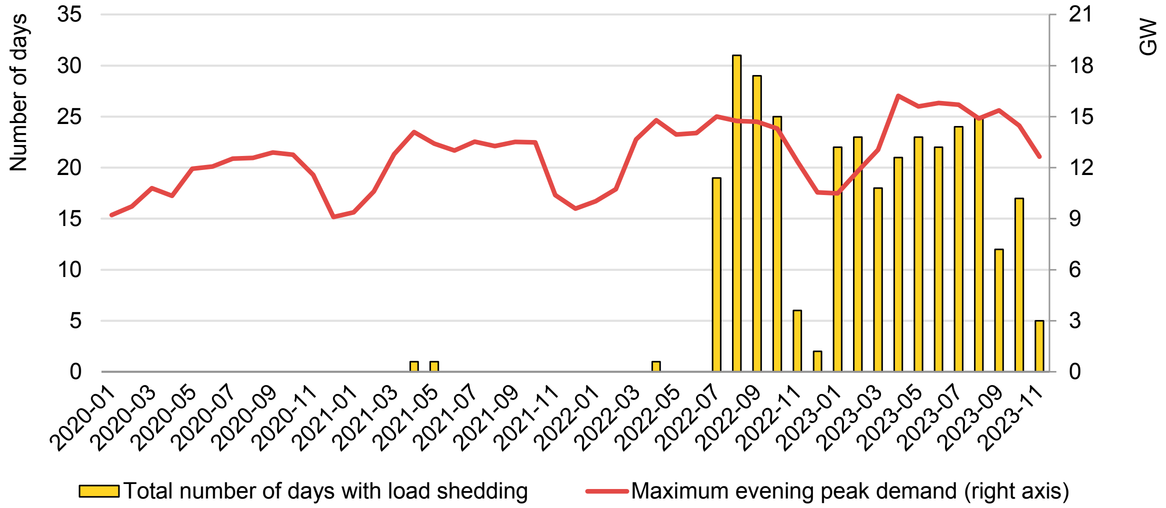
Total number of days with load shedding and maximum evening peak demand per month in Bangladesh between January 2020 and November 2023



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Source: Monthly Management Report, Power Grid Company of Bangladesh.

Sri Lanka had a national blackout in December 2023. Power disruptions persisted for six hours on account of a systemic failure due to a lightning strike on a critical transmission line in the country.

Several other countries have struggled with power supply challenges in 2023 without experiencing full-scale blackouts. **Bangladesh** faced increased power cuts due to rising demand exacerbated by unpredictable weather patterns and fuel shortages. **India** encountered power shortages driven by higher temperatures and decreased hydroelectric output. Peak power demand reached 223 GW in June amid soaring temperatures, with power outages observed in the northern states. In **Madagascar**, rolling power cuts were implemented due to low water reservoirs, reduced solar energy and fuel shortages during the winter months. **Yemen** had to shut down power stations due to fuel shortages in August. South Africa continued to have load shedding in 2023 due to supply challenges, with the total volume of load shedding up to the end of September already being higher than the total volume of load shedding in the previous eight years together.

Understanding the human factor in power disruptions and outages

The recent IEA report Electricity Grids and Secure Energy Transitions showed that grid-related technical/equipment failures alone cause at least USD 100 billion economic damages per year globally. This underlines the need to better identify the cause of failures and the components involved in them. The origin and the components causing a power outage can vary between countries, depending on

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the unique conditions and structure of their power grid. Power outages can be due to a generation and demand imbalance (e.g. fuel shortages, power plant outages or insufficient adequacy) or grid-related issues. Grid-related causes for power outages can be categorised into three main groups: natural causes, human error and technical/equipment-related issues. Human-related factors such as car crashes involving poles and transformers, poor workmanship, errors during new connections, vandalism and cyberattacks can lead to disruptions in the power supply. In many regions, these factors are significant causes of power outages and deserve more attention.

Better standardisation, digitalisation and training can help minimise human errors

Data transparency on the detailed reasons of power outages is generally limited. While several countries publish data on power outages, exact causes and the associated equipment of outages are generally not provided in detail. Chile is one of the few countries where a detailed dataset on the causes of (transmission-level) outages and the associated equipment are provided, which makes for an interesting case study.

Our analysis of Chile's transmission-level power outages in 2021 shows that one-third of the reported outages were due to human errors or human-related incidents. Poor workmanship is reported as a major cause. Among the outages that resulted from protection systems, causes include errors in parameter programming, connection-related issues, or hardware malfunctions. Most power outages associated with bus bars and points of connection are reportedly due to poor workmanship, with errors during maintenance or operational work, or faults caused by cut distribution conductors, control unit issues and overloads.

On the technical side, outages can stem from a diverse set of component and equipment failures. In the example of Chile, our analysis of transmission-level outages shows that the main causes of incidents are related to power lines, which made up about half of the almost 400 reported outages in 2021. Outages arising from power lines are often due to short-circuits stemming from weather, animal and tree-related events. Short-circuits can arise due to branches touching power lines or storms taking down trees. Consequently, electrical current surges trigger the activation of protection mechanisms to de-energize the system. Other equipment causing outages are the protection systems, bus bars, substations, transformers, circuit breakers and point of connections.

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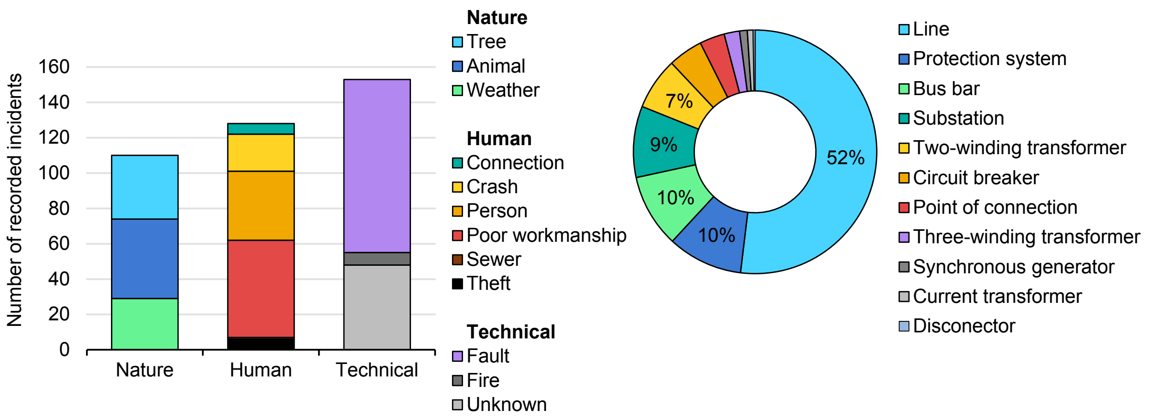
Power outages at the transmission level in Chile in 2021 by cause (left) and associated electrical equipment (right)



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Note: The data is clustered by the IEA according to the reasons provided in the original source.
Source: IEA analysis based on data from Unavailability indices, Coordinador Electrico Nacional.

Human error in power outages is a universal phenomenon. Approximately 5% of outages are attributed to human error in the United States. In 2023, human error led to a 48-minute power outage on Hong Kong's Long Island. Incidents like this underscore the need to review maintenance procedures and staff training. For example, HK Electric proposed to improve the management procedures of the 48-minute power outage incident after conducting an investigation. The list of procedures identified to update were the energy management system circuit diagrams, quality control of transmission construction and maintenance works, on-site equipment critical inspections, and technician training and qualification requirements. This highlights the need to consider human factors when determining maintenance policies.

To minimise the share of human errors in power outages complimentary approaches are advantageous. Leveraging technology to digitalise and automate processes can effectively reduce evaluation time while improving the outcomes. Employing AI in repetitive and manual tasks such as power grid inspections enables the identification of discrepancies that could result in power outages and even reduce wildfire risks related to electric equipment. For example, the American Pacific Gas & Electric Company (PG&E) in California has been using drones to remotely conduct infrastructure inspections. The utility is saving costs and time while improving operator safety by commissioning drones with cameras that use AI-powered algorithms to scan the area. AI-based software can also be used for preventive maintenance purposes. It can, for example, identify vulnerabilities in power grids as well as measure economic benefits using vast amounts of historical data and climate models to make grid failure predictions.

Other options to mitigate power outage incidences are increased staff training and standardisation. Staff certification is a method to ensure a standardised and safe

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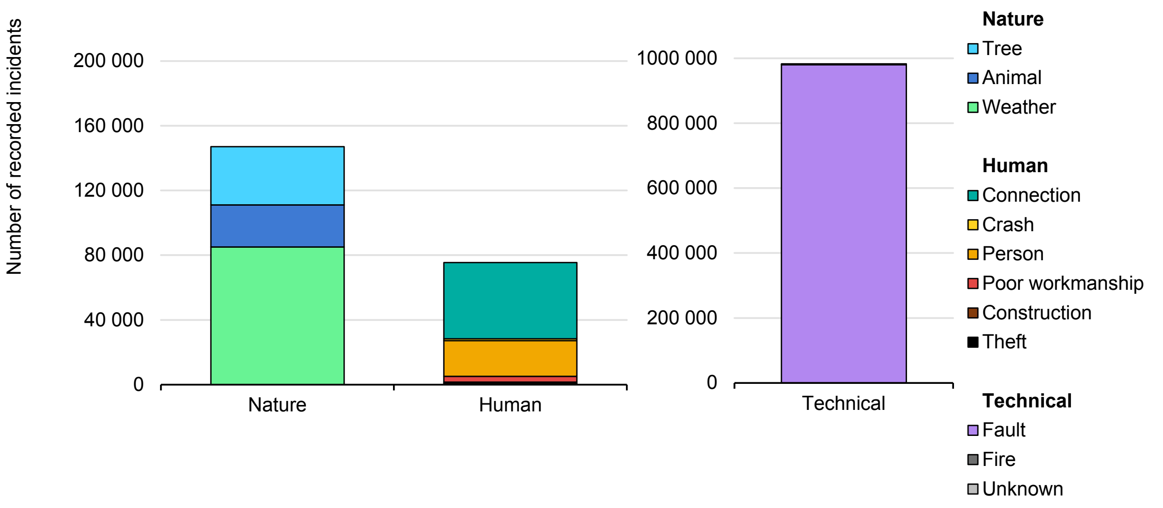
approach to maintain and repair infrastructure. Local level and international certifications provide updated knowledge and skills to follow safe and proven protocols in electrical installation and maintenance.

Greater data transparency on distribution-level outages can provide better insight into the causes

Most outages occur due to distribution level issues, which can represent 80% of total customer service interruptions. Usually, these power outages impact smaller areas and fewer people compared to transmission-level incidents. Detailed data on distribution-level incidents is generally not publicly available, limiting systematic analysis. Türkiye is one of the few countries where detailed data on power outages with high temporal and locational granularity is made publicly available. The DSOs in Türkiye systematically collect outage data, which are centrally gathered and published on the EPİAŞ transparency platform.

Our clustering and analysis of power outage data in Türkiye shows that of the unplanned outages reported for 2021 at the distribution level, about 80% were reported as technical/equipment-related, followed by natural causes and human factors. Among human-caused incidents, issues during new connections were the main cause in most of the reported outages. This is followed by third-person involvement, where accidental damaging of equipment during construction works but also vandalism are common. Mentioned at a smaller scale, poor workmanship was also cited as a cause. According to the Turkish statistics, equipment commonly associated with distribution-level outages includes power transformers, instrument transformers and cables.

Unplanned power outages at the distribution level in Türkiye by cause, 2021



IEA. CC BY 4.0

Note: The data is clustered by the IEA according to the reasons provided in the original source.
Source: IEA analysis based on data from Epiaş Seffaflık Platformu (2021), Outage Information.

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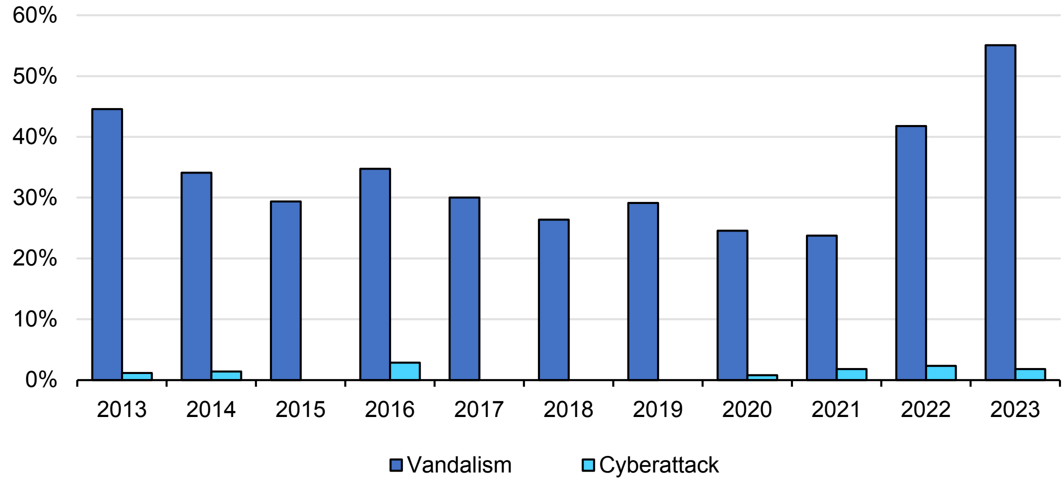
Vandalism and cyber threats to the electricity system are increasing

The **US** power grid is currently facing a surge in physical attacks, which has reached a decade high. Nearly half of the 4 493 attacks recorded in 2020 to 2022 were targeted at substations, according to a February 2023 briefing from NERC. This wave of attacks resulted in outages, prompting calls from both state and federal lawmakers for enhanced security measures. In response, state lawmakers in North Carolina have passed an amendment, effective July 2024, that will mandate public utilities to operate a 24-hour security system at substations while stricter penalties will be enforced upon electric utility infrastructure damage.

While physical attacks have captured headlines, the cyber threat is also a growing concern. Between 2020 and 2022, the average number of cyberattacks against utilities worldwide more than doubled. As power systems evolve in line with digitalisation, protection against cyber threats will become increasingly more important. Governments are developing regulations to safeguard the integrity of information and communications technology (ICT) against any action that compromise them.

Share of power outages caused by vandalism and cyberattacks in total reported transmission-level outages in the United States, 2013-2023



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Notes: Vandalism includes outages reported with the causes listed as physical attack, sabotage, and suspicious activity. Cyberattack includes outages reported with the causes listed as cyberattack and cyber event.
Source: IEA analysis based on data from Electric Disturbance Events Annual Summaries, U.S. Department of Energy.

Between the period of July 2022 to June 2023, ICT in the **European Union** underwent approximately 2 580 cyberattacks, mainly to ransomware (34%), Distributed Denial-of-Service (DDoS), known for blocking a system to access relevant data by overloading components of the network (28%), and data

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breaches (17%). These incidents have experienced a monthly growing trend of 15% within the same two-year period, starting from 125 reported incidents in July 2022 to 607 cases by July 2023. From the total number of cyberattacks, 190 were reportedly directed at the energy sector. In April, a malware targeting the power grid was discovered to be within the operative systems of different power providers in Europe, the Middle East and Asia.

The EU's Network and Information Directive (NIS), adopted in 2016, identifies critical entities – generators, retailers, TSOs and DSOs – and sets a series of measures to maintain the reliability and security of the involved ICT as well as setting co-operation platforms to further improve cybersecurity. In October 2023, the NIS was modernised. The directive, NIS2, extends its predecessor's scope and is to be fully implemented by late 2024. In this update new entities are listed as critical, such as recharging point operators and various electricity market participants, as well as reinforcing cybersecurity requirements along their supply chain. Additionally, in September 2023, the European Commission unveiled new plans urging EU countries to enhance collaboration on cross-border threats and strengthen co-operation with NATO.

Since 2013, the **US** Federal Energy Regulatory Commission (FERC) set mandatory cybersecurity controls to the Critical Infrastructure Protection reliability standards. In 2022 the DOE published their voluntary framework to mitigate cyberattacks in the energy sector. It prioritises cybersecurity considerations at all stages of energy systems, from their conceptualisation to their decommissioning.

FERC approved, in March 2023, new cybersecurity standards to improve the reliability of the evolving power grid by expanding the security controls of less critical generation and transmission facilities. These standards require the operators to have the means to detect and disable vendor remote access in case of cyberattacks. This was followed in September 2023 by the DOE awarding funding totalling USD 39 million for research, development and demonstration projects to improve cybersecurity tools and technologies of distributed energy resources (DER).

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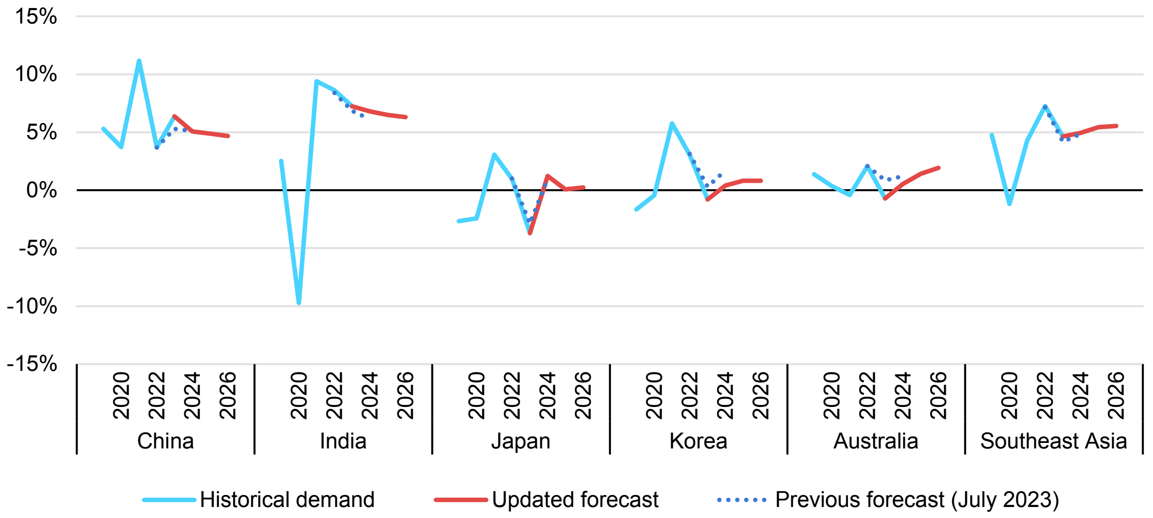
Regional focus

Asia Pacific

Renewables meet growing share of electricity supply but coal remains the major source

Electricity demand in Asia Pacific rose by 4.8% in 2023, and provided most of the additional growth in global electricity use. Demand is forecast to rise by an average annual 4.6% from 2024 to 2026, with China expected to provide close to 70% of growth in the region by 2026. Asia Pacific, which accounts for just over 50% of global electricity consumption, will see renewables share of power generation rise from 27% to 35% in 2026 but coal-fired power remains the major source of supply. In 2023, coal accounted for 57% of the region's electricity generation, with low-carbon sources such as nuclear, hydro, solar and wind contributing for 32% of the mix. Due to its strong reliance on coal for power, Asia Pacific has the highest electricity generation CO2 intensity of our analysed regions, at 590 g CO_2/kWh in 2023, compared to a global average of 455 g CO_2/kWh. The region's emissions from electricity generation are expected to record slight increases of 0.2% in 2025-2026, after a decline in 2024 due to an assumed recovery in hydropower.

Year-on-year percent change in electricity demand, Asia Pacific, 2019-2026



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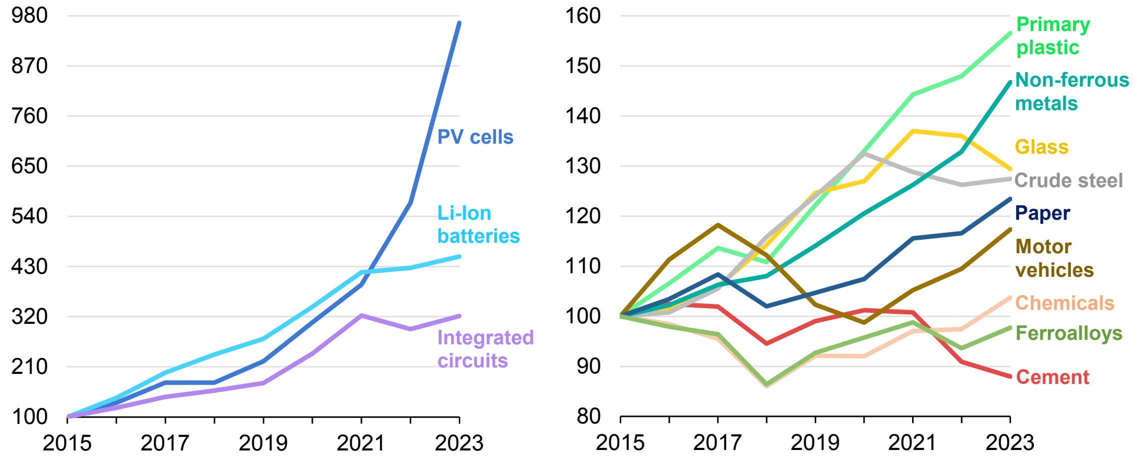
China

Production of solar PV modules and batteries, and processing of related materials are significant drivers of electricity demand

In China, the post-pandemic economic recovery paved the way for a strong increase in electricity demand of 6.4% in 2023, with the services and industry sectors experiencing the most robust rebound. With the country's economic growth expected to slow and shift away from heavy industry, we forecast the pace of electricity demand growth to ease to 5.1% in 2024, 4.9% in 2025 and 4.7% in 2026, which is well below the average growth rate of 6.5% observed over the pre-pandemic period of 2016-2019. Electricity consumption per capita in China surpassed that of the European Union at the end of 2022. This is, however, propped up by the industry sector, as electricity use per household is still below that in the European Union. The rising consumption of electricity by Chinese households will remain a driver of electricity demand.

Continued electrification of China's industrial sector and strong growth in road transport (EV charging) accounts for an increasing share of China's electricity demand over the forecast period. The rapid adoption of EVs, which now account for over 8% of the vehicles in the country, is markedly eroding growth in gasoline consumption in favour of electricity. A downward trend in the cement and glass industries can be observed since 2021, which is relevant for the construction sector. By contrast, manufacturing of PV modules, EVs and processing of associated materials were significant drivers of growth in electricity demand in the industry sector in recent years and will remain on a solid upward trend.

Indexed production output in selected industries in China, 2015-2023



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Note: Non-ferrous metals include copper, aluminium, lead, zinc, nickel, tin, antimony, mercury, magnesium, and titanium.

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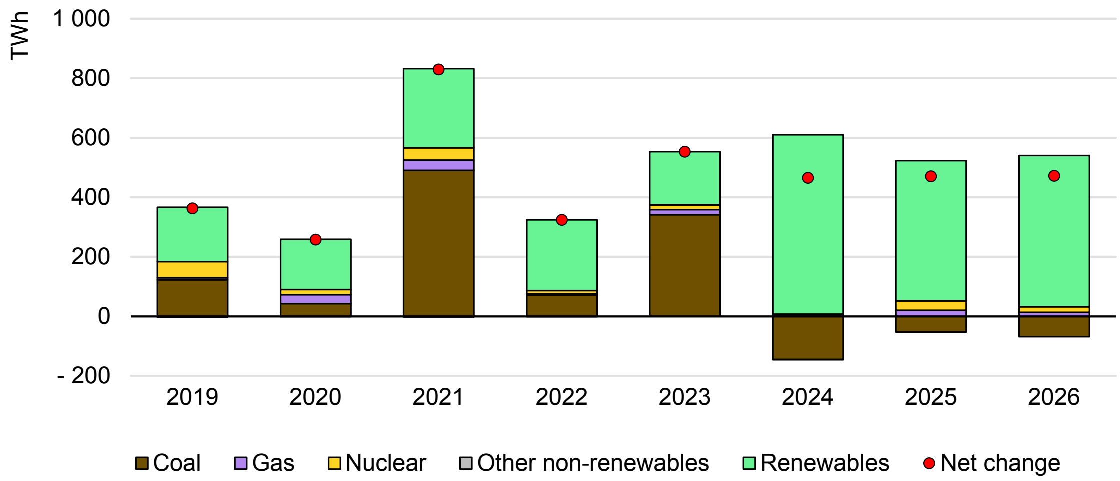
Renewables and nuclear are set to meet all of the growth in electricity demand in 2024-2026, curbing coal-fired generation

Hydropower generation declined significantly in 2023, by 5.6% year-on-year, due to severe droughts, which led to a rise in coal-fired generation of 6.2%. As a result, 60% of the increase in electricity demand in 2023 was met by coal-fired supply. Although wind and solar PV occupy a growing share in the generation mix (15%, up two percentage points compared to 2022), the increase in thermal generation led to a 6.2% increase of electricity sector emissions in 2023.

Assuming normal weather conditions and a recovery in hydropower output, total renewable generation is expected to increase by 21% in 2024. Over the 2025-2026 period, we expect an annual growth of 13% on average amid continued strong expansion of solar PV and wind generation. Renewable energy sources are expected to meet almost all the increase in electricity demand in our forecast period and start displacing coal-fired generation together with increasing nuclear generation. As a result, we forecast an average annual decline of around 1.5% in coal-fired generation over 2024-2026, with coal's share in total generation contracting from 62% in 2023 to 51% in 2026. The weather and the extent of the slowdown in demand growth remain the main sources of uncertainty in the forecast period.

Year-on-year change in electricity generation in China, 2019-2026



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Notes: Other non-renewables includes oil, waste and other non-renewable energy sources. The figures for 2024-2026 are forecast values.

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Coal's role is changing from a source of bulk generation to a more flexible operation to support renewables and ensure energy security

Our forecast shows a declining trend in coal-fired generation through 2026, despite a wave of new coal projects that have been commissioned or permitted since 2022. We expect 40 to 50 GW of new coal-fired power plant capacity to be added annually from 2024 through 2026. As the share of renewables rises, the role of coal-fired plants is changing from providing base-load supply to more flexible operation. The average capacity factor of coal-fired power plants in China has come down from 61% in 2010 to 53% in 2023, and this trend is set to continue. Government authorities announced a new capacity remuneration mechanism for coal power plants, starting in January 2024, which aims to help them recover part of their fixed costs as low-carbon generation meets an increasing share of the load.

Energy security remains a significant issue. Following power outages in 2021 and 2022, concerns emerged at the beginning of the summer of 2023 that the country would struggle to keep the lights on amid record heat waves. Summer peak load reached historic highs of 1 340 GW, up 50 GW compared to the previous year. Droughts and higher than normal temperatures from winter 2022 to spring 2023 resulted in exceptionally low water reservoir levels. The government implemented policies to boost domestic coal production and imports.

While the central government pledged to stop permitting coal plants solely for bulk generation, provinces continue to approve new projects for economic stimulus and, amid energy security concerns, to meet peak load and address a lack of flexible generation and demand. Building coal power facilities near large wind and solar bases in western China is also a strategy to ensure higher utilisation rates on ultra-high-voltage (UHV) lines exporting power to eastern regions. More than 40 GW of thermal plants were commissioned during the first ten months of 2023, surpassing installation rates observed over the past 13 years.

Gas-fired generation is forecast to grow at an average rate of around 4% over our forecast period. While the easing of the LNG market from 2025 onward due to more liquefaction capacity coming online is expected to put downward pressure on gas prices and boost gas-fired generation, the massive expansion of renewables will temper its growth. We expect nuclear generation in China to grow annually by 4% on average, as new reactors start commercial operations.

Record renewables uptake brings new challenges to the power sector

In 2023, newly deployed solar PV capacity broke records, with 130 GW of solar installed during the first three quarters – primarily in the form of distributed

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projects. The new capacity is equivalent to twice the combined solar additions of the European Union and the United States in 2022. This capacity surge resulted in a massive 29% increase in solar generation in 2023. Solar PV continues to dominate renewable capacity expansion but it will still lag behind wind-generated electricity to 2026. As of December 2023, grid-connected solar PV and wind capacity was close to reaching the symbolic milestone of 1 000 GW at the end of 2023. This rapid installation pace will enable the country to meet the 14th Five-Year Plan target of doubling annual wind and solar power generation from 2020 by as early as 2024.

However, grid integration challenges at the distribution level could limit the rate of renewables capacity growth in some regions, as observed in eastern provinces like Hebei, Shandong and Henan. Grid saturation has led some localities to limit the approval of new distributed renewable projects until grid upgrades are completed. Moreover, falling prices across the entire solar PV industry chain, driven by fierce competition and manufacturing overcapacity, could also hinder installation rates as some major solar companies are already reporting declining profits. Similarly, top Chinese wind manufacturers have incurred losses amid plummeting prices, despite the growth in newly installed capacity.

Ensuring adequate electricity supply during summer and winter demand peaks remains a top priority for the government. The National Energy Administration (NEA) has forecast a tight power supply and demand balance for the 2023/2024 winter period in some provinces, with an anticipated peak load 140 GW higher than last year. Policies and pilot projects related to peak load management and variable renewable energy (VRE) integration are being promoted, and a new measure now requires demand-side response to cover 3-5% of the peak load of each province by 2025.

New policies to facilitate growth in renewables unveiled

Major policies impacting the power sector were introduced in 2023. The Green Electricity Certificates (GECs) market is expected to soar after an announcement that the scheme is expanded to cover all types of renewables and that GECs become the sole certification for the production and consumption of green electricity and the only proof of environmental attributes. Some renewable projects will also be eligible to issue carbon offsets under the China Certified Emission Reductions (CCER) scheme, which is about to relaunch. There is currently a lack of clarity on how overlaps between the two schemes will be managed to avoid double-counting. Finally, although the share of electricity traded on spot markets remains limited, progress on provincial, regional and interprovincial pilot spot markets is ongoing. In September, the NEA released the final version of the spot market rules, marking the first national standards issued for spot market development.

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India

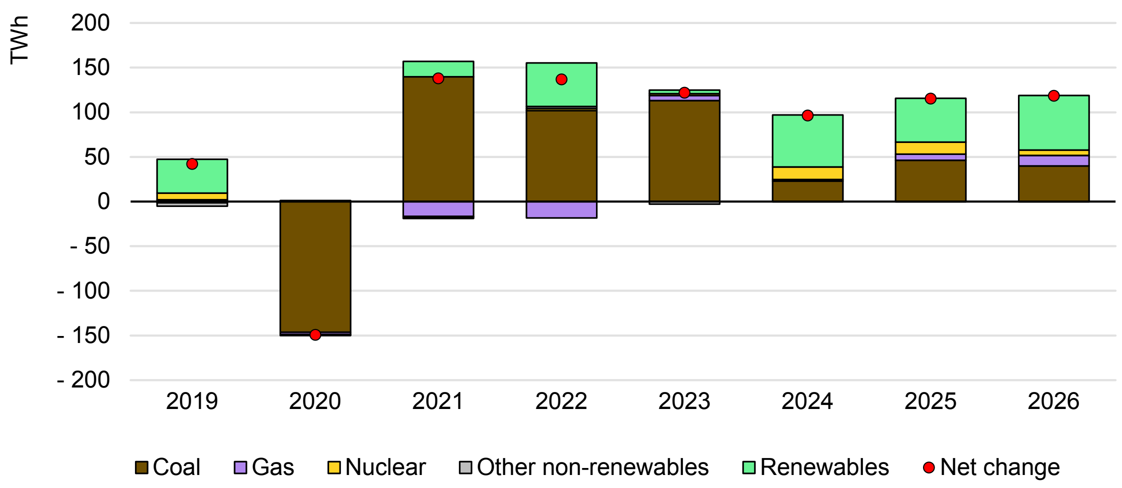
Coal-fired supply remains the mainstay, but the share of renewables in electricity generation is expected to reach the 25% mark in 2026

Non-fossil-fuelled capacity accounted for nearly 44% of total installed capacity in Q3 2023, with close to 21 GW of renewables added during the year. Renewable generation remained relatively stable with a 21% share of electricity generation in 2023, with a rise in solar and wind largely offset by reduced hydropower output.

India's electricity demand in 2023 was heavily influenced by varying weather patterns. The country experienced the driest August in over 100 years and power demand soared, surpassing 240 GW on 1 September amid increased space cooling demand. The higher demand and low availability of hydropower resulted in the government directing all generation companies and independent power producers (IPPs) to extend the mandate of blending a minimum of 6% of imported coal with domestic coal until March 2024 to ensure uninterrupted power supply.

Electricity demand rose 7% in 2023, with growth forecast at close to 6.5% on average in 2024-2026. To meet rising demand, about 80 GW of additional thermal capacity is needed in the next decade according to the government. Coal-fired generation will remain dominant but is expected to fall from 74% of total electricity generation in 2023 to 68% in 2026. Renewable energy generation is forecast to grow from around 21% of the mix to reach a 25% share in 2026.

Year-on-year change in electricity generation in India, 2019-2026



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Notes: Other non-renewables includes oil, waste and other non-renewable energy sources. The figures for 2024-2026 are forecast values.

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Hydropower, nuclear, storage and increased power system efficiency are high on the Indian government's agenda

India saw a massive 15% fall in hydropower generation in 2023 compared to a year earlier, which resulted in shortages and outages in several parts of the country. For example, the state of Karnataka had power shortages of approximately 1 500-2 000 MW linked to insufficient rain. In addition to promoting wind and solar generation in the country, there is renewed focus on developing large hydro and nuclear power plants for base load and balancing of the grid. To support hydropower development, over 12 stalled hydro projects (11.5 GW total capacity) that were awarded to private sector companies 15 years ago were transferred in August 2023 to central public sector entities under the Ministry of Power, to enable the projects to advance.

In a milestone for India, its largest domestically built nuclear power plant, the 700 MWe Kakrapar Unit 3 reactor, commenced operations in Gujarat in June 2023, and reached full capacity in August. Based on the country's project timeline, we expect nuclear power generation to increase rapidly during 2024-2026, with new plants totalling an estimated 4 GW of capacity entering commercial operation over the period. India currently has 23 operable nuclear reactors providing about 2% of the country's electricity.

We expect India's share of variable renewable energy (VRE) generation (wind and solar PV) to reach 15% by 2026. In order to ensure secure electricity supply and adequately utilise high shares of renewable energy, the government announced several policy measures to promote and develop energy storage technologies. The National Electricity Plan (NEP), released by the Central Electricity Authority (CEA) in May 2023, estimates an energy storage requirement of 16.1 GW (7.5 GW pumped storage hydropower and 8.7 GW of batteries) by 2026-2027. Related to this, the Ministry of Power announced the preparation of a national framework for the planning and establishment of energy storage systems. Following that, viability gap funding (VGF) for 4 000 MWh of battery energy storage system (BESS) projects was formalised. In a current tariff-based competitive bidding process, the discovered cost for BESS is INR 10.18/kWh (USD 0.12/kWh). The VGF scheme targets a reduction in the levelised cost of BESS ranging from INR 5.5/kWh to INR 6.6/kWh (USD 0.066/kWh to USD 0.079/kWh) by 2030-2031. To enable local development of long duration storage at a cheaper rate than BESS, the government released new guidelines for pumped storage hydropower projects in April this year, with interstate transmission charges being waived for pumped storage construction awarded by June 2025.

Distributed renewable energy (DRE) is currently far behind set targets but is likely to increase with dedicated Renewable Purchase Obligations (RPO) introduced that require designated consumers to meet a minimum of 2.7% of their total

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consumption from DRE by 2026-2027. Efforts are also underway to achieve higher efficiencies and to reduce the carbon footprint of thermal power plants, with about 94 units of total capacity of 65 GW operating with supercritical and ultra-supercritical technologies. While several measures were introduced in the past that allowed replacing thermal power with renewables, in 2023 the government introduced minimum Renewable Generation Obligations (RGO) for coal/lignite-fired power plants of 6% by 2026 and 10% by 2028. This means that a designated consumer which is a coal/lignite-based plant will be obligated to supplement its fossil-fired generation with a minimum supply of renewable electricity to fulfil its RGO. It can do that via either supplying the renewable electricity itself or procuring renewable power, e.g. through a power purchase agreement (PPA).

Grids and electricity market designs are receiving attention to support decarbonisation

In 2023, India announced new plans to strengthen the interstate transmission system to enable renewable integration. In October, the Cabinet approved the Green Energy Corridor (GEC) Phase-II interstate transmission system for 13 GW of renewable energy projects in Ladakh, with central financial assistance of INR 8.3 billion (around USD 100 million). In order to boost power trade with neighbouring countries, India also plans to buy 10 GW of power from Nepal in the next 10 years, which will mean expanding the capacity of cross-border power lines. The market for hydropower imports from Nepal may be further boosted with an additional clause introduced under the renewable purchase obligation guidelines announced in October allowing obligations to be met by projects located outside India. The G20 New Delhi Leaders' Declaration recognised the role of grid interconnections and cross-border power systems integration. In addition to strengthening interconnections with neighbouring countries in South Asia, the government announced plans in the second half of 2023 to establish electricity interconnections with Saudi Arabia, UAE and Singapore as part of the One Sun One World One Grid (OSOWOG) initiative.

In 2023, the new grid code came into force along with general access network regulations. These initiatives provide for renewable energy grid integration, reliability and adequacy of reserves, reactive power and inertia support, flexibility for buyers to optimise their procurement cost, and several aspects of scheduling, dispatch and performance monitoring.

A roadmap on redesigning the electricity market in India was prepared in 2023 by a high-level group under the Ministry of Power, outlining short-, medium- and long-term interventions to enable integration of renewable energy into the grid and optimisation of electricity generation resources. The Central Electricity Regulatory Commission (CERC) approved a plan for the Indian Energy Exchange Limited (IEX) to introduce trading in a high-price day-ahead market (HP-DAM). This

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separate market segment will enable utilising available power capacity with cost of production higher than the price cap of INR 12/unit (introduced in 2022 to rationalise prices for buyers at the exchange), with a ceiling price of INR 20/unit. The HP-DAM could, for example, cater to gas-fired power plants, imported coal-fired power plants, and battery energy storage systems. CERC also approved power exchange platforms to launch the tertiary reserve ancillary service (TRAS) market segment to help maintain grid frequency levels and accommodate higher shares of VRE.

In June 2023, India announced its carbon credit trading scheme, which aims to reduce greenhouse gas emission for obligated entities by pricing emission through carbon credit certificates. The announcement includes a comprehensive overview of the institutional structure for the scheme with details on roles and responsibilities for each ministry and agency involved. In our forecast, we expect India's emission intensity to improve, declining by 2.7% annually during 2024-2026. The carbon credit trading scheme could support India's long-term targets for reduction in emission intensity by 2030.

Japan

Coal use in power generation is set to contract as nuclear and renewables ramp up

In 2023, Japan's electricity demand fell by 3.7% year-on-year due to rising electricity prices and concerted energy conservation efforts. The impact of weather on electricity demand was mixed. The winter months of 2023 were significantly milder, with -12% heating degree days (HDD) compared to 2022, reducing electricity demand. At the same time, summer was hotter at +10% cooling degree days (CDD), supporting demand for space cooling. The manufacturing sector contracted in 2023, according to purchasing managers index (PMI) trends, while at the same time services expanded year-on-year.

The spike in prices for energy commodities following Russia's invasion of Ukraine prompted utilities to raise their rates. In June 2023, seven major utilities increased their regulated household rates by around 30% from previous levels. In response to the crisis, the Japanese government provided subsidies for electricity and gas bills in December 2022, and later extended this support until the spring of 2024.

We forecast a modest electricity demand growth at an average annual rate of around 0.5% from 2024 through 2026, supported by an assumed gradual recovery in the manufacturing sector as well as EV uptake. In 2023 the Ministry of Economy, Trade and Industry (METI) published its preliminary guidelines for EV chargers,

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increasing the installation target, and also decided to expand support for semiconductor factories under the GX (Green Transformation) programme, formalised in February 2023.

Gas and coal accounted for two-thirds of Japan's total power generation mix in 2023. Nuclear generation increased by 54%, to reach 8% of the generation mix as a result of more reactors coming back online following periodical inspections in 2022 while the Takahama Units 1 and 2 were restarted in August and October 2023, respectively. Renewables also continued to grow, up by 6% with a share of 24%. This combination of expanding low-carbon power generation and falling electricity demand led to a significant 10.3% year-on-year reduction in total emissions in 2023.

Higher nuclear generation, expected once the Onagawa Unit 2 and Shimane Unit 2 reactors are restarted in 2024, and a steady increase in renewables of about 5% annually to 2026, will reduce coal- and gas-fired generation by around 3% and 2% per year respectively and see emissions intensity improve by 4% per year during the forecast period. Additional reactors may be brought back online in the coming years following a government announcement in August 2022 that the restart of nuclear power plants will be accelerated. In December 2023, the regulator lifted the operational ban on the TEPCO-owned Kashiwazaki-Kariwa nuclear power plant following safety improvements. Approval from the local governments is also required before a restart.

In 2024, Japan’s capacity market is on track to become operational, and the balancing market is expected to introduce trading of new products as part of electricity system reforms. In addition, the first auction for long-term investment in power sources for decarbonisation is planned for January 2024. These initiatives aim to ease supply tightness in Japan's electricity system by ensuring sufficient power capacity and flexibility.

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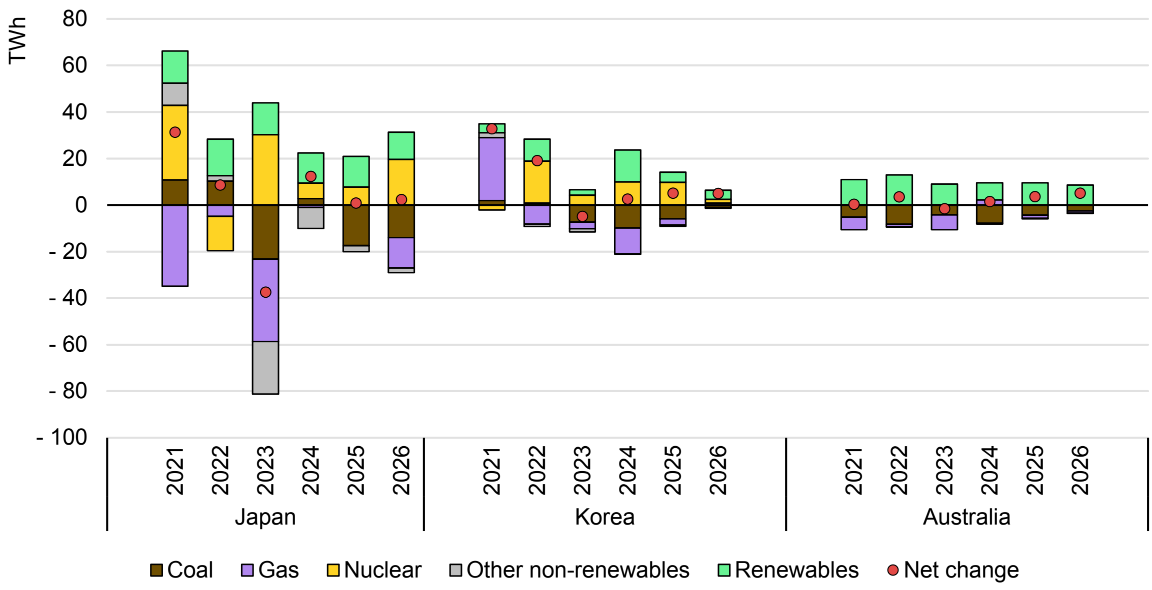
Year-on-year change in electricity generation in Japan, Korea, and Australia, 2021-2026



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Notes: Other non-renewables includes oil, waste and other non-renewable energy sources. The figures for 2024-2026 are forecast values.

Korea

Plans unveiled to expand and strengthen Korea's power supply and transmission infrastructure to meet growing demand

Korea posted a 0.8% decline in electricity demand in 2023, primarily due to a weaker industrial sector. However, we expect average annual demand growth of slightly below 1% for 2024 to 2026. The peak electricity demand for the entire power system surpassed 100 GW for the first time in history on 7 August, reaching 100.8 GW.

In 2023, the country's total power capacity increased by 7 GW. This included nuclear (1.4 GW) as well as coal-fired (1.1 GW), gas-fired (2 GW), and renewable energy (3.8 GW) capacity. In 2024, further capacity additions are expected for nuclear (1.4 GW), coal-fired (1.1 GW), gas-fired (0.7 GW) and renewable energy (4.1 GW).

Coal is the mainstay of Korea's electricity system, accounting for about one-third of the total generation in 2023. However, coal power plant capacity is expected to gradually decrease to 2026, with plans to convert seven coal-fired power plants to gas-fired plants, with a total capacity of 3.6 GW. Nuclear capacity is forecast to increase from about 25 GW in 2022 to 29 GW in 2026, with no plans to retire any nuclear power plants in the latest plan. The share of renewable energy and nuclear power in the generation inches higher, while coal and LNG post marginal declines

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over the forecast period. Coal's share is expected to edge lower from 32% in 2023 to 29% in 2026 while the share of gas falls from 29% to around 26%. By contrast, the share of renewable energy in power generation will remain comparatively modest, though growing, rising from 8% in 2023 to 11% in 2026.

The year 2023 saw a wave of announcements on policies and plans for new generation installations, major transmission lines and substation facilities, among other initiations to improve and expand the electricity system as part of its 10th Basic Plan for Long-term Electricity Supply and Demand (BPLE), which was released in January 2023. The 10th power transmission and substation facility plan was unveiled in May. In addition, in October, the Special Act on Expansion of the National Power Grid was proposed in the National Assembly, which aims to reduce transmission lines construction time and support power grid expansion, including the establishment of a new long-distance transmission network, which are essential to ensure the competitiveness of high-tech industries. Reportedly, there is a critical need for expanding the power grid to meet growing electricity demand from semiconductor factories, as well as to integrate nuclear and renewable energy sources in the power mix. This draft law aims to include Variable Renewable Energies (VREs) in the process of deciding which power units to operate, known as the "unit commitment procedure". These VREs will be dispatched based on their merit order, meaning they will be ranked and used based on their efficiency and cost, along with other traditional energy resources. The draft law also aims to create a real-time market, which would generate price signals for all types of technologies every 15 minutes. The Korea Power Exchange (KPX) intends to expand this new market design across the mainland by the end of 2025.

Lastly, the Special Act on the Promotion of Distributed Energy was enacted in June 2023. The government aims to reduce the existing centralised power generation and raise the share of distributed power generation in the Korean energy market up to 30% by 2040, with a set of measures that, in particular, would promote the use of small renewable IPPs close to demand centres and enable them to sell electricity generation directly to consumers.

To manage the energy crisis, the government implemented a System Marginal Price (SMP) upper limit system in the electricity market starting from December 2022. Since the SMP needs to exceed the upper limit to be activated, the limit was triggered for only four months, spanning from December 2022 to February 2023 as well as April 2023. The price cap concluded in November 2023.

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Australia

South Australia surpassed 75% wind and solar share in generation, marking a milestone

Electricity demand in Australia fell by around 0.7% in 2023, with milder winter and summer temperatures compared to the previous year contributing to the decline. Demand is forecast to rise by just over 1% on average annually in 2024-2026, with growth coming primarily from the residential sector and higher EV deployment. Efficiency is expected to play an increasing role in limiting demand growth, with multiple initiatives implemented in 2023. Plans to improve efficiency include new investments for retrofitting commercial properties and government grants for small and medium-sized businesses. Consultations have also been initiated to improve the efficiency of electronic screens.

Most capacity additions in the coming years are anticipated to come from renewable sources, with a small contribution from new gas-fired capacity. In 2023, almost 6 GW of renewables capacity was installed, including over 4 GW of solar PV and around 1.5 GW of wind. We expect a similar pace of installations to be maintained over the forecast period. Coal capacity continued to decline, with the Liddell coal power station closing its remaining three units (1 500 MW) in April 2023. Multiple large-scale battery projects were connected to the National Electricity Market in 2023, bringing utility battery capacity close to 1.5 GW and exceeding the capacity of pumped storage hydropower. Residential battery systems have been estimated at almost 2 GW.

In 2023, total renewables generation reached 35% of the electricity mix, consisting mainly of solar (15%), wind (12%) and hydropower (6%). The share of renewables is expected to reach 43% in 2026, surpassing coal for the first time and driving a steady decline in fossil fuel generation. Coal fell slightly from 49% of the mix in 2022 to 48% in 2023 and is expected to decline to 41% in 2026. The share of gas fell to 16% in 2023 and is forecast to drop to around 15% by 2026. The regional South Australian electricity market saw the share of VRE generation reaching 75% in 2023, which rose from 71% the previous year, and up from about 50% in 2019.

Due to the rising contribution of renewables and declining coal share, in 2023 Australia continued to see reductions in both total emissions (-5%) and emissions intensity (-4%). We expect emissions intensity to continue declining by around 5% annually on average to 2026, while total power sector emissions fall 3% per year on average.

In December 2023 Australia opened the first bids in its Capacity Investment Scheme, which was established at the end of 2022 to encourage investment in

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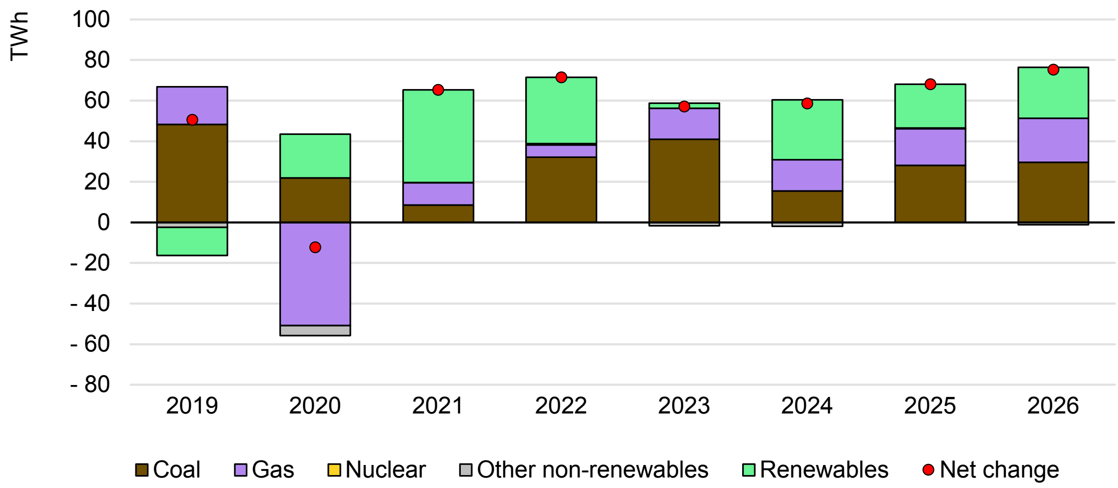
dispatchable renewable energy. Emissions reduction ambitions for electricity are also now reflected in law, with the inclusion of an emissions reduction objective in the National Electricity Objective.

Southeast Asia

Strong economic growth drives the region's electricity demand in the 2024-2026 outlook period

In 2023, electricity demand grew by 4.6% in Southeast Asia, down from 7% in 2022, and below the average 6% observed during the pre-pandemic period of 2015-2019. Electricity demand growth is forecast to accelerate to an average 5.3% from 2024 to 2026, supported by strong economic growth in the region via expanding industries and rising electricity consumption per household. Growth in Indonesia, the largest electricity consumer in region with a share of just below 30%, will underpin the gains, rising by an annual average of 6.3% in 2024-2026.

Year-on-year change in electricity generation in Southeast Asia, 2019-2026



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Notes: Other non-renewables includes oil, waste and other non-renewable energy sources. The figures for 2024-2026 are forecast values.

About 35% of the additional demand out to 2026 is expected to be met by generation from coal, 40% from renewables and 25% from natural gas. Coal-fired generation grew in 2023 by 7.5% and is forecast to continue growing by 4%, but at a slower pace compared to its 2015-2019 average 11%. Gas-fired output rose 4% in 2023 and is anticipated to increase on average by around 5% per year, well above the 1% growth observed in 2015-2019, driven by additional LNG availability from 2025 onward. Renewables are forecast to record an average growth rate of

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7% through 2026, but their share in generation rises only slightly, from 26% in 2023 to 28% in 2026.

Emissions from electricity generation are set to increase by an annual average rate of 4% through 2026. With a high share of fossil-fired generation, which is expected to remain relatively constant, the region is expected to continue to register a steady CO_2 intensity of around 600 g CO_2/kWh through 2026.

Indonesia

Coal retains dominance but growth of renewable electricity generation on track to rise rapidly to 2026

In 2023, the share of coal in total electricity generation in Indonesia rose to 66%, up from 65% in 2022 and 61% in 2021. Electricity demand posted a y-o-y increase of almost 7%, which was met mainly by coal power generation. Gas-fired power made up 13% of total generation, while renewable energy technologies accounted for 20% of the mix. This translated to an increase in total emissions of 6.8% y-o-y in 2023, with emissions intensity of generation reaching 790 g CO_2/kWh. Hydropower, geothermal and biomass make up almost all renewable electricity, with solar and wind still covering less than 1% of the total generation.

In the coming years, we expect that electricity demand will continue a steady rise of about 6% for the 2024-2026 period, in line with the strong economic growth forecast in the country. Growth in renewables is forecast at 8% per year in 2024-2026. Coal and gas-fired generation increase by around 5% and 6%, respectively, over the same period, and maintain a steady share in the electricity generation mix.

While current generation expansion programmes still show a continued deployment of gas and coal-fired technologies through 2030, the Comprehensive Investment and Policy Plan (CIPP), published at the end of November 2023 under the umbrella of the Just Energy Transition Partnership (JETP), shows a more ambitious trajectory for renewable technologies in the country. The plan, which is conditional on receiving financial support from the International Partners Group (IPG) and the Glasgow Financial Alliance for Net Zero (GFANZ), lays out a pathway for decarbonising the on-grid power sector by 2050. It includes a rapid expansion of solar and wind technologies, reaching 7.3 GW of deployment by 2025 and 72 GW by 2030. Under the JETP scenario, the on-grid electricity demand increases by a robust 6.4% annually from 2022 to 2030 and 5.8% from 2022 to 2050.

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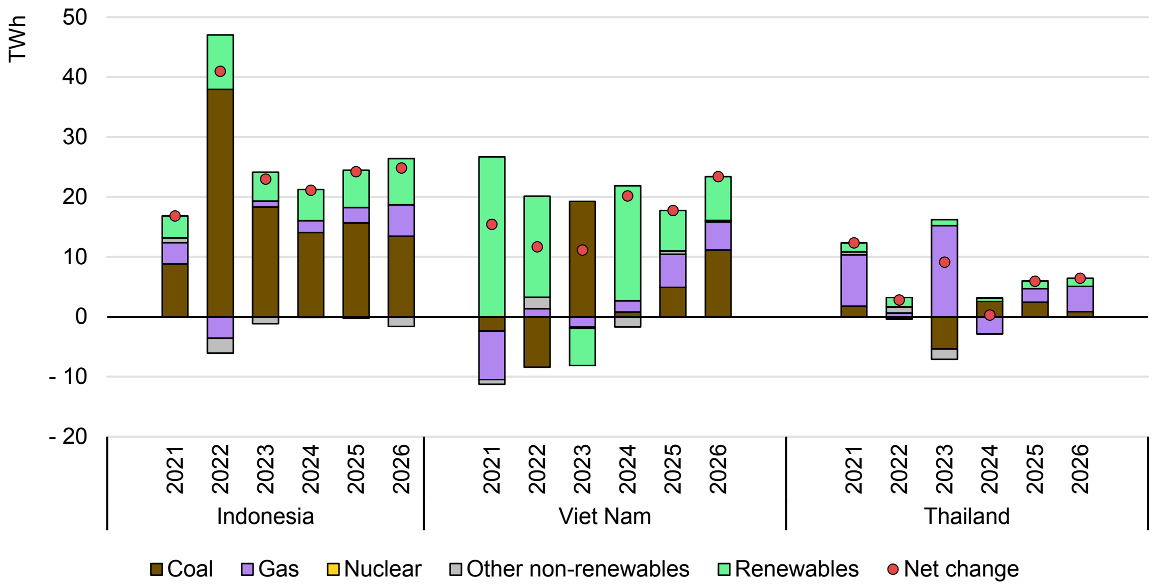
Year-on-year change in electricity generation in Indonesia, Viet Nam, and Thailand, 2021-2026



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Notes: Other non-renewables includes oil, waste and other non-renewable energy sources. The figures for 2024-2026 are forecast values.

Viet Nam

Strong electricity demand growth through 2026 is expected to go hand in hand with the accelerating economy

Viet Nam posted electricity demand gains of more than 4% in 2023, but we expect stronger growth of an average 7% from 2024 out to 2026, led by an accelerating economy. Around 2.7 GW of renewable capacity was added in 2023, fairly evenly split between solar PV and wind. We expect this trend to continue in similar amounts over our forecast horizon, supported by Viet Nam's power development master plan, which was approved in May 2023. It includes a target for generation from non-hydro renewable sources of 20% of the country’s electricity by 2030, with efforts to equip half of the office buildings and homes with rooftop solar panels expected to play a large part.

New renewable capacity additions will bring the share of non-hydro renewable electricity in total generation from 16% in 2023 to 19% in 2026, just shy of the target. The share of gas in total generation is expected to increase from 9% to 11%, while coal averages around 43% in 2024-2026, down from 46% in 2023. To meet demand growth, total generation from gas, coal and renewables are all expected to rise until 2026.

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Demand growth in 2023 was mainly met by coal generation. Renewable generation is estimated to have declined by around 5% y-o-y, falling to 44% of the electricity generation mix, largely due to a drought-induced hydro power shortage. This caused a power crisis in 2023, where peak load in July exacerbated by a heatwave could not be met due to reduced water levels in several hydropower reservoirs. Generation from gas is estimated to have decreased by 6%.

Due to its high reliance on domestic hydropower and high gas prices, Vietnam had to significantly ramp up coal-fired generation in 2023, increasing its average CO_2 intensity of electricity generation by 11%. This level is expected to fall in 2024 by 6% on an assumed rebound in hydro availability as well as higher PV and wind generation. Interconnection is seen as a key mechanism to smooth out these variations.

During the power crisis, Northern Viet Nam suffered rolling blackouts and sudden power outages, with an estimated peak demand and supply deficit of 1.8 GW and cost of USD 1.4 billion. During this power crunch, Viet Nam received support from China, which resumed cross-border electricity exports to the country for the first time since 2016. Given the structure of the Vietnamese power grid, the exposure of the northern region is particularly acute. According to the Ministry of Industry and Trade, in 2024 Vietnam's northern region is likely to face a power shortage of up to 1.8 GW. Against a backdrop of a strong rise in annual power demand, Northern Viet Nam may continue facing power shortages in the coming years.

In 2022, the state utility recorded a loss of VND 20.7 trillion (USD 874.5 million) due to rising fuel production prices. In the first half of 2023, the losses rose to more than VND 35.4 trillion (USD 1.46 billion), according to a report by the Ministry of Planning and Investment.

Thailand

Energy security concerns sharpen the focus on boosting domestic natural gas production to support gas-fired power generation

Electricity demand in Thailand rose by around 3% in 2023. Natural gas-fired generation increased by almost 13%, whereas coal-fired output decreased by 14%. Renewable generation grew by 3%. As a result, CO_2 intensity of the power sector declined from 470 g CO_2/kWh in 2022 to 452 g CO_2/kWh.

Supported by economic growth, electricity demand in Thailand is forecast to rise at an average annual rate of 3% from 2024 out to 2026. Growth is expected to be met by increased supply from coal, gas and renewables. Currently, gas supplies around 65% of the electricity mix, coal 18% and renewables 17%. By 2026, the

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share of coal is expected to rise by two percentage points while gas decreases by two percentage points, and renewables grow slightly. This corresponds to growth in both emissions and intensity through the forecast period.

Thailand gets more than 60% of its electricity from natural gas and has been increasing imports to meet demand. Recent increases in LNG prices have triggered concerns of another gas and power crisis. Despite this, the cabinet decided in September 2023 to reduce the electricity rate as a means to lower the cost of living.

There is a call to expand reserves and production at domestic gas fields to boost the country's energy security. State-controlled PTT Exploration & Production plans to double gas production at Erawan, its biggest field, to 800 million cubic feet per day in early 2024. Imported LNG accounted for about 29% of the gas used in power generation in 2022, more than double the share in 2018, according to data from the Energy Regulatory Commission.

Additions to the 3.4 GW of solar PV and 1.5 GW of wind power were limited in 2022 while solar capacity increased around 400 MW in 2023. The largest source of renewables in Thailand is bioenergy, with a more than 50% share of renewable electricity generation. Achieving the national target for carbon neutrality requires renewable electricity to reach 68% of power generation by 2040. Growth out to 2026 is expected to come predominantly from solar PV, with some wind.

Feed-in tariffs are offered for small power producers in specific parts of the country, as well as PPAs for commercial scale projects, in order to reach a quota for renewable electricity projects. However, the Thai Energy Regulatory Commission has said that there is potential for faster growth of rooftop solar if the government enacts policies to encourage private sector uptake.

Thailand's Power Development Plan (PDP) is typically updated or revised every few years, with the most recent revision published in 2020 (PDP 2018 Revision 1). The upcoming update remains under discussion to ensure the balance between accelerated deployment of distributed variable renewables and measures to ensure that grid integration capabilities are adequately captured.

Malaysia

Gas-fired power generation is expected to overtake coal in 2026, while hydropower dominates growth in renewables

In 2023, electricity demand in Malaysia is estimated to have grown around 3% year-on-year. While the economic growth slowed down from the 2022 highs of a GDP growth of above 8%, economy is estimated to have grown robustly by almost 4%, which supported electricity demand. The completion of several new

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semiconductor plants and data centre investments in 2024 are expected to boost electricity demand in the following years. We forecast average annual electricity demand growth of 3.4% through 2026.

Coal-fired power generation accounted for around 46% of Malaysia's generation mix in 2023. The government's National Energy Transition Roadmap (NETR) aims to reduce reliance on coal by increasing the use of gas and renewables. We expect the growth of coal-fired power generation to almost plateau by 2026, while gas-fired power grows steadily and overtakes coal generation in 2026. After having increased by 1% in 2023, emissions intensity is forecast to fall by around 1.5% annually on average from 2024 to 2026, due to the declining coal share. Growing fossil-fired generation is expected to increase total power sector emissions by about 2% per year on average.

The Malaysian government has set a new target of 70% renewable energy in the power generation mix by 2050. Efforts to accelerate renewable energy investment include increasing the green energy tariff, ten initiatives in the NETR and removing barriers to renewable energy growth. In addition, the ban on renewable energy exports was lifted in 2023 to encourage investment in local renewable resources.

Malaysia is driving electrification of its transport sector and strengthening co-operation with neighbouring countries as part of the National Energy Transition Roadmap. Tenaga Nasional Berhad, the country's largest utility, is working with various stakeholders on developing 500 MW Large-Scale Solar Parks (LSSP), 2.5 GW Hybrid Hydro-Floating Solar (HHFS), and co-firing hydrogen and ammonia projects to diversify its energy portfolio and progress towards net zero carbon emissions by 2050.

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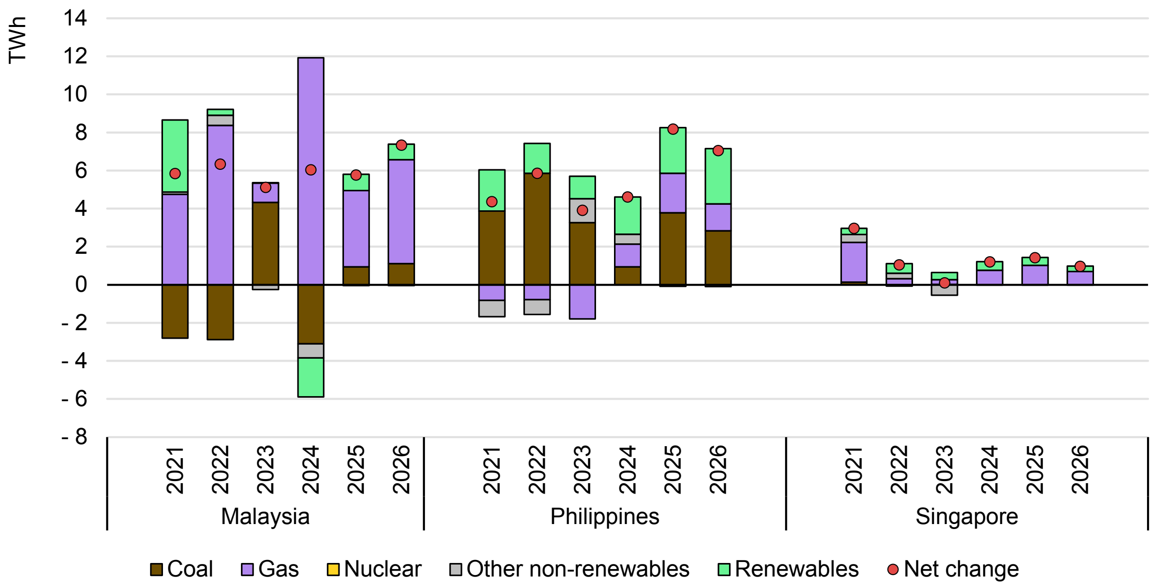
Year-on-year change in electricity generation in Malaysia, Philippines, and Singapore, 2021-2026



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Notes: Other non-renewables includes oil, waste and other non-renewable energy sources. The figures for 2024-2026 are forecast values.

Philippines

Robust economic growth fuels higher coal-fired power generation to meet strong demand for electricity

GDP growth in the Philippines is estimated at 5.3% in 2023, despite global macroeconomic challenges and high inflation. The gains largely reflect high household consumption and public spending on infrastructure and social services. As a result, electricity demand posted strong growth of about 4% in 2023, and is forecast at a higher annual average rate of 6% from 2024-2026, underpinned by continued robust economic activity.

In 2023, coal-fired generation increased by an estimated 5%, and is forecast to continue to grow at an annual average rate of 3.4% from 2024-2026. The share of coal in the generation mix is set to decline gradually, from 61% in 2023 to 58% in 2026. Despite some efforts to gradually phase out coal, including the moratorium on new coal plants in place since 2020 and signing the coal exit at COP26, the country ranks sixth in the world in 2022 for new coal capacity. Coal generation will continue to increase during the outlook period, with almost 3.5 GW of capacity in construction coming online. Nevertheless, coal capacity additions are expected to fall in the future as new projects will not be added to the pipeline. As coal generation increases, total emissions rise around 4% annually during 2024-2026.

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Emission intensity decreases by 1.5% per year as the share of coal declines with growing renewables and natural gas-fired generation.

Gas-fired output is forecast to rise by almost 9% on average from 2024-2026, resulting in a slight increase in its share of the electricity mix from 14% in 2023, to 15% in 2026. Various efforts are being made by the Philippines to promote the use of natural gas as a transition fuel, including the proposed Downstream Natural Gas Industry Development Act, which would offer tax incentives for gas development, as well as a draft circular clarifying the policy framework for development of generation facilities in the Luzon grid.

The Philippines is targeting 35% renewables in its electricity mix by 2030. In 2023, the share sat at around 23%, and it is forecast to grow by close to 8% per year on average from 2024-2026, bringing its share in electricity to 25% in the same period. This increase is mostly driven by solar and wind, whose share in the electricity mix more than doubles from 3% in 2023 to 7% in 2026. Measures in place to support growth in renewables include the Green Energy Option Program, which enables consumers with sufficient load and metering to directly procure renewables, and allowing 100% foreign ownership of renewable assets, since December 2022.

Singapore

Significant progress in the approval of the planned regional interconnection projects was achieved

Singapore's electricity demand rose by less than 0.5% in 2023, down from 2% in 2022. For 2024-2026, we expect demand to increase by an average 2%, in line with economic growth. EVs will account for an increasing share of new electricity demand, with the country planning to phase out the purchase of combustion vehicles by 2030.

Natural gas made up around 93% of Singapore's generation in 2023 and its share is expected to decline to 92% in the coming years as clean sources increase, despite average annual growth of gas-fired electricity around 1.5%. Renewable generation is forecast to reach 6% of the generation mix in 2025, mainly from solar PV and biomass. Solar PV generation sees nearly 15% annual average growth for 2024-2026 due to ongoing capacity additions. New gas-fired capacity is also coming online, with construction started in July 2023 on a 600 MW advanced combined-cycle gas turbine power plant in Jurong Island, and expected to be completed in the first half of 2026. The plant will initially run purely on natural gas but is designed to co-fire with up to 30% hydrogen and can be converted to run entirely on hydrogen.

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Singapore's emission intensity fell by 2.2% in 2023, driven by increased renewables and a decline in oil-fired generation, which saw a spike in 2022 due to high gas prices. We expect a continued decrease in intensity over the forecast horizon at around 0.7% per year.

During 2023, the Singapore Energy Market Authority (EMA) announced conditional approval for multiple interconnection projects under a Request For Proposal process, initiated in 2021, aiming to reach an import target of 4 GW of low-carbon electricity by 2035. These include projects amounting to 2 GW from Indonesia, targeted for completion in the next five years, 1 GW from Cambodia and another 1.2 GW from Viet Nam, which would total more than half of Singapore's current peak demand. These significant regional integration projects are expected to build on the success of the existing 100 MW Lao PDR-Thailand-Malaysia-Singapore Power Integration Project that allows Singapore to import hydropower from Laos via Thailand and Malaysia, operating since 2022.

Due to the high dependency on natural gas, electricity prices in Singapore have experienced substantial volatility due to spikes in global fuel prices and gas supply disruptions. In addition to measures including a standby LNG facility and a temporary price cap, in October 2023 Singapore's Minister for Trade and Industry announced that an entity will be established to undertake centralised procurement of gas for the power sector, which the EMA expects to set up in 2024.

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Americas

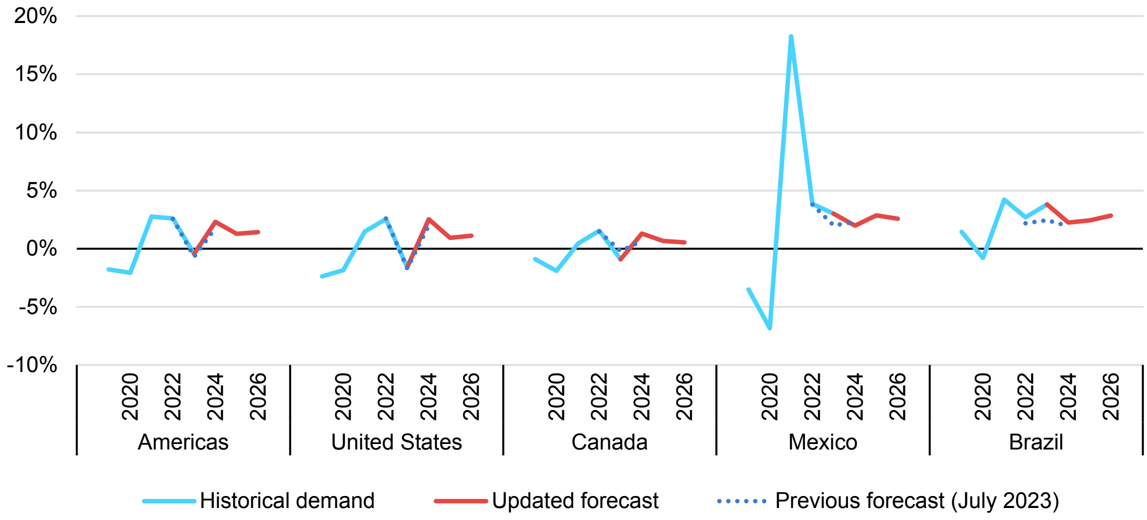
Strong growth in renewable power increasingly displaces fossil-fired generation

Electricity demand is estimated to have declined by 0.4% in 2023, largely because of fall in US demand due to milder weather bringing down the average. By contrast, Brazil and Mexico posted robust demand growth. From 2024-2026, we forecast electricity demand to increase on average by 1.7% per year in the region.

Renewable generation is forecast to grow annually by 7% on average over the outlook period. The increase in renewables is set to more than offset the additional electricity demand and displace coal-fired generation, which is expected to record a substantial 10% decline on average from 2024-2026. The United States dominates these developments, where around two-thirds of the electricity in the Americas is produced and consumed.

Due to strong growth in renewables, the share of fossil fuels in electricity generation is expected to fall from 50% in 2022 to 44% in 2026. Emissions of electricity generation in the Americas are set to decline by 4% per year on average over the forecast period, and its emissions intensity will fall to 235 g CO_2/kWh in 2026, down from 280 g CO_2/kWh in 2023.

Year-on-year percent change in electricity demand, Americas, 2019-2026



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United States

Milder weather led to lower electricity demand in 2023, but growth resumes as electrification accelerates to 2026

Despite the US economy growing at an annualised rate of above 3% in the first three quarters of 2023, including 4.9% in the third quarter, electricity demand declined by 1.6% for the year compared to growth of 2.6% in 2022. Electricity use was curbed due to milder weather across many parts of the country compared to 2022 in both in the summer and winter months, reducing heating and cooling demand. In addition, manufacturing activity fell despite growth in the overall economy, amid a drawdown of inventories, strikes in the automotive industry and overall inflationary pressures. The number of heating degree days (HDDs) in the first quarter, typically the peak period of heating demand, was more than 10% lower in 2023 than in 2022, with the Northeast and Midwest regions particularly below average. In the third quarter, cooling degree days (CDDs) in these peak months for cooling demand were 1.5% below the level in 2022.

From 2024 to 2026, we expect a return to growth in electricity demand of 1.5% on average, fuelled by increased manufacturing activity and electrification in the transportation and building sectors. Around one-third of the additional demand out to 2026 is expected to come from the rapidly growing data centre sector alone. Projects supported by the US government's 2022 Inflation Reduction Act (IRA) and the Bipartisan Infrastructure Law (BIL) through special financial vehicles, grants, tax credits, loan guarantees, among other incentives, are assumed to accelerate over our forecast period. These initiatives enable households and commercial businesses to monetise IRA tax credits, loans and rebates for the installation of electric heat pumps, water heaters, and other energy saving electric appliances. In September 2023, governors from 25 states, under the umbrella of the U.S. Climate Alliance, and the Biden administration announced plans to quadruple the number of heat pumps in US homes by 2030, from 4.7 million to 20 million.

The IRA and BIL supported significant investments in the power sector, with USD 110 billion for clean energy manufacturing projects, of which more than USD 70 billion was for the electric vehicle (EV) supply chain as of August 2023. A further USD 125 billion has been awarded for clean energy generation projects. As of November 2023, the BIL awarded funding for 44 000 major infrastructure projects across the 50 states, including spending on electricity grid reliability and resilience. The IRA also launched the Energy Infrastructure Reinvestment (EIR) Program (section 1706) that guarantees loans for projects that aim to retool, repower, repurpose, or replace energy infrastructure or to improve the efficiency of existing energy infrastructure.

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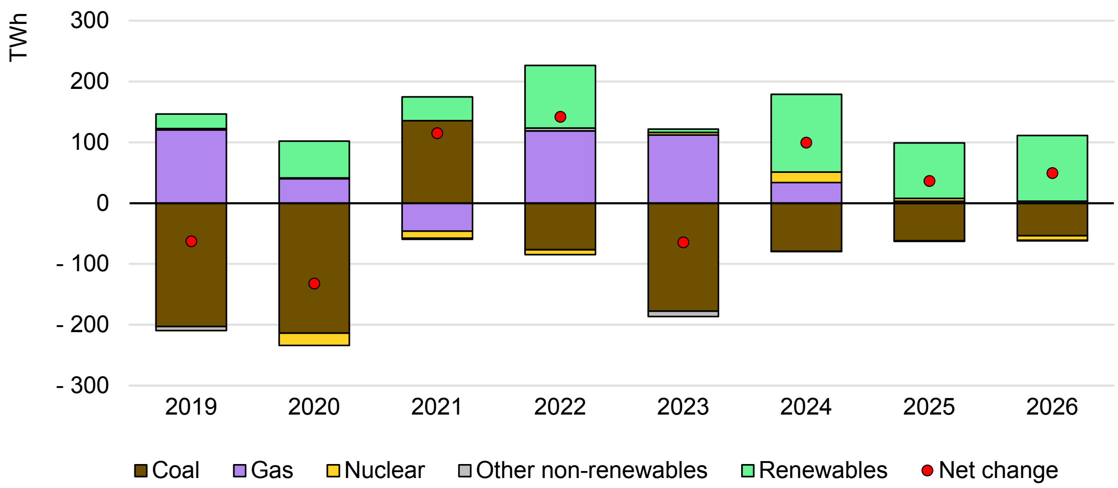
Gas gained at the expense of coal, while renewable output was below average in 2023

Gas-fired generation increased by 6.4% in 2023 compared to 7.3% in 2022, as prices tumbled. Gas prices declined steeply at the benchmark Henry Hub in 2023, from around USD 6/MBtu in 2022 (the highest level since 2008) to a low of USD 2.15/MBtu in May 2023 due to strong growth in domestic production and mild weather. The rise in gas-fired generation came largely at the expense of coal-fired generation, which declined by 7.7% in 2022 and 19% in 2023 as the decrease in the cost of gas encouraged fuel switching. Capacity factors of coal plants declined from 52% to 42% in the period while gas combined-cycle plants increased from 55% to 59%. In addition, around 30 GW of coal-fired capacity was retired since the start of 2022, owing to the ageing fleet (average age of 43 years) as well as more stringent state and federal environmental regulations. The share of gas in the electricity mix reached a record of 42% for 2023, while coal declined to 17%. This continues the long-term trends for both fuels, as gas and coal's shares were 24% and 40%, respectively, in 2011.

Year-on-year change in electricity generation in the United States, 2019-2026



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Notes: Other non-renewables includes oil, waste and other non-renewable energy sources. The figures for 2024-2026 are forecast values.

Growth in renewables generation was muted by unfavourable weather conditions, particularly for wind, despite significant new installations. Wind generation was almost the same in 2023 as in 2022 despite an increase of around 8 GW of capacity. In addition, output from hydro power plants was down 4.4% as rapid spring snowmelt caused by record high temperatures in the Northwest depressed output in the region, which accounts for around 50% of US hydropower capacity.

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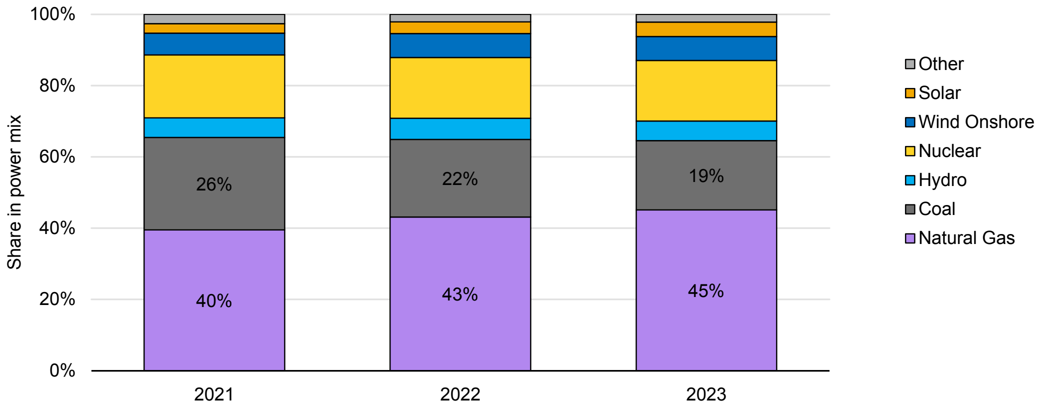
Solar PV generation increased by 16%, driven by new installations at both grid-scale (26 GW) and distributed generation (8 GW) levels.

Power generation share in the United States in July and August, 2021-2023



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Source: IEA analysis based on official data from country and national regulatory authorities.

Nuclear output increased slightly as Plant Vogtle Unit 3 entered commercial operation in July 2023, ten years after the start of construction. Unit 4 is expected to follow in 2024. Developers Utah Municipal and NuScale Power agreed to cancel their small modular reactor (SMR) project that was planned for construction in Idaho after not meeting the target subscription level of 80% of the project's output.

Solar PV and wind generation are set to surpass coal-fired generation in 2024, marking a milestone

Installations of wind and solar are expected to increase renewable generation by around 10% annually between 2024 to 2026, although financing and supply chain issues are causing delays and cancellations of some projects, particularly for offshore wind. Solar and wind generation are expected to surpass coal-fired generation in 2024. Coal output is expected to fall by almost 10% per year over the 2024-2026 period as retirements continue, although at a slower pace than seen in 2022-2023. Gas output will be mostly unchanged, as new capacity additions will replace retiring units and moderately low gas prices will keep the variable cost of gas-fired generation competitive with coal. As a result of the increase in renewables and decline of coal, total power sector emissions and emissions intensity are expected to decline at annual rates of 4% and 5%, respectively, between 2023 and 2026.

Reliability concerns for winter

A large portion of the United States is at elevated risk of insufficient electricity supply during peak winter conditions according to the North American Electric

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Reliability Corporation (NERC), as reserve margins have declined in many areas. A replay of the prolonged cold snaps, like Winter Storm Uri in the South-Central states in February 2021 and Elliott in December 2022, which caused significant load shedding, threaten to reduce gas-fired generation while also compromising fuel delivery, particularly in regions where facilities are not designed for such conditions. Load forecasts also become highly uncertain and complex, and underestimating demand is cited as a reliability risk. Wide area events like Elliott would reduce transfers from neighbouring regions.

Canada

Electricity demand returns to growth in the 2024-2026 outlook, with higher gas-fired generation to offset the fall in nuclear

In Canada, a milder winter offset a warm and dry summer, contributed to a decline in electricity demand of 1% in 2023. We expect demand will increase by around 1% per annum over the next three years.

Hydropower, which contributes more than half of electricity supply in the country, fell by almost 7% due to reduced supply from snowmelt as a result of the mild winter. This in turn caused Canada to reduce electricity exports to the US by around 15% from Quebec and 30% from British Columbia in the first half of the year.

Nuclear generation is expected to increase by around 4% in 2024 before falling by around 10% in 2025 and 16% in 2026 as additional units will be taken offline for the ongoing refurbishment programmes at Bruce (6.2 GW) and Darlington (3.5 GW) nuclear stations. Each unit will be offline for around three years for the work, which will extend the units lifetimes by 30 years. The Pickering station (3.1 GW) is expected to close Units 1 and 4 when their operating licences expire at the end of 2024, although the Ontario provincial government had announced intentions to seek a licence extension through 2026 for Units 5-8, citing tight reserve margins.

The decline in nuclear output is replaced by a combination of gas-fired generation and renewables. As a result, overall emissions from electricity generation are expected to rise by 6% in 2025-2026. In August, construction began on a 1 250 MW converter station for the Champlain Hudson Power Express transmission line that will bring power from Quebec to New York City. It is expected to start operating in 2026.

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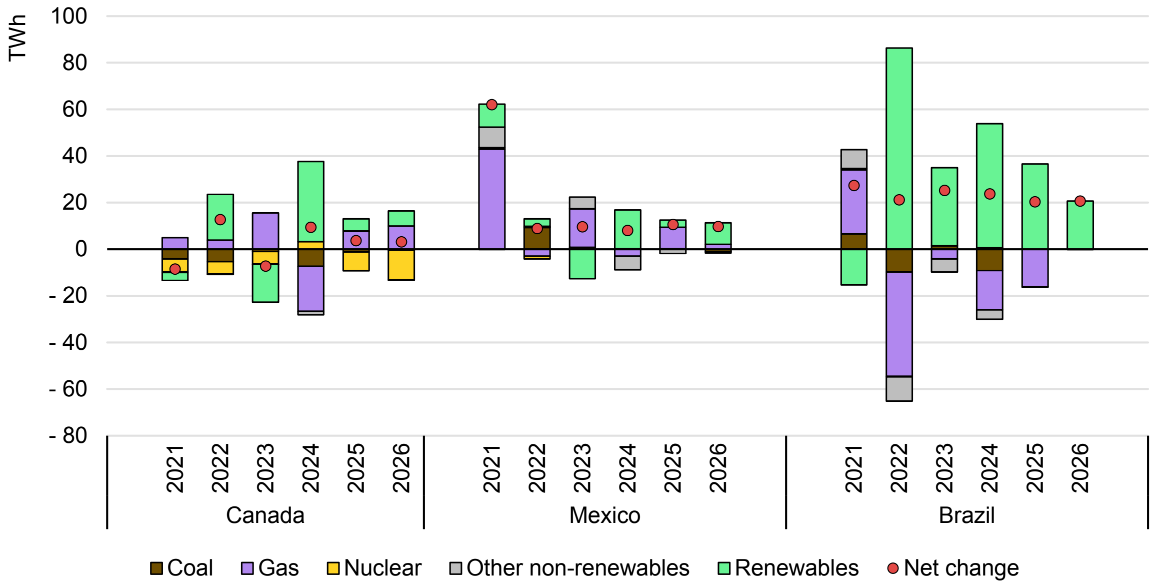
In November, Prime Minister Trudeau's government exempted home heating oil from the federal carbon tax programme (currently CAD 65/t CO_2) for the next three years, owing in part to a recent doubling in the price of oil. This was twinned with additional incentives to switch from heating oil to electric heat pumps.

Year-on-year change in electricity generation in Canada, Mexico, and Brazil, 2021-2026



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Notes: Other non-renewables includes oil, waste and other non-renewable energy sources. The figures for 2024-2026 are forecast values.

Mexico

Hydropower generation fell to record lows in 2023 due to drought, pushing up oil and gas-fired output

In 2023, electricity demand in the country grew at rate of 3% y-o-y, closely following the economic growth rate of an average 3.2%. Strong growth in the industrial sector, services industry and agricultural all combined to boost power demand. We expect that electricity demand will maintain stable growth of 2.5% for the period 2024-2026. This is a lower overall annual growth rate than that seen in the past two years as the country was rebounding from the effects of the Covid-19 pandemic, however, it will still closely follow economic activity in the country.

Electricity demand and economic growth will be supported by a requirement for a higher percentage of regionally commercialised products to be manufactured within the region (regional value-content requirements) in the US-Mexico-Canada Trade Agreement (USMCA), and nearshoring. Nearshoring is a strategy in which companies move part of their production closer to the final consumer, thereby

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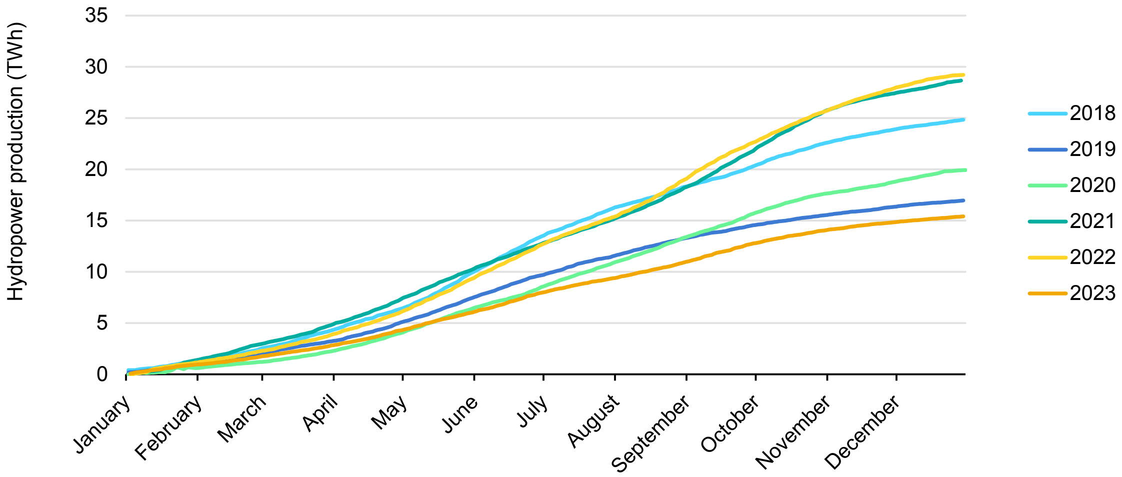
reducing costs and logistical setbacks. The impact of nearshoring will likely unfold gradually in coming years, and steadily increase electricity demand in the forecast period.

Hydropower makes up about 40% of Mexico's renewable energy supply and is an important source of generation during the peak summer season, as well as providing flexibility and backup power when other sources of generation are disrupted. However, recent multi-year droughts have compromised its availability. During summer 2023, an operational alert was issued as a result of a period of low operating reserves (below 6%) but CENACE, the national ISO, later clarified that electricity supply was not at risk. The situation was due to a sudden increase in peak demand – 9% higher than that recorded in 2022 (52.9 GW) – and low hydro availability.

Despite higher electricity demand, the cumulative annual hydropower generation in 2023 was more than 40% lower than that for 2022 and 2021, and 9% lower than that of 2019 – the year with the lowest hydropower generation in recent history. The available alternatives to cover the reduction in hydro generation require more expensive fuel sources, such as natural gas that is mainly imported, diesel or fuel oil, which could ultimately result in higher electricity production costs.

Cumulative yearly hydropower production in Mexico, 2018-2023



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Source: IEA analysis based on data from Sistema de Información de Mercado.

In 2023, the emissions intensity of the power sector rose by about 4% y-o-y, reaching 446 g CO_2/kWh due to lower hydropower generation. An increase in natural gas, nuclear, solar and wind production combined to substitute for the loss of hydropower. The growth of solar and wind in Mexico are expected to be limited

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to those projects previously committed in auctions, which were halted in 2019. These projects will push the share of solar and wind in total electricity generation from 10% in 2023 to 13% in 2026.

Along with increased solar and wind power, gas-fired generation falls from 59% to 57% while coal's share declines from 7% to 6%, which combined lead to a reduction in power sector emissions intensity of almost 3% per year for 2024-2026.

Brazil

Solar and wind output rise by a combined 50% in 2026, and new transmission lines are set to transform the power sector

Electricity demand in Brazil rose by about 4% in 2023, compared to 2.7% in 2022, largely reflecting robust economic activity and higher consumption in the buildings sector. The largest absolute growth in 2023 came from the northern subsystem, due to higher average temperatures and increased electricity access. Notably, on 13 November 2023 the country's interconnected system reached record-high instantaneous demand above 100 GW. On that day, a heatwave pushed up air cooling needs, particularly in the Southeast/Centre-West subsystem, which reached its own record high (61 GW).

Capacity factors of hydropower in Brazil had fallen from an average 56% in 1990-2021 to 42% in 2017-2020, and to a record low 38% in 2021 – its lowest level at least since 1990. Severe droughts in 2021 had caused water shortages and power cuts. In 2022, hydropower generation recovered, rising by 17% year-on-year, and recording an average capacity factor of 44%. In 2023, hydro capacity factor was again about 44%, with generation increasing by 1%. At the same time, gas-fired generation declined by 10%, whereas coal-fired output increased by 10%.

Electricity demand in Brazil is forecast to increase at an average 2.5% per year in 2024-2026 compared to 2.2% over the 2018-2023 period. Growth is supported by continued brisk economic activity and higher residential consumption. The rural electrification programme *Luz Para Todos* (Light for All), which has benefited over 18 million people since its creation, celebrated its 20th anniversary in November 2023. It will include up to 2 million more people by 2026, providing an additional boost to electricity demand growth.

Out to 2026, we expect most of new electricity demand in Brazil to be met by wind and solar PV. In our forecast, combined wind and solar PV generation in 2026 will be almost 50% more than that of 2022, reaching over 200 TWh, and achieving a combined generation share of almost 30% (up from around 20% in 2023). With this, total renewable generation in Brazil will account for about 95% of the electricity mix in 2026. Considering the growing high share of renewables in the

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system, which includes over 20 GW of distributed power capacity currently, Brazil's Ministry of Mines and Energy opened a public consultation in November 2023 to validate a mechanism to reduce thermal plant contractual inflexibility in times of excess supply. The measure would allow thermal power plants to make offers to the system to reduce their inflexible generation.

Complementary to grid expansion, electricity storage has been considered an enabling solution for higher wind and solar PV integration. For instance, in March 2023, the first large-scale battery system (30 MW/60 MWh) in Brazil was deployed in the State of Sao Paulo for grid reinforcement. In October 2023, the electricity regulator opened a consultation on regulatory solutions for the grid connection of storage systems, with topics under consideration such as the definition of the grid capacity to be contracted by storage systems and the network usage tariffs.

Other announcements on grid development in 2023 are set to transform Brazil's power sector in the coming years. In June, the first transmission auction of the year was awarded for a total BRL 15.7 billion (around USD 3 billion), in line and substation investments, with one project expected to be commissioned within 36 months. A second auction – the largest ever by the regulator – awarded three lots worth a total BRL 21.7 billion (around USD 4 billion) for transmission lines in December 2023. The new lines will raise renewable generated power in the northeast, which has both abundant sunshine and wind, to increase supplies to the southern demand region of the country. China's State Grid was awarded the lion's share of the contracts in largest-ever electricity transmission line auction, and already holds 24 transmission concessions, 19 as sole operator and five in joint ventures, and overall operates more than 16 000 km of power lines in Brazil.

Other Americas

Electricity demand in **Chile** in 2023 rose by less than 1% year-on-year, mirroring flat economic growth. A highlight in 2023 was the record share of more than 60% of renewables in the electricity mix. Thanks to strong rainfall, hydropower output was around 10% above the 2018-2022 average. Additionally, solar PV and wind provided around one-third of generation in 2023, reaching hourly shares of over 70% in the national power system in more than 30 hours throughout 2023. For the 2024-2026 period, we expect an average growth in demand of 2.4% per year. The corresponding rise in electricity demand will be more than met by increased solar PV and wind generation, which combined are expected to rise by around 15% per year on average, based on the current pipeline of projects. This would push both gas and coal-fired generation down rapidly, to around one-third of the 2023 level in 2026, bringing power generation emissions intensity below 100 g CO_2/kWh. Chile has a coal-power phase-out plan by 2040 at the latest.

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The public agenda of the Chilean power sector in 2023 was centred around electricity tariffs and reforms to advance infrastructure development. The tariffs for consumers were first frozen in 2019, to avoid price increases against a background of social unrest. In 2023, the government abolished the “winter tariff” for certain user segments. This means that a surcharge on the price will not be applied anymore during autumn and winter months, aiming to reduce household energy expenditure and to foster electrification of heat. On the other hand, in the context of the high levels of VRE curtailment, the government proposed measures to improve market conditions for renewable projects. These measures include redistribution of congestion income for renewable projects affected by congestion, a tender for additional battery storage capacity (more than 500 MW is under construction), and updated transmission planning. These actions are part of the “Initial Agenda for the Second Phase of the Energy Transition”, which is meant to be implemented by 2024. Further, the 2 x 1.5 GW high-voltage direct current (HVDC) transmission line project Kimal-Lo Aguirre, set to connect solar-rich areas with large load centres, started the environmental permitting process, and is expected to be operational before the end of this decade.

In **Colombia**, electricity demand grew by around 3% year-on-year in 2023, below the post-covid rebound rate of 4.7% in 2022. The impacts of the El Niño Southern Oscillation, the cycle which began in May 2023, threaten to reduce hydropower generation until around May-June 2024. In November, Colombia, which relies heavily on hydropower at about 70% of its annual electricity generation, officially announced the start of El Niño in the country, with the potential for much higher temperatures and droughts, warning this can potentially lead to higher electricity prices and stronger electricity demand from increased cooling needs. This weather phenomenon typically reduces rainfall in Colombia, leading to drought conditions which can severely affect water supplies, impacting hydropower generation. For 2024-2026, we expect demand to grow by around 3% per year, and most of that additional supply to be met by renewables. Wind and solar PV still only account for under 2% of generation.

There were several important developments to note in the Colombian electricity sector in 2023. Due to power outages in Ecuador in early October as a result of the dry period caused by El Niño, Colombia agreed to increase cross-border exports (coming from thermal units) to enhance Ecuador’s electricity security.

In June, the government published Decree 0929, which, among other aspects, mandates the regulator to design market mechanisms for demand response, for the remuneration of small-scale generation energy excess and for the update of the wholesale price formation process. These measures aim to promote efficiency and competition in the provision of power. Although the decree does not directly modify the electricity tariff structure, it provides guidelines for the upcoming work of the regulator. Further, after tariffs were frozen during the Covid-19 pandemic,

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which has put financial pressure on several electricity suppliers, the government enabled a COP 1 billion credit line (around USD 230 million). This is aimed at guaranteeing that these companies can keep providing power to end users.

Costa Rica's electricity demand rose more than 2% in 2023, in line with economic growth. The impacts of El Niño led to lower hydropower output over the year, resulting in thermal generation to account for more than 5% of the 2023 electricity mix – moving Costa Rica's power system away from its typical renewables share close to 100%.

Concerns over demand-supply imbalances during the summers of 2024-2026 related to uncertainty over hydropower output have emerged. Near term, in anticipation of the impact of curtailed hydropower output from El Niño in the summers of 2024-2026, the national electricity company ICE procured 140 MW of additional thermal power. This measure, aimed at ensuring sufficient electricity supply, had a total cost of CRC 82 million.

In 2023 the government of Costa Rica also focused on market and regulation reforms. In October, a proposed law (project 23 414) seeks to increase competition in the electricity market, harmonise the regulatory framework and create an independent system operator, among other measures.

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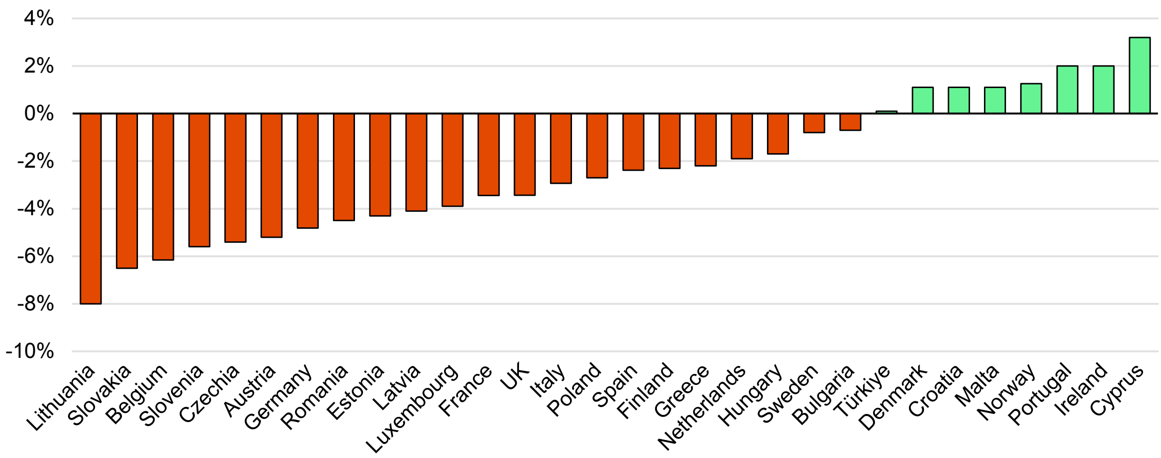
Europe

A slowdown in manufacturing and industrial activity reduced electricity demand in 2023

Electricity demand in Europe declined by 2.4% y-o-y in 2023, following a 3.6% fall in 2022. In the majority of EU countries, electricity demand decreased amid the sluggish macroeconomic environment and weak manufacturing and industrial activity. However, different demand trends were observed across the region. In the southern part of the continent, Portugal, Croatia, Cyprus[1] and Malta saw increases in their electricity consumption. Whereas the summer of 2023 was hotter in Portugal and Cyprus[1] compared to 2022 supporting demand growth, it was cooler in Malta, indicating non-weather-related factors drove the demand there. Ireland, Denmark and Norway in the north also saw significant growth, which are seeing rapid expansion in the data centre sector. Nevertheless, while the winter was milder in Ireland (as well as in Europe overall), it was colder in the Nordic countries boosting space heating needs.

Year-on-year percent change in electricity demand in Europe, 2023 vs 2022



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[1] Note by the Republic of 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 the United Nations, Türkiye shall preserve its position concerning the "Cyprus issue".
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.

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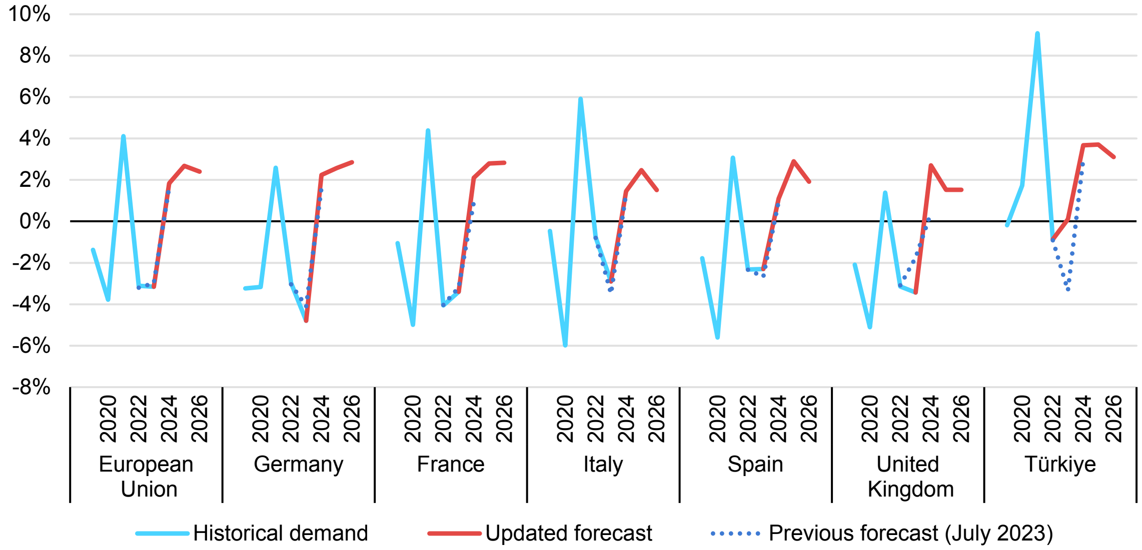
We expect electricity demand to grow by 2.4% per year on average over the 2024-26 forecast period in Europe, supported by a gradual recovery in the industrial activity, further electrification of the heating and transport sectors and the expansion in the data centre sector.

Weaker growth in European electricity demand in 2023 led to a decline in fossil-fired power, with generation from gas (-16%) and coal (-19%) down substantially. At the same time, renewable generation grew by 9%. Hydropower generation in the European Union rose by 16% from 2022, which was affected by droughts. By contrast, Türkiye continued to see below-average hydropower generation due to droughts in both 2022 and 2023, and fell by a further 4.5% last year. We expect European renewable generation to grow by 14% in 2024, led higher by the assumed recovery in hydropower output in Türkiye, followed by an average growth rate of 6.6% over the 2025-26 period as wind and solar PV capacities continue expanding. Electricity generation from coal in Europe is forecast to continue declining by a further 10% per year on average and gas by 6%. Power sector emissions are expected to fall on average by 9% per year, with CO_2 intensity of power generation similarly declining at an average rate of 11%, from about 223 g CO_2/kWh in 2023 to 157 g CO_2/kWh in 2026. Europe will remain among the regions with the lowest CO_2 intensity of power generation.

Year-on-year percent change in electricity demand in Europe, 2019-2026



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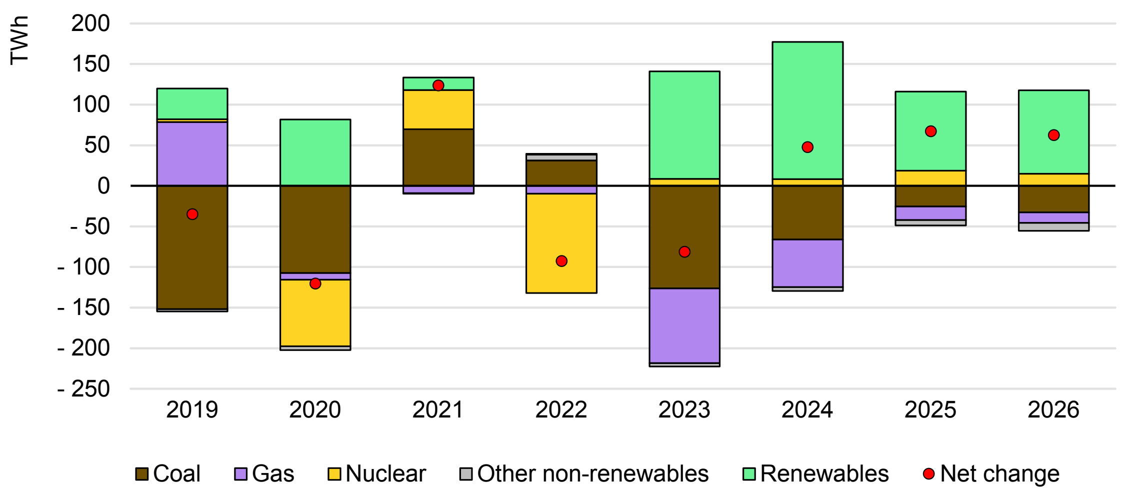
European Union

Clean electricity share in generation is set to surpass 75% in 2026, rapidly reducing the CO_2 intensity of electricity supply

Following two consecutive years of electricity demand decline in the EU (-3.1% in 2022 and -3.2% in 2023), we expect demand to rebound by 1.8% in 2024, followed by an average 2.5% growth during the 2024-2026 period. Demand is not expected to return to 2021 levels until 2026 at the earliest. An anticipated gradual recovery in the industrial sector accounts for 40% of incremental demand, while the growth in electric vehicles, heat pumps and data centres accounts for 50%.

Over the outlook period, renewable generation is expected to grow at an average rate of around 9%, offsetting all of the additional electricity demand and displacing fossil-fired generation. Coal-fired power fell by around 26% in 2023 and is set to decline at an average 13% from 2024 to 2026. Gas-fired generation fell by 17% in 2023, and is forecast to decline by a further 7% annually to 2026. Nuclear output rose 1.4% last year and is forecast to grow by 2.2% annually to 2026, as the maintenance schedule of the French nuclear fleet progresses, and the reactors Flamanville-3 (France) and Mochovce-4 (Slovakia) commence operations according to announced plans. The share of renewables in generation is set to rise from 45% in 2023 to 50% in 2024 and to about 55% in 2026. The share of low-emissions supply – renewables and nuclear – is expected to increase from 67% in 2023 to 77% in 2026.

Year-on-year change in electricity generation in the European Union, 2019-2026



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Notes: Other non-renewables includes oil, waste and other non-renewable energy sources. The figures for 2024-2026 are forecast values.

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Emergency interventions of 2022-2023 had varying implementation challenges and effects

In response to surging energy prices following Russia's invasion of Ukraine, the European Union adopted a number of emergency interventions to lower consumption and reduce household energy bills. The Council Regulation published in October 2022 included binding and non-binding demand reduction targets (for the period 1 December 2022 – 31 March 2023), a revenue cap of EUR 180/MWh for inframarginal producers (1 December 2022 – 30 June 2023), and allowed for below-cost regulated prices for households and small and medium-sized businesses (8 October 2022 – 31 December 2023).

In June 2023, the Commission reported its review of the emergency interventions. Accordingly, the binding target of 5% electricity demand reduction in peak hours was adopted as proposed, however challenges emerged in many member states in the implementation of the indicative target of reducing total monthly gross electricity consumption by 10% (compared to the last five years). Reportedly, the implementation of the revenue cap was problematic due to the short time frame within which the measure had to be introduced and because of difficulties with data collection and processing. Concerns were raised by various stakeholders that the revenue cap may have impacted existing PPAs and other long-term contracts, as well as discouraged them from the initiation of new agreements. A detailed analysis of the introduced measures are provided in the 2023 Market Monitoring Report by the EU Agency for the Cooperation of Energy Regulators (ACER).

A provisional agreement was reached on the European Union's electricity market reform

Negotiations on the EU electricity market reform took place in 2023, after the European Commission had adopted the proposal in March the same year. In October 2023, the European Council agreed on a General Approach reform of the electricity market. The agreed general guidelines provided a basis for the position of the member states in the subsequent negotiations with the European Parliament on the details of the legislation.

In December 2023, the European Council and the Parliament reached a provisional agreement on the reform of European Energy Markets, aiming to protect the electricity market against shocks in light of the recent energy crisis, mitigate price volatility and prepare the energy system for increased renewable penetration. On the demand side, measures to shield consumers from price hikes include the promotion of PPAs by retail energy providers, establishing free choice of energy providers and granting the right to participate in energy sharing schemes for self-consumption for all consumers. Energy providers are further obliged to hedge their price risks for all volumes sold under fixed price contracts.

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Energy-poor communities will be protected from disconnection and member states will have to establish suppliers of last resort ensuring electricity supply to all consumers in times of crisis. Further, the proposed reform extends the mandate of member countries to apply regulated prices to small and medium-sized enterprises (SMEs) in times of crisis. In addition to member states, the Council receives the right to declare an EU-wide energy crisis, allowing the above-mentioned measures to be implemented by all member states.

On the supply side, the reform enables member states to introduce remuneration schemes for providing back-up capacity and medium- to long-term secured supply services more easily, and agrees that capacity remuneration mechanisms should play an integral part in the future electricity market design. The requirement for net zero emissions for these capacity services can be derogated until 2028. Member countries are also granted the possibility to introduce support measures for demand response and storage.

Further, according to the market design agreement, public funding and support schemes for renewable and nuclear projects should be increasingly built on two-sided contracts for difference (CFDs). This has been a matter of dispute between some EU member states, including Germany and France, when these reforms were tabled. This dispute centred around the concern that with the new power market reforms, France would receive substantial profits from their existing nuclear power fleet. Some EU countries were concerned that France could then use these excess profits, estimated in the range of EUR 7-20 billion to subsidise its industry. This led Germany to request that CFDs not apply to existing nuclear power plants. The compromise reached by EU countries proposes that while CFDs are mandatory for support schemes for new investments in renewable and low-carbon power generation, CFDs are optional for existing infrastructure. This alleviated the concerns of some countries as the European Commission's competition authorities would ensure fair competition throughout the process. Two-way CFDs distribute excess revenues to consumers if the market price is above a pre-agreed strike price, while if the market prices are below a pre-agreed strike price, then the difference is reimbursed to the generator. The aim is to help increase the deployment of renewables by providing a guaranteed return on investment as well as more predictable pricing. The proceeds of the CFD instruments are supposed to be directed back to consumers, either directly or via investments targeted to reduce energy prices.

The new Renewable Energy Directive was formally adopted and Action Plan for Grids was launched

The European Union has formally adopted the new Renewable Energy Directive (RED III), raising the 2030 target for the share of renewable energy in the EU's final energy consumption from 32% to 42.5%, with an aspiration to reach 45%. A

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central element of the regulation are provisions to speed up the approval of new renewable energy projects. Specifically, renewable energy projects will be defined as of “overriding public interest”, reducing the legal options to object against them. In the transport sector, member states commit to either reduce the emission intensity by 14.5% or establish a binding share of 29% renewable energy by 2030. There are also minimal requirements for various sources of biofuels introduced. For industry, the goal is to increase the renewable energy share by 1.6% every year, with an additional specific target to source 42% of hydrogen from renewable sources by 2030 and 60% by 2035. In the building sector, a target of 49% renewable energy by 2030 was agreed, with a minimum annual increase of 0.8% until 2026, and subsequently 1.1% through 2030.

In its EU Action Plan for Grids, published in November 2023, the European Commission reinforced its position concerning the central role of electricity grids to support a more decentralised, digitalised and flexible electricity system. The plan recognises the challenge of increased capacity needs and ageing infrastructure. Various measures are proposed to enable the necessary investments. These include the Implementation of Projects of Common Interest plan, improve the incentives for investment through regulatory clarity, faster permitting, and promoting funding programmes for smart grids and distribution networks. The long-term planning of grids is proposed to be improved through facilitating the communication and exchanges between TSOs, DSOs and generators.

Germany

After plummeting in 2023 amid weak industrial activity, electricity demand gradually recovers through 2026

Electricity demand in Germany declined by a remarkable 4.8% in 2023 despite wholesale energy prices coming down from their previous record highs. Demand reduction is especially prominent in energy-intensive industry, which faced a decrease in production of 13% during the first six months of 2023.

We anticipate a gradual but slow recovery in demand for electricity in the industrial sector in 2024, given subdued energy prices. EV and heat pump sales are then expected to result in electricity demand growth of 2.2% in 2024, followed by an average 2.6% annually until 2026. At the same time, we forecast fossil generation to continue its downward trajectory, with coal and gas plunging 20% and 8%, respectively, per year. In 2024, we expect renewable generation to reach more than 60% of total generation, and to have an average annual growth rate of 11.5% over the 2024-2026 period.

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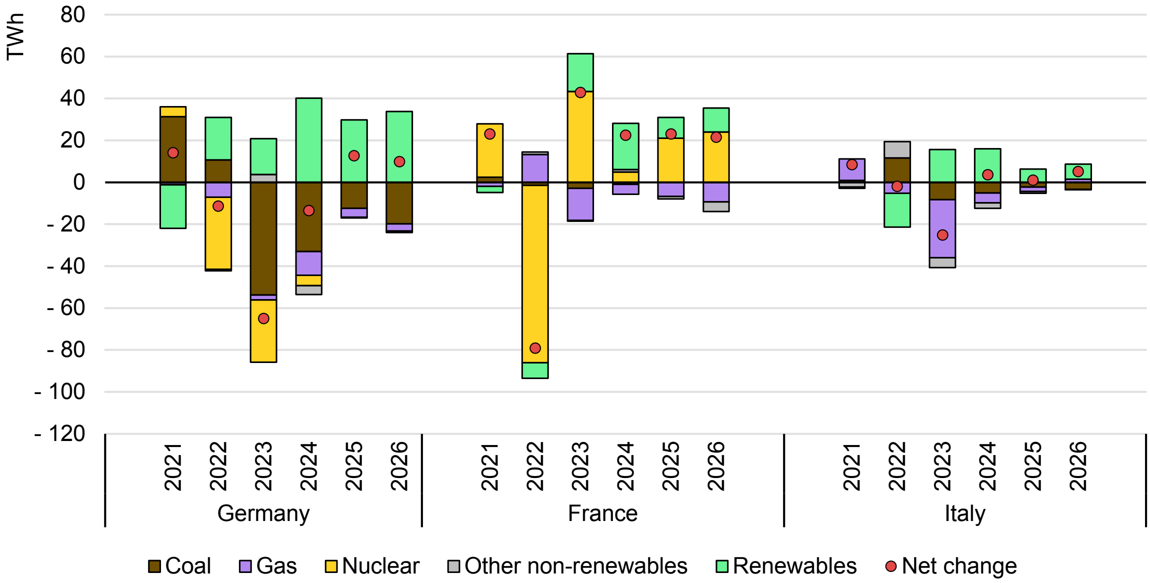
Favourable weather conditions and accelerating deployment of solar PV pushed renewable generation up during 2023, with Solar PV accounting for more than half of the growth. For the first time, the share of renewable generation surpassed the 50%-mark in total power generation. Germany was a net-importer of electricity in 2023, with about 12 TWh of net imports.

In the renewables segment, solar PV reached its expansion targets for 2023 already in October and is forecast to continue growing rapidly to reach 23% of generation in 2026. In contrast to rapid solar development, wind deployments fell short of installation targets in 2023, as permitting challenges hampered faster deployment. Based on the current project pipeline, we expect growth of around 12% in wind generation during the forecast period, bringing its share to 35% in generation in 2026.

Year-on-year change in electricity generation in Germany, France, and Italy, 2021-2026



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Note: Other non-renewables includes oil, waste and other non-renewable energy sources.

In April 2023, the last three nuclear reactors were taken offline, marking the end of Germany's nuclear power generation. Against the backdrop of the completed nuclear and planned coal phase out, the government announced in 2023 its so-called *Kraftwerksstrategie*, which seeks to tender gas-fired power plants, and to enable decarbonised generation from dispatchable units, which will complement increasing shares of renewables. The tendered volume for the next years aggregates to at least 10 GW of hydrogen-ready capacity by 2026, temporarily running on natural gas, and another 4.4 GW of so-called hydrogen-fired sprinter plants until 2028, running on hydrogen from commissioning, and 4.4 GW of hybrid

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power plants to be built in locations that would be connected to a hydrogen network at a later stage.

The government prolonged the temporary participation of 1.9 GW of lignite-fired reserve capacity in the market to save gas over the 2023/2024 winter period in case of a tight European gas market.

To address grid congestion between Germany's RES resource-rich north and the demand centres in the west and south, following ACER’s decision, the TSOs are currently examining four distinct configurations for German bidding zones from a total of twelve potential options.

France

A recovery in nuclear power generation reverses the 2022-2023 declines, and is expected to resume its upward trajectory to 2026

Following adverse supply-side dynamics starting in late 2021, the French electricity market saw a partial turnaround in 2023. Electricity demand continued its downward trend, falling by 3.4% versus 4.1% in 2022. At the same time, a rebound in nuclear power plant availability and a recovery in renewable power output boosted overall electricity generation and drove a return to net exports toward neighbouring markets.

While the French government extended the electricity tariff shield put in place to protect customers from the worst of 2022 power price highs to the end of 2023, the regulated market price cap (which applies to households, small enterprises, and local administrations under a certain size) was increased on two occasions. The two price hikes – 15% in February and 10% in August – weighed on consumer bills and electricity consumption habits, contributing to the year-on-year fall in power demand, notably through the first three quarters of the year.

Electricity generation followed an opposite trend in 2023, recovering from the record lows reached in 2022 linked to extensive planned nuclear maintenance and the discovery of critical corrosion problems at a number of reactors. Nuclear output recovered by almost 15% year-on-year in 2023 as reactors progressively came back online. Nevertheless, nuclear output remained approximately 13% below the 2017-2021 average, returning to typical monthly generation levels in September and October before additional unplanned maintenance issues impacted output in Q4 2023.

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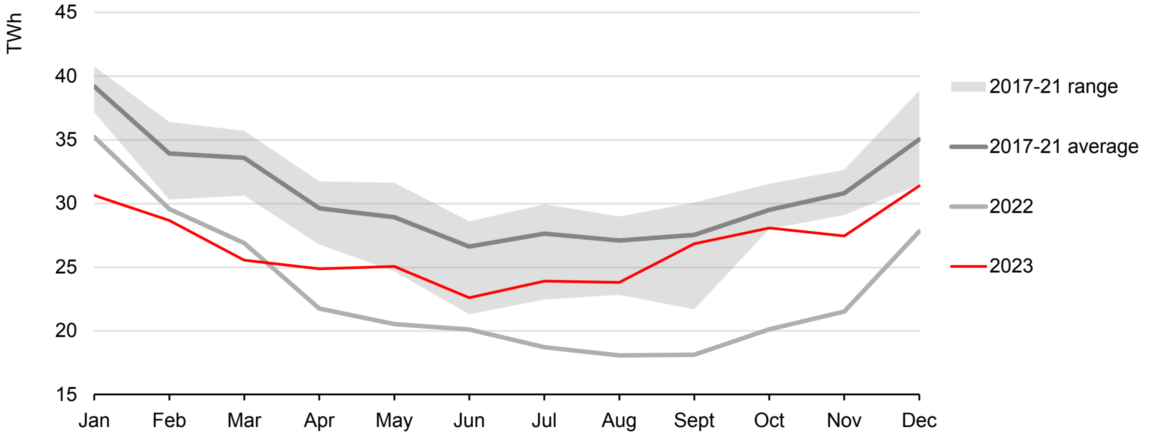
French nuclear power generation by month, 2017-2023



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Source: IEA analysis based on data from RTE, éCO2mix.

A recovery in renewable power generation also helped France to return to its traditional electricity exporter status in 2023. Thanks to a record 5 GW of solar PV and wind capacity additions in 2022 and more favourable weather conditions, combined wind and solar production increased by around 25% in 2023, making up for relatively modest growth in the previous year. Hydropower generation recovered from 2022 lows. Total renewable power generation grew by 16% in 2023, helping reduce power sector gas burn by about 30% and drive the 9% growth in overall power generation.

In March 2023, the French government passed its Renewable Acceleration Bill, aimed at facilitating the deployment of renewable technologies, notably through the acceleration of permitting procedures and garnering more civil society buy-in through increased participation of local actors. Nevertheless, the bill was met with a mixed reception from market and political actors and much of its impact is likely to be felt only later in the decade.

Electricity demand is set to grow by an annual average of 2.6% over the outlook period, recovering to pre-crisis levels only by 2026. Average annual total generation growth of 4% should ensure a strengthening export margin for the French market over the coming years.

French renewable power production is expected to increase at an average rate of approximately 10% through 2026, thanks to modest capacity additions and a recovery in hydropower output to typical levels. This growth should lead to a 76% reduction in gas- and coal-fired generation from 2022 levels. By 2026, 30% of power generation is set to come from renewables, up from about 24% in 2022.

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Italy

Gas-fired supply will continue to play an important role, but its share in total generation is expected to decline with expanding renewables

Electricity demand in Italy decreased by 2.9% in 2023, following the 0.8% reduction in 2022. Despite wholesale energy prices falling, the decrease in demand persisted, amid a slowdown in the economy and successes in energy savings. In the building sector, the super bonus scheme has helped reduce electricity use. As of October 2023, Italian households had applied for more than 400 000 energy efficiency projects for tax deductions under the super bonus programme, with approximately 78% of these applications submitted in 2022 and 2023. Some of the slowdown in economic growth is due to factors such as weak domestic demand for goods and services and reduced industrial activity, particularly in sectors with higher production costs. Provided the manufacturing sector starts recovering in 2024, we expect demand to grow by 1.8% per year on average over the 2024-26 period.

Renewable generation increased by 16% in 2023. Hydropower experienced a recovery, with higher reservoir levels than in 2022, transitioning from a year-on-year decrease of 38% in 2022 to an increase of around 35% in 2023. The annual generation from variable renewables also increased in 2023, with wind power growing by 13% and PV generation by around 7%. This growth was largely driven by incentives for residential photovoltaic installations, which represented 47% of the PV power capacity added in the first half of 2023. In 2024, the share of renewables in total generation is set to surpass 50%. The positive trend in renewable power is expected to continue with the new National Integrated Plan for Energy and Climate proposed in 2023.

Coal fell to 7% of the generation mix in 2023, a 3 percentage point reduction from the year before. The decline was influenced by restrictions of coal-fired power generation to a minimum, as the country scaled back emergency measures implemented in 2022 due to risks of gas shortage. It was also a result of the combined effects of lower demand and higher renewable generation and imports.

Despite a 20% year-on-year decline in 2023, natural gas remains a major fuel source for power in Italy, with an estimated share of 43% in generation. However, renewables surpassed gas in 2023 with a share of 45%. Out to 2026, we expect gas-fired generation in Italy to decline by around 1.6% on average, its share falling to 39% in 2026.

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The Italy-Austria interconnector, construction of which began in November 2020, was commissioned in December 2023. The interconnector doubles the current import capacity of both countries to 300 MW.

Spain

Strong solar PV expansion is set to displace fossil-fired generation

Following a 2.3% decline in 2022, electricity demand in Spain fell by a further 2.3% in 2023, to below the 2020's Covid-19 low. The main driver has been the decline of industrial production. Despite gas and electricity prices falling significantly from last year's levels, industrial demand continued to decline during the first three quarters and recovery has been slow.

On the generation side, PV expansion continues, growing from 15.3 GW by the end of 2021 to 20 GW by the end of 2022 and 22.7 GW by the end of September 2023. PV reached around 16% of the generation mix after having grown around more than one-third. Self-consumption from distributed PV generation has been increasing in Spain. Wind capacity rose only slightly, from 30.2 GW in 2022 to 30.4 GW in 2023. The expansion of renewables has given rise to an increase in the utilisation of pumped hydro of almost 50% compared with 2022.

The decline in total generation (around 4.5%) was higher than the drop in demand, as electricity exports decreased by roughly 30% following the surge that occurred in 2022 due to high gas prices and the Iberian Exception mechanism. Most of the drop was in combined-cycle generation, which is estimated to have decreased by one-third. Coal power generation in Spain will come to an end during the forecast period as the country's last four coal plants operating (Aboño, Soto de Ribera, Los Barrios, As Pontes and es Murterar) have announced conversion to gas, alternative uses like hydrogen or closure. In the meantime, the Spanish Supreme Court has authorised Naturgy to temporarily close ten combined-cycles after a long judicial case. At the time of the writing of this report, the company had not yet announced its final decision for the plants, with implications for the security of supply and future regulation of capacity mechanisms.

The Iberian Exception mechanism was extended until the end of 2023, despite an easing in the gas prices following the highs in 2022 that motivated its introduction. In the coming years, successful integration of growing renewable generation (particularly, solar PV), especially in months with weaker demand and strong sunlight – typically April and May – will be important. The schedule of nuclear closure is still foreseen to take place from 2027 to 2035.

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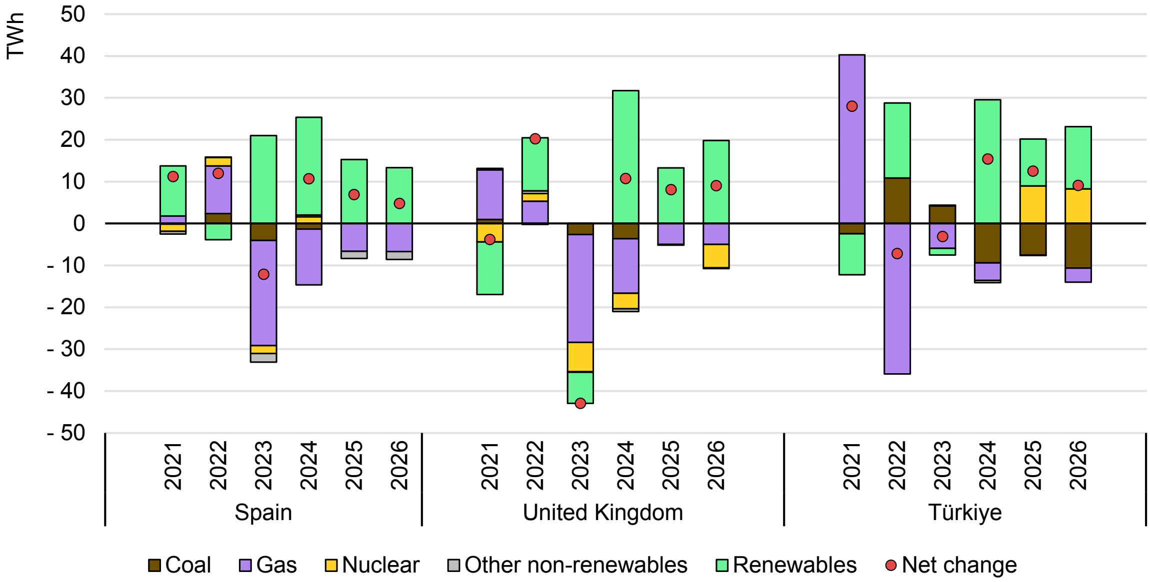
Year-on-year change in electricity generation in Spain, United Kingdom, and Türkiye, 2021-2026



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Note: Other non-renewables includes oil, waste and other non-renewable energy sources.

United Kingdom

As coal-fired generation is phased out by 2024, gas-fired output is also set to decline as renewables continue to expand

Electricity demand declined by 3.4% in 2023 as high energy prices and sluggish economic growth slowed electricity consumption. 2023 saw large year-on-year declines in coal (-36%), gas (-20%) and nuclear (-15%) power generation. Renewable generation declined by around 5% as gains in wind and solar respectively, were offset by a large decrease of more than 15% in biomass power generation due to maintenance outages.

For the 2024-2026 period, we forecast electricity consumption to increase by slightly below 2% per year on average. Coal's share in the electricity generation mix is set to decline to almost zero in 2024. Electricity generation from nuclear is expected to remain relatively constant until 2026, when a 15% cut in nuclear generation will occur as plants are decommissioned. Gas-fired generation is forecast to decline by an annual average rate of 8%. Renewables are forecast to increase by more than 14% per year on average, with most of the generation coming from wind.

A portion of the UK's existing supply of electricity has been secured by EDF extending the operating life of two nuclear power plants until March 2026, which provide 5% of Britain's current power supply. Coal-fired generation was necessary

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to ensure electricity supply in 2023. National Grid ESO was forced to call upon reserve coal power plants due to tight supply as a cold snap in March increased demand for heating and a heatwave in June raised air conditioning demand. Following these events the plants were decommissioned, in line with the UK's commitment to phase out coal-fired electricity generation by 2024.

In 2022, the United Kingdom became a net electricity exporter for the first time as continental Europe bought cheaper UK electricity to compensate for nuclear plant outages and reduced hydro output. This was reversed in 2023 when the UK's net imports amounted to about 25 TWh.

A response on how to develop the UK-ETS consultation was published in June 2023. From 2024, the 2021-2030 cap on emissions will be lowered from 1 365 Mt CO_2 to 936 Mt CO_2. Other measures have been to distribute allowances equivalent to 53.3 Mt CO_2 from reserves between 2024 and 2027 as well as to increase industry's free allocation of allowances to 40% of the annual cap from 37%. Emission traders have suggested that the tightening of the cap on emissions is weakened by these measures and is contributing to the UK carbon allowance

price trading at a lower price than the EU price. The CBAM is likely to lead to levies on exports such as steel and aluminium to the European Union as a result of the lower carbon pricing in the United Kingdom.

The Department for Energy Security and Net Zero published their response to the consultation for the Review of Electricity Market Arrangements. A wide range of reforms were proposed to incentivise decarbonisation, increase security and ensure affordable prices. One such proposed reform is to split the market into renewable and non-renewable pools whereby cheaper, but more volatile prices, could be accessed from a renewable power pool. Another proposed reform is to switch to a zonal or nodal pricing system to use the network more efficiently and avoid grid congestion. While the vast majority of those who participated in the consultation agreed that power market reform is necessary, there is a lack of consensus on the degree and speed at which the reforms should be implemented.

Ireland

Booming data centre sector is driving up electricity demand, resulting in Ireland having the highest growth rate in Europe

Electricity demand rose 2% in 2023, making Ireland one of the few countries in Europe that recorded an increase in electricity demand for the year. 2023 saw a year-on-year fall in coal-fired generation of 17% and a modest decline in gas-fired output of 1.2%. Renewable generation remained relatively stable as increases in

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solar, hydro and biomass power generation were outweighed by a decline in wind. Ireland is in Phase 4 of the IEA's phases of system integration, where variable renewables meet almost all demand in some periods. This is mainly due to wind power, which made up about 33% of total power generation in 2023.

For the 2024-2026 period, we estimate electricity consumption to grow by an average of almost 7% per year, which is the highest demand growth rate in Europe in our forecast. This strong increase will be driven by a rapid expansion in the data centre sector. We forecast average year-on-year declines in gas-fired electricity of 0.5% out to 2026, with strong demand growth preventing more substantial declines despite strong growth in renewables. We expect renewables to grow faster over this period at an annual average rate of around 13%, largely driven by wind.

In Ireland, data centres are estimated to have consumed about 5.3 TWh of electricity in 2022, up by 31% compared to 2021. This accounts for 17% of Ireland's electricity demand, equivalent to the consumption of all urban dwellings. Considering a high-case scenario with current projections and announced plans, we estimate that this could reach around 12 TWh by 2026, when it could make up more than 30% of national electricity demand. The state-owned TSO EirGrid has imposed a de facto moratorium on data centres in Greater Dublin due to a rapid growth in data centre stock, hence grid congestion especially in that area. The moratorium prohibits the submission of data centre planning applications from late 2022 to 2028 but does not impede contracts that are already in the pipeline. Some data centres have instead connected to Dublin's gas network to produce their own power as an alternative to connecting to Ireland's electricity network but this work-around was also closed by the government.

Ireland's electricity system experienced an alert in June, warning of the possibility that supply may fall short of demand. This was attributed to a combination of both low wind and solar power, and outages at several generators. Concerns around power outages have prompted the Moneypoint coal-fired power station, originally planned to be decommissioned in 2025, to be converted from coal to oil and have its lifetime extended. Furthermore, gas-fired power stations are also being built to operate as emergency backup generators for peak demand.

Ireland currently has a single interconnection to the UK market with a capacity of 500 MW and will double this capacity in 2024 with its Greenlink interconnection to Wales. By 2027, it will have its first connection to continental Europe through a 700 MW interconnection to France, the Celtic Interconnector. This project has been designated a Project of Common Interest by the European Commission as it is an infrastructure project that links the energy systems of EU countries. This allows the project to benefit from better regulatory conditions, an accelerated planning process and financial support.

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Denmark

Total share of wind and solar PV in electricity generation is set to reach the 70% milestone in 2024, up from 63% in 2023

Electricity demand increased by approximately 1% in 2023, making Denmark among the few countries in the European Union to have recorded demand growth in 2023. Coal-fired generation declined by 35% and a decrease in gas-powered generation of 10% was observed. Renewable generation grew by 5% with solar power generation accounting for a significant portion of this growth, although wind continues to be the largest contributor to the renewable generation mix.

For the 2024-2026 period, we estimate electricity consumption will grow by an average of 3.3% per year, largely supported by the expanding data centre sector as well as new electric vehicles and heat pumps. We forecast significant growth in renewables, increasing by around 7% per year on average, with large amounts of solar and wind powered generation expansion over this timeframe. In 2024, Denmark's VRE share in total generation is expected to reach 70%.

Denmark is the country with the highest share of variable renewable energy (solar PV and wind power) in the world at an estimated 63% of electricity generation in 2023. Denmark is in Phase 5 of system integration of renewables and maintaining power system stability. This has been addressed so far through a combination of electricity trade through interconnections, increasing power plant flexibility, demand flexibility, as well as other measures.

Denmark has expanded its interconnection capacity with the completion of the 1 400 MW Viking Link Interconnector. The world's longest land and subsea interconnector connects Denmark to the United Kingdom in addition to existing interconnections with Germany, Sweden, the Netherlands and Norway. This is key for Denmark as it can export electricity during periods of surplus wind power generation and import electricity under low wind conditions.

Denmark passed a bill to allow direct electricity lines, opening up the possibility of Power-to-X projects which connect power producers to power consumers directly, bypassing the power grid. This set the foundation for a world first Power-to-X tender whereby state support would be provided for projects using abundant and cheap electricity from wind for the electricity-intensive process of producing green hydrogen. Denmark plans to utilise its offshore wind resources to develop energy islands in the North Sea that will generate up to 10 GW of electricity when fully expanded. A tender has thus far been delayed as consultation is currently ongoing to make the project economically viable.

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Türkiye

Reduced hydropower amid droughts resulted in increased coal-fired output to meet demand

Electricity demand was largely unchanged year-on-year in 2023 amid moderate economic growth. Despite a surge in demand for air conditioning and agricultural irrigation in the summer, the milder winter temperatures of 2023 compared to the previous year put downward pressure on electricity demand growth. The economy grew moderately, with GDP growth for 2023 estimated at almost 4% by the IMF, down from 5.5% in 2022. We expect an average annual increase in electricity demand of more than 3% in demand from 2024 to 2026 alongside accelerating economic growth.

Following the recovery in 2022, hydropower output declined by 4.5% in 2023 due to an extended drought. Wind generation remained at similar levels, while PV generation increased by 24%. This year's investments in solar power achieved a significant milestone, with the country reaching more than 10 GW of solar power capacity. Overall, the share of renewables in total power generation remained stable compared to 2022.

While renewable generation fell slightly in 2023 compared to 2022 due to a decline in hydropower, we forecast an upswing this year driven by an assumed recovery in hydropower and advancements in solar and bioenergy. By 2026, these factors will contribute to renewables comprising 53% of the electricity mix, up from 42% in 2023.

Türkiye's efforts to increase low-carbon energy by 2035 include the development of nuclear energy with commercial production of its first reactor expected to start in 2025. The country aims to achieve an installed nuclear power capacity exceeding 20 GW by the 2050s. Currently, the country is in discussions with Russia, China, South Korea, the United States and the United Kingdom regarding construction of its second and third nuclear power plants, as well as the implementation of small modular reactors (SMRs).

Gas-fired power generation fell by 8% in 2023 amid continuing spikes in natural gas prices, while coal-fired output rose 3.7% compared to the previous year. In June 2023, Türkiye emerged as Europe’s largest coal-fired electricity producer. Nonetheless, we expect declines in both coal and gas-fired generation throughout the forecast horizon as renewable generation continues to grow. This sees coal's share declining from 36% of electricity generation in 2023 to 25% in 2026, and gas falling 4 percentage points to 17% over the same period.

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Ukraine

Targeted attacks caused damages to energy infrastructure, limiting electricity supply

Ukrainian power system stakeholders have used the summer months to restore infrastructure damaged by Russia's over 1 200 drone and missile attacks in the winter of 2022/23 and to bolster defences for the winter season, including purchases of back-up equipment like generators, batteries and spare parts. These attacks caused damages estimated at USD 10 billion and have caused the system to operate in emergency mode with limited safety margins. December 2023 saw a particularly tight supply-demand situation, with nearly 500 settlements having faced blackouts. Adverse weather conditions and damages to the power plants due to shelling limited electricity supply at a time when electricity demand soared due to increased heating needs because of cold weather.

Around half of the high-voltage transformers on the Ukraine grid have been damaged or destroyed, while power capacity has been reduced by nearly 50% of its pre-2022 levels, from 37 GW to 19 GW. As a result, electricity demand in Ukraine stayed roughly 20% below pre-2022 levels, despite increasing slightly in 2023. Nuclear remains the largest source of electricity generation at around 60% of total output. Renewables supplied around 10%, mostly hydro (6%), followed by solar PV (2%).

Forecasts for supply and demand are highly uncertain, but it is anticipated that demand will increase slightly over the next three years. The most likely source of supply increase would be from nuclear power, followed by renewables.

Ukraine synchronised its grid with the EU electricity grid in March 2022 and has halted power exchanges with Russia and Belarus. Imports from Moldova have increased while overall trade has decreased, leaving a balanced external position.

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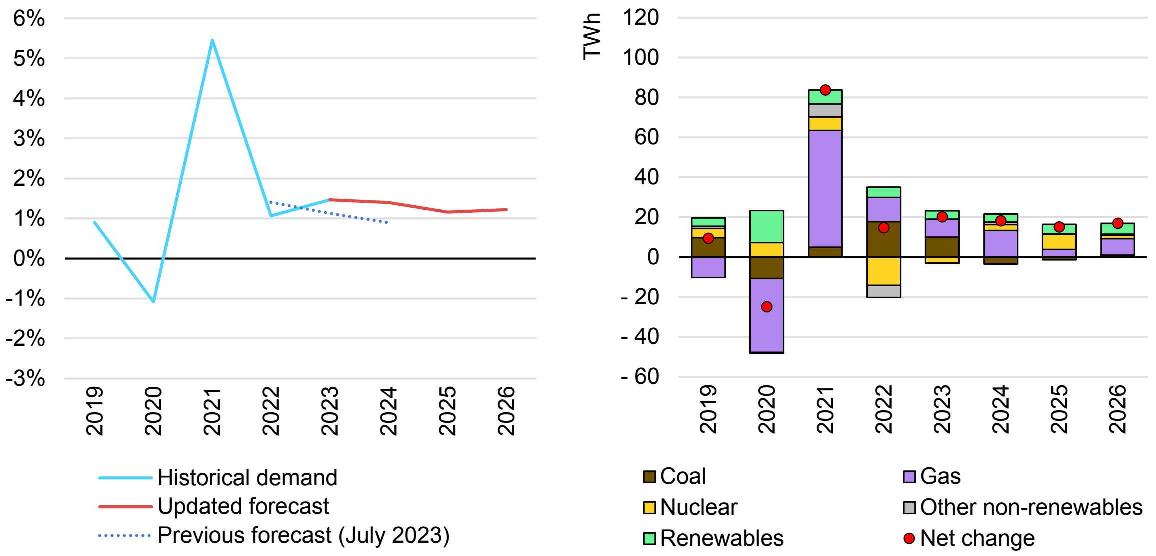
Eurasia

Fossil fuels remain the dominant source of supply for the region's electricity generation

Countries in Eurasia post a recovery in consumption levels in 2023 despite the depressed economic climate. Following an annual average growth rate of 1.5% in 2015-2019, Eurasia's electricity consumption growth slowed to 1% in 2022. Preliminary data suggests that the region's electricity demand growth rebounded to around 1.5% in 2023. Russia alone accounted for about half of incremental electricity demand in 2023. The region's demand growth is expected to remain depressed compared to the pre-war period, at an annual rate of 1.2% over the 2024-2026 period.

Fossil-fired generation is set to continue to dominate Eurasia's electricity mix at a share of around 66% over the forecast period. While the pace of renewables deployment remains slow, improving nuclear availability in Russia is expected to reduce the CO_2 intensity of power generation from 388 g CO_2/kWh in 2023 to 382 g CO_2/kWh in 2026.

Year-on-year percent change in electricity demand (left) and year-on-year change in electricity generation (right), Eurasia, 2019-2026



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Note: Other non-renewables includes oil, waste and other non-renewable energy sources.

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Russia

Electricity demand is estimated to have increased by around 1% in 2023, but significant uncertainty remains

Russian electricity demand is difficult to estimate, given its ongoing war against Ukraine. Russia's electricity demand is estimated to have grown by around 1% in 2023, similar to its 2022 growth rate, despite the depressed industrial, manufacturing and commercial activity compared to the pre-war period. Russia's overall electricity generation increased by 0.8% y-o-y in the first eleven months of 2023. Fossil-fired thermal generation rose by 2% and accounted for 63% of total power supply during this period. Higher fossil-fired generation was due to lower nuclear output, down by 3.5% y-o-y. Hydropower generation increased by 0.7% y-o-y. Solar and wind power generation continued to grow strongly, both up by around 10%. Russia's electricity exports to China dropped by over 25% y-o-y in the first eleven months of 2023 amidst lower electricity generation in Russia's Far East. The region suffered from extreme heatwaves and lower hydro availability which depressed its ability to export electricity to China.

Electricity demand growth is forecast at a slower growth rate of 0.7% on average in 2024-2026. Nevertheless, there is significant uncertainty surrounding Russia's economic development and its structure, which can impact electricity demand trends in the country. The share of fossil-based thermal generation in the country's power mix is set to marginally decline, to just above 60% on average in the medium term. The build-up of wind and solar capacity remains slow. Unit 1 of the Kursk II nuclear plant is expected to be commissioned in 2025.

Kazakhstan

Power demand moves apace with economic growth, with gas-fired generation rising to meet the additional consumption

Electricity consumption in Kazakhstan returned to growth and increased by more than 2% y-o-y in the first ten months of 2023, following a decline of 1.4% in 2022 amidst slower economic growth. Fossil-based thermal generation accounts for nearly 90% of the country's generation mix, with coal providing 60% while gas-fired power has a share of 27%. The share of coal is expected to decrease to 56% by 2026, while that of gas rises to 32%.

Hydropower generation declined by 4.6% y-o-y, while fossil-based thermal generation fell by 1% compared to the same period of 2022. The gap between demand and domestic generation was bridged by higher electricity imports from

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Russia, which surged by 75% y-o-y in the first ten months of 2023. Domestic power generation was largely supported by stronger wind power output, which increased substantially by 35% y-o-y .

Power disruptions and scheduled cut offs have been ongoing in major cities and adjacent regions of the interconnected nations of Kazakhstan, Kyrgyzstan, and Uzbekistan since 2022, primarily attributed to grid imbalances such as system overloads. In 2023, Western Kazakhstan experienced frequent controlled power outages lasting up to five hours while the regional authorities developed a strategy to prioritize electricity supply. Kazakhstan has recently been making efforts to modernize its outdated electricity grid infrastructure after gas exports were interrupted by energy crises in the country.

Kazakhstan's electricity demand is forecast to grow by around 2.2% per year between 2024-2026, largely to be met by expanding gas-fired power generation. There are also plans for Russia's Inter RAO to construct three coal-fired power plants in Kazakhstan, which would be relevant outside our forecast period.

Other Eurasia

Following the strong rebound in 2021 of 4%, electricity demand growth slowed in other Eurasian markets to an average of 3% per year in 2022 and 2023.

In **Uzbekistan**, preliminary data indicates that the country's electricity output rose by 3% in the first eleven months of 2023 compared to the same period a year before. Uzbekistan continued to expand its power generation capacities in 2023. Gas-fired generation accounted for just over 80% of power generation. The Shirin thermal power plant (1.5 GW) started operations in October 2023 and is expected to ramp-up to full operations in Q1 2024. According to the Ministry of Energy, around 1.5 GW of wind and solar capacity was targeted to be installed in 2023. The continued decline in natural gas production in Uzbekistan (down by 9.5% y-o-y in the first eleven months of 2023) continues to weigh on electricity supply security.

In gas-rich **Turkmenistan,** electricity generation rose by an estimated 2.7% y-o-y in the first eleven months of 2023. Turkmenistan exports electricity to Afghanistan, Iran, Kyrgyzstan and Uzbekistan. Turkmenistan started electricity exports to Kyrgyzstan in August 2021 and deliveries reached 1.6 TWh in 2023. In October 2022, Turkmenistan and Uzbekistan agreed to ramp up electricity supplies to 4 TWh/yr, which could improve electricity supply security in Uzbekistan.

In **Azerbaijan**, electricity demand growth is estimated to have eased to 1% in 2023 from more than 4% in 2022, marking a further slowdown compared to the 7% rebound recorded in 2021. The country's electricity system is almost exclusively gas-fired powered. Fossil-fired thermal generation remained stable in 2023, as renewables continued to increase. Hydropower output rose by 15%, while wind

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generation fell by 30%. Solar power generation rose by 30%. Overall, the share of renewables in Azerbaijan’s power remained broadly stable at around 6%.

Electricity demand in Eurasia excluding Kazakhstan and Russia is expected to rise at an average growth rate of 3.5% per year in the 2024-2026 period. This will be largely supported by the region’s rising population and economic expansion, although the macroeconomic outlook has worsened since Russia’s invasion of Ukraine.

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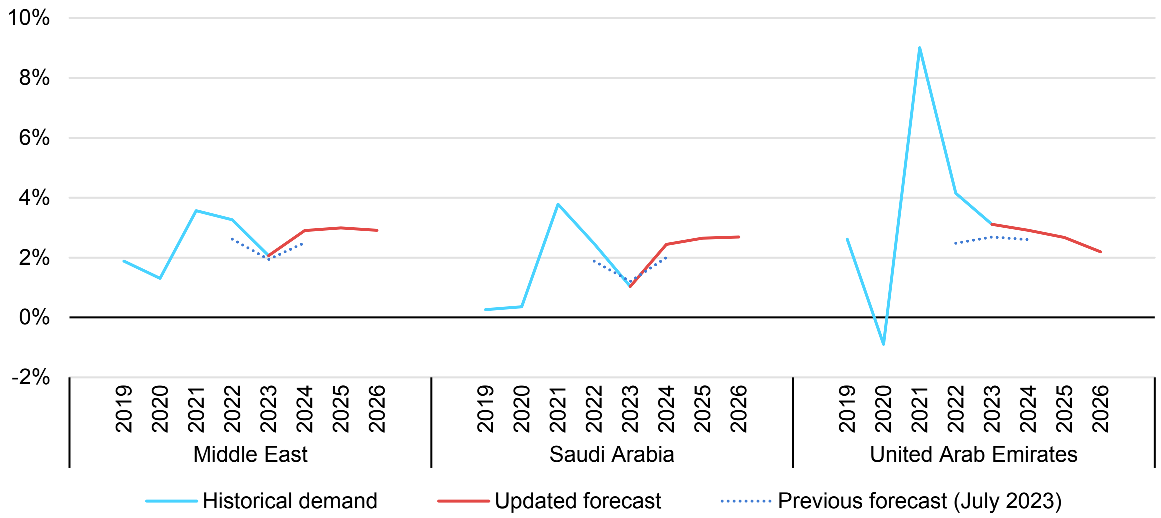
Middle East

Natural gas-fired generation continues to grow, but renewables gather pace

Middle East electricity demand growth is estimated to have increased by 2% in 2023, down two-thirds from the 3.3% observed in 2022 amid weaker economic activity and despite higher temperatures boosting cooling. For the 2024-2026 outlook period, we forecast stronger growth of an average 3%, led higher by economic growth. Fossil fuel's share in electricity generation is expected to decline from 93% in 2023 to 90% by 2026.

In parallel, the share of low-emissions sources rises from 7% to 10%. Nuclear power generation increased by 50% in 2023 versus 2022, and is forecast to rise by 29% in 2024 and 14% in 2025, before plateauing in 2026. At the same time, renewable generation rose by about 20% in 2023, and is set to increase by a similar 23% in 2024 before easing to 11% on average in 2025-2026.

Year-on-year percent change in electricity demand, Middle East, 2019-2026



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Annual power generation emissions remained largely unchanged in 2023, as increased use of nuclear and renewables in power generation offset higher fossil fuel use. However, from 2024 to 2026, electricity generation emissions are set to increase by an average annual growth rate of 1%, as natural gas-fired generation grows by 2.4% per year. Oil-fired output is expected to decline on average by less than 1% per year. CO_2 intensity of power generation in the Middle East declined

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by 2.3% to 552 g CO_2/kWh in 2023, amid the rising share of nuclear generation led by in the UAE. Over the 2024-2026 outlook period, CO_2 intensity is forecast to fall further, by an average annual 1.7% to 497 g CO_2/kWh, as the share of nuclear and renewables rise in the region's electricity generation mix.

Saudi Arabia

Cooling and water desalination is expected to support electricity demand, as renewables make significant gains

Saudi Arabia's electricity demand rose by a modest 1% in 2023, down from 2.5% in 2022 amid weaker economic growth. The commercial, government and industrial sectors dominated demand gains, with cooling and water desalination the primary sources of consumption. Cooling alone represents around 70% of Saudi Arabia's electricity demand. Water desalination will also drive demand growth in the forecast time-frame.[2] The country is the largest producer of desalinated water globally, with 70% of Saudi Arabia's drinkable water produced by desalination. For 2024-2026, we expect a stronger 2.6% boost in electricity demand, supported by economic growth and increased electrification.

Saudi Arabia's total generating capacity stood at 82 GW at the end of 2022. Natural gas-fired power provided more than 60% of generation, the remaining coming largely from oil-fired plants. Although the country currently does not have nuclear power capacity, it established the Nuclear Energy Holding Company to act as the national nuclear developer. On 28 September 2023, the country announced plans to initially build two 1.4 GW reactors, with a goal to increase capacity to 17 GW by 2040.

Furthermore, the country is looking to develop electricity interconnections with its neighbours and beyond. The India-Middle East-Europe (IMEC) corridor involves infrastructure projects that would enable transport of electricity between Asia and Europe through Saudi Arabia. In addition, In September 2023 Saudi Arabia and the United States signed an MOU to develop a protocol for establishing green transit corridors through the Kingdom.

Saudi Arabia aims to reach 50% of renewables in its generation mix by 2030. In 2023, the country shortlisted contractors for 1.5 GW of solar PV projects to be

[2] While there is no clear desalination capacity target in the country, key actors such as the state-owned Saline Water Conversion Corporation (SWCC), which is the country's largest operator by capacity, made recent announcements saying that 8 of its 13 thermal desalination plants (94% of its production from thermal desalination) are either being replaced with reverse osmosis or under construction. In addition, SWCC aims for 30% of its production to come from renewable sources, including solar PV, which signals an increase in power demand in the coming years.

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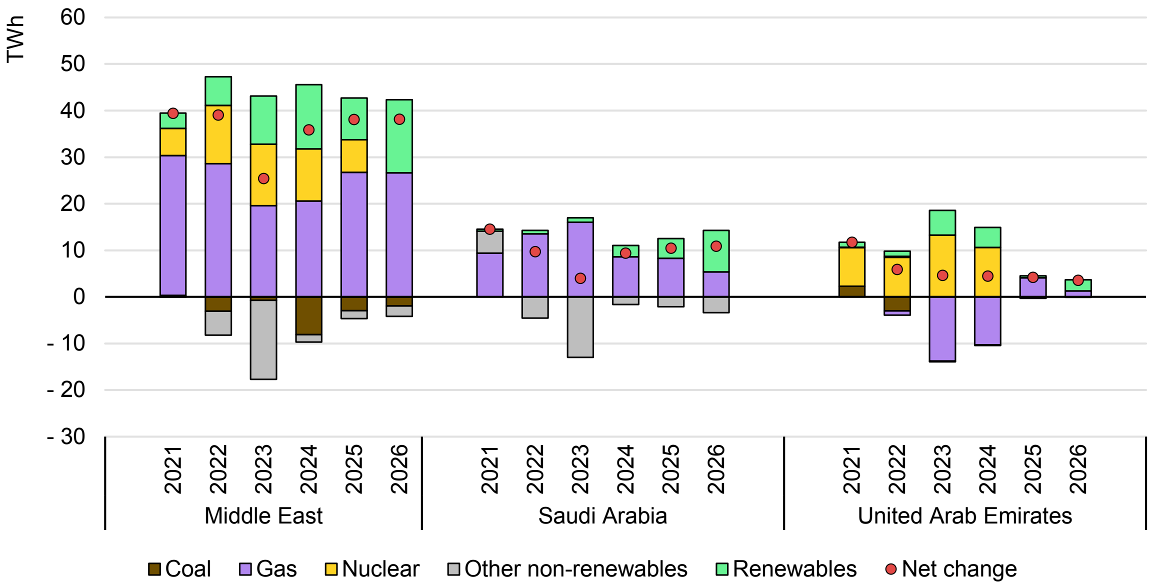
commissioned by 2026. In addition, through the Neom Green hydrogen project, the Kingdom expects to produce 600 t/d of low emission hydrogen and 1.2 Mt/y of green ammonia powered by 3.9 GW of renewable energy over the same time frame. The project reached a final investment decision (FID) in 2023. Renewable generation, though growing rapidly, is expected to account for only around 4% of Saudi Arabia's total generation in 2026, up from 1% in 2023.

Year-on-year change in electricity generation in the Middle East, 2021-2026



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Notes: Other non-renewables includes oil, waste and other non-renewable energy sources. The figures for 2024-2026 are forecast values.

United Arab Emirates

The share of renewables in electricity generation is set to reach 12% in 2026, more than double the 2022 level

In the UAE, electricity consumption rose by an estimated 3% in 2023, following an increase of 4% in 2022. We anticipate total electricity demand to expand at an annual average rate of around 2.6% over the 2024-2026 period. The country is aiming to achieve a target of 50% of electric vehicles on the road by 2050. While an official federal-level medium-term target for EV penetration has not been announced, there are ambitious plans mapped out to install 70 000 charging points throughout the country by 2030. At the same time, Dubai increased its annual government procurement target for EVs and hybrid vehicles to 20% in 2025 and 30% in 2030. Another key sector is water desalination. Abu Dhabi is expecting to meet over 90% of total water demand through reverse osmosis desalination.

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The total share of renewable energy in the generation mix increased significantly, from 5% in 2022 to 8% in 2023. The Emirates Water and Electricity Company (EWEC) intends to increase Abu Dhabi's total solar power capacity to 7 GW by 2030. Current total power demand is estimated at 7.7 GW. Moreover, Abu Dhabi aims to produce 60% of power generation from nuclear and renewables combined by 2035. At the federal level, this target reaches 50% by 2050. After final testing in late 2023, the UAE is getting ready to bring online the fourth reactor of the Barakah nuclear plant in early 2024. With this newest addition, the plant is expected to meet over 25% of the country's power demand.

While nuclear generation grew by about 70% in 2023, the biggest share in electricity generation remains gas, accounting for more than 70% of total supply. The share of natural gas in the country's power mix, however, is expected to decline to 64% by 2026 as nuclear generation rises and renewables deployment accelerates. Due to the large increases in both renewable and nuclear generation, power emissions fell by 11% in 2023. We expect a further sharp decrease of 9% in 2024 as the fourth unit of the Barakah nuclear power plant becomes operational, followed by a gradual increase as renewables only partially meets demand growth to 2026. The renewable share in electricity generation is set to rise to 12% in 2026, while the share of low-emissions sources (nuclear and renewables together) reaches 36%.

On the demand side, the Abu Dhabi Distribution Company (ADDC) committed to investing AED 20 million (around USD 5.4 million) in air-conditioning optimisation, which would cover around 850 mosques in the Abu Dhabi, including the massive Dhafra region that covers nearly two-thirds of the emirate. The company estimates emissions savings to reach 26 GWh and 4 600 tonnes of CO_2 annually. This measure feeds into the country’s Demand Side Management (DSM) and Energy Rationalisation Strategy, which aim to reduce overall electricity consumption by 22% and water consumption by 32% by 2030.

Other Middle East

Kuwait’s installed power capacity is just over 20 GW, of which over 99% are oil- and gas-fired power plants, with only 70 MW of renewable capacity at the Shagaya solar complex. Kuwait's capacity installations have stagnated since 2020. At the same time, demand increased by 2% in 2023 due to strong population growth, rising demand for water desalination and high summer temperatures. This was slightly below the 2018-2023 CAGR of 2.6%. Kuwait's existing power generation fleet has been under a heavy strain since the start of 2023, with production setting monthly records even outside the peak summer months.

Kuwait’s peak electricity load hit a new all-time high of 17.6 GW in August 2023, up almost 5% on the previous year’s high. The severity of the situation has led to

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power shortages. With no new capacity set to come online before summer 2025, the Ministry of Electricity, Water and Renewable Energy launched in May 2023 a national awareness campaign to save electricity and water (Weffir campaign).

In our outlook to 2026, we forecast total electricity demand to grow at an average pace of 2.5% per year. Electricity will continue to be generated mainly from oil (40%) and gas (60%). Over the longer term, Kuwait's government has renewed its long-standing target for 15% of its generation coming from renewables by 2030, corresponding to some 14 GW. This objective is expected to be met by the expansion of the Shagaya solar project, which aims to reach 4.5 GW by 2027-2028, for which the Request for Qualification was recently issued. At the same time, the Gulf Cooperation Council Interconnection Authority's led Gulf Electricity Interconnection Expansion Project would enable Kuwait to increase the capacity of its electricity network by 2.5 GW.

In 2023, electricity demand in **Israel** grew by an estimated 2%, a slowdown compared to 4% the previous year. Out to 2026, we anticipate average annual growth of 2.5%. Production from renewables rose significantly in 2023, up by 43% year-on-year, increasing its share to 14% of the electricity mix. Despite the rapid growth, capacity additions would need to accelerate to meet Israel's goal to generate 40% of its electricity from renewables by 2030.

According to the roadmap released in February 2022 by the Ministry of Environment, Israel would have to install between 18 GW and 23 GW of solar projects along with 5.5 GW storage (with 33 GWh energy capacity) to meet the target. The roadmap also recommends the creation of a regulatory framework for managing distributed renewable energy and storage systems and for virtual power plants (VPPs) to manage 100 MW of renewables and 50 MW of storage.

Plans for renewables received a boost when the Ministry of Energy announced on 10 September 2023 that ongoing grid modernisation plans would add 2 GW of renewables from wind and solar to the grid, although no timetable was provided. We see renewable generation rising to 23% of the mix by 2026, mostly coming from solar PV. Gas-fired generation also increases by around 6% per year, while coal declines sharply, leading to annual emission reductions of around 10% out to 2026.

Qatar's electricity demand increased by an estimated 3% in 2023, and we expect a similar growth of 3.1% for the 2024-2026 period.

Prior to the opening of Qatar's first major solar power plant, the 2 TWh/year Al Kharsaah, in October 2022, all power capacity was based on fossil fuels, mainly from gas. The Qatar National Vision 2030 aims to generate 20% of electricity from renewable energy sources by 2030, with a focus on solar PV to meet that goal. Two new solar plants in the Mesaieed and Ras Laffan industrial cities are expected

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to be operational by the end of 2024. This will double the country's renewable energy output once completed and bring renewables to 5% of the power mix in 2025-2026.

In September 2023, QatarEnergy, the world's largest Liquefied Natural Gas (LNG) producer, announced that it was expanding its targets for installing photovoltaic power capacity from 4 GW to 5 GW by 2035, to liquefy natural gas using renewable electricity. The company has a major expansion project under construction that will lead to a 64% increase in Qatar's LNG production from 2021 to 2030.

Oman's electricity consumption increased by an estimated 2.5% in 2023, and we anticipate an annual growth rate of around 3% for the next three years.

Oman has only one operating utility-scale solar facility, the 500 MW Ibri II solar PV plant, which came online in 2021, and one 50 MW wind farm. Two additional solar photovoltaic power plants, Manah I and II, with a combined capacity of 1 000 MW, are due to start operations in 2025, which would nearly triple the existing capacity from renewables. We expect renewables to reach nearly 8% of the generation mix in 2026, while gas-fired electricity falls from 93% currently to 88%.

To support the development of new production capacities, Oman is connecting its north and south standalone grids with the Rabt project. A significant milestone was reached in August 2023 with the commissioning of the USD 49 million Suwayhat grid station by the Oman Electricity Transmission Company (OETC). In September 2023, a competitive tender was launched for a 132/33 kV grid station on Masirah Island, which would be connected to the mainland by a subsea cable, reducing the island's dependency on diesel-fired power generation.

The energy crisis prompted the government to increase electricity subsidies by 15% in 2022 and 2023. However, Oman's energy subsidy reforms are still ongoing, with the aim to gradually raise utility tariffs until the total elimination of subsidies by 2025.

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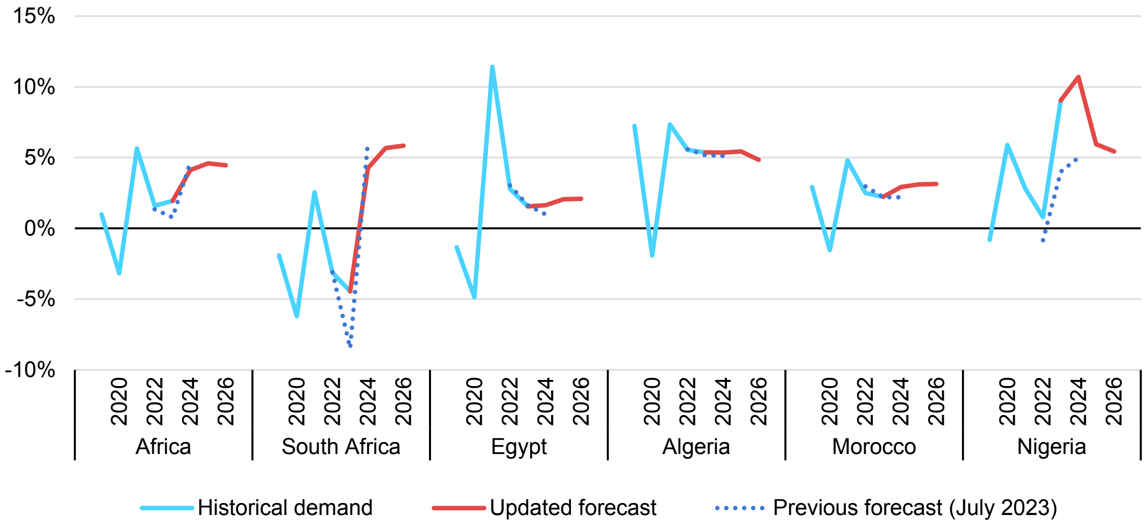
Africa

Insufficient power capacity and infrastructure issues continue to curb growth

Electricity demand in Africa increased by 2% in 2023, marginally higher than the year before. The lacklustre growth primarily reflects a sharp contraction in demand in South Africa, the continent's largest electricity consumer, due to chronic power capacity constraints. Egypt and Algeria, the region's second and third largest consumers, are estimated to have seen growth of 1.5% and 5%, respectively. Combined, these three countries make up 60% of demand in Africa.

Our forecast for Africa anticipates much faster growth for the 2024-2026 period, with average annual electricity demand rising by more than 4%. The higher growth rates also reflect a rebound in South African power demand following the restart of shut-in capacity. We expect per capita electricity consumption in Africa to recover to its 2010-2015 levels by the end of 2026 at the earliest. In our forecast, two-thirds of additional demand growth in Africa is expected to be met by expanding renewables, with natural gas supplying most of the rest. Emission intensity of electricity generation is expected to fall from 520 g CO_2/kWh in 2023 to 490 g CO_2/kWh in 2026.

Year-on-year percent change in electricity demand, Africa, 2019-2026



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South Africa

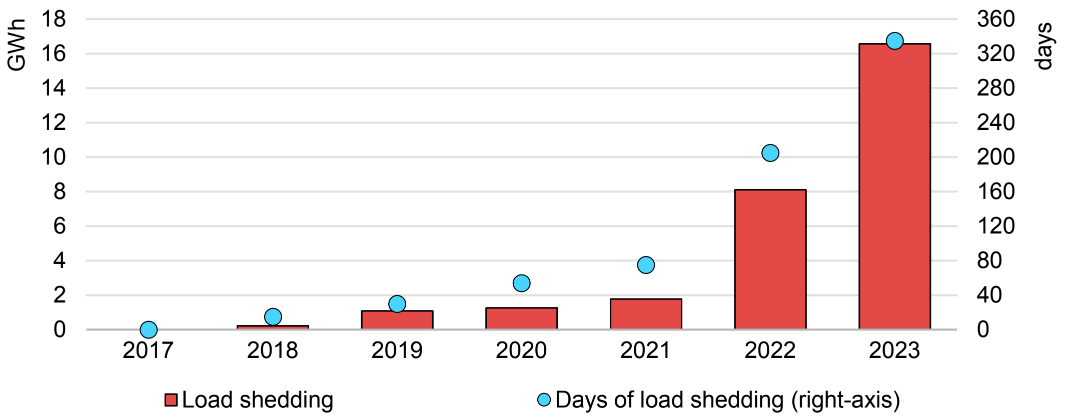
Demand supressed by ever-worsening power generation shortages in 2023, and the outlook remains precarious

Electricity consumption in South Africa declined sharply in 2023, dropping more than 4% y-o-y due to increased load shedding. This extends the downward trend in demand observed since 2018, when the current power crisis started – with the exception of 2021 when demand rebounded from the Covid-19 shock.

The power sector continues to be plagued by load shedding due to a shortage of power capacity as the availability of its ageing coal fleet has degraded further. At the same time, much-needed new power capacity has struggled to come online to replace this fleet. Most notably, three units of the newly commissioned 4 800 MW Kusile power station suffered critical damage when half of its units were taken out of service when a chimney collapsed towards the end of 2022. This has been further exacerbated by ongoing maintenance at the Koeberg nuclear plant, where one of the two units was restarted in November 2023 after almost a year out of service, before the other unit was taken out of operation for similar maintenance a month later.

Meanwhile, the timely procurement of new power capacity through auctions since the Covid-19 pandemic has proven largely unsuccessful due to a number of issues. Escalating costs as a result of inflation have prevented successful projects from reaching financial close.

Load shedding in South Africa, 2017-2023



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Source: Eskom (2023), Eskom Data Portal.

As a result of these challenges, 2023 will be the worst year to date for load shedding, with the total volume of load shedding up until the end of September already exceeding the total in the previous eight years combined.

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The latest renewable auction has fared no better. During evaluation of the bids it emerged that the grid hosting capacity in the Eastern and Western Cape (where all wind bids had been received) had been reduced to zero and so only 860 MW of solar capacity (out of 5 200 MW renewables tendered) was procured. This will further hamper the success of the latest plans for procurement. The government of South Africa announced several new auctions in December 2023 for a suite of technologies, including 5 000 MW of wind and solar PV capacity, 2 000 MW of gas-fired projects and 615 MW of battery storage capacity. The latter comes after the successful procurement of around 500 MW of battery storage capacity last year, the first auction of its kind in South Africa. In addition, the government announced plans to procure 2 500 MW of nuclear capacity. In an attempt to solve the ongoing power crisis, also approved an updated integrated resource plan, although this is yet to be released for public comment.

Despite these critical issues around power capacity, demand is expected to grow by 5%. on average over the forecast period. This is a sharp reversal of the -2% average for the 2018-2023 timeframe. This is based on the return to service of nuclear generation and damaged units at the Kusile coal-power plant. Additionally, we expect renewable capacity to continue to come online from previous auctions through direct procurement via PPAs in the private sector. This will result in the emission intensity of the system decreasing by around 2% y-o-y on average over the forecast period, reaching just under 800 g CO_2/kWh in 2026.

Despite the lack of capacity delivered by the procurement programmes, strong policy is opening up new possibilities for the private sector to respond outside the traditional procurement channels. Following the easing of licensing requirements for private generators, there has been a significant increase in the number of applications for licenses as commercial and industrial consumers have started to invest in renewable generation for their own consumption. This trend is clear from publicly available data of private projects registered with the regulator. It is equally supported by analysis from Eskom, which estimates that around 4.4 GW (and an increase of 3.5 GW over the calendar year from June 2022 to July 2023) of distributed solar PV was connected to the system.

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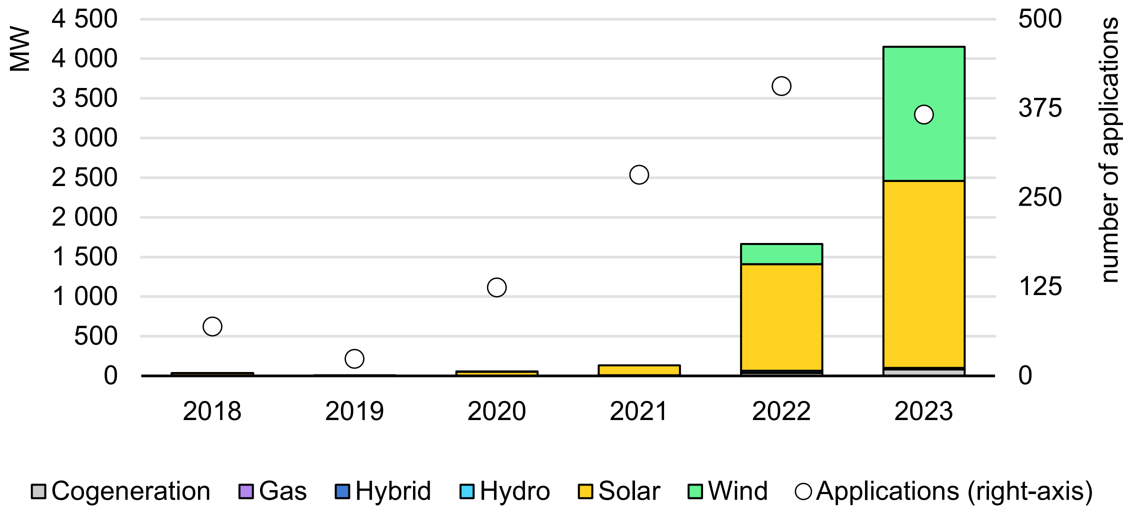
Registered private generation facilities in South Africa, 2017-2023



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Source: National Energy Regulator of South Africa (2023), Registered Generation Facilities (06/11/2023)

The increase in private generation projects may soon be equally aided by a new regulation that allows for the wheeling of power from private projects to multiple customers via power purchase agreements (PPAs). This will be further enabled through the development of a new digital platform by Eskom that can circumvent structural constraints around billing and allow for the wheeling of power from private generators to direct offtakers at the distribution level. The so-called Virtual Wheeling Platform has recently passed from concept to implementation as Vodacom, the largest telecommunications provider in South Africa, signed an agreement with Eskom whereby they will be able to purchase power from renewable energy projects directly to power their operations through the platform. Up until now, private projects for wheeling have been relatively slow to reach financial closure, and so the speed at which they can contribute to the generation mix may be quite limited.

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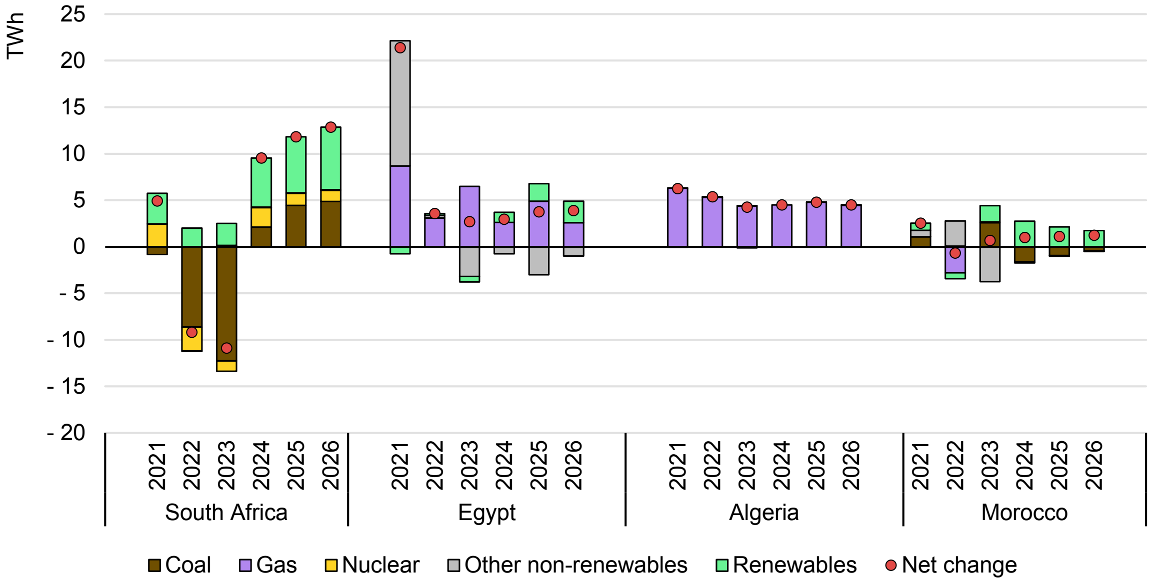
Year-on-year change in electricity generation in South Africa, Egypt, Algeria, and Morocco, 2021 – 2026



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Notes: Other non-renewables includes oil, waste and other non-renewable energy sources. The figures for 2024-2026 are forecast values.

Egypt

Government support enables growth in renewable energy electricity generation

Electricity demand in Egypt rose by an estimated 1.5% in 2023. Gas-fired generation is estimated to have increased by around 2%. A decline in the share of generation from oil products versus the previous year in favour of gas resulted in a 1.2% annual decrease in the emissions intensity of the energy mix.

Since 2018, the Egyptian government has taken significant steps to support the electricity sector, attract foreign investments and expand the infrastructure for electricity transmission and distribution. As a result, the sector has become more competitive, with numerous international companies competing for market share and substantially raised investment in the country.

We anticipate sustained growth in electricity demand of an average 2% per year until 2026, supported by higher demand for air conditioning. In addition, Egypt has committed to drastically reduce its energy subsidies as part of a financial support programme with the IMF. Electricity prices will remain unchanged for consumers until January 2024, however after this, rising prices could put downward pressure on demand growth.

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Growth in renewable capacity will be supported by the Energy Pillar of Egypt's Country Platform for the Nexus of Water, Food and Energy (NWFE) Program, launched by the government at COP27 in November 2022. NWFE aims to deploy an additional 10 GW of renewable energy capacity (solar and wind) between 2023 and 2028. It also includes the decommissioning of 5 GW of inefficient fossil fuel capacity from 2023 onward. Continued growth of renewables will raise its share in the generation mix from around 11% today to 13% in 2026.

We forecast power generation emissions to remain relatively stable for 2024-2026, as expanding renewables restrain the growth in natural gas-fired power. Egypt's Vision 2030 plan, which was launched in 2022, targets a 10% reduction in GHG emissions in the energy sector, including oil and gas, by 2030 compared with 2016 levels.

Launched in 2023, the Red Sea Wind Energy project, supported by the European Bank for Reconstruction and Development (EBRD), will contribute to Egypt's green transition with the development of a 500 MW onshore wind farm in the Gulf of Suez region.

Algeria

The country's bountiful natural gas reserves provide almost all of power generation but renewables making inroads

Electricity demand in Algeria rose by about 5% in 2023, largely unchanged from the year before. Over the 2024-2026 forecast period, we anticipate total electricity demand to expand at an average annual rate of 5.2%, mainly driven by economic growth, along with additional consumption coming from water desalination and electric vehicles. Although the electrification of the transport sector remains limited, this will increase over time, with the government aiming to reach 1 000 electric vehicles on the road and 1 000 charging stations by 2024.

Algeria's installed power power capacity is currently around 25 GW. The power mix is heavily dominated by natural gas, representing 99% of generation in 2023. The government is taking steps to accelerate the deployment of renewable energy sources to meet its target of 22 GW of renewables by 2030. Following a tender launched in December 2021 for 1 GW solar PV that did not result in any contracts, in August 2023 the government issued a new tender aiming for a total solar PV capacity of 2 000 MW. Of over 100 bids, 73 from both international and local applicants were accepted as meeting the requirements. Two additional tenders took place in the following months, the first for 1 GW – reopening the original tender from 2021 – and a second for 3 GW.

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However, by the end of 2023 no winners had been announced nor private contracts signed for any of the tenders. In the absence of a late-stage development project pipeline, the forecast is conservative regarding the amount of utility-scale projects that will be commissioned by 2026 and therefore we expect gas will continue to account for the majority of generation (99%). This would result in power sector emissions growth of around 4.5% CAGR during 2024-2026 amid increasing power demand.

Algeria's interest in renewable energy is also linked to the country's water desalination programme. In March 2023, the government signed off on the creation of an independent national agency for water desalination with a view to ensuring water security and reaching 50% of drinking water from desalination by 2030. Six months later, the Algerian Energy Company (AEC) announced that the new 80 000 m^3 plant at Corso had hit full capacity. All seawater desalination plants combined are expected to have a capacity of 3.6 million m^3/d by 2024. The additional electricity use could be in the range of 1-4% of Algeria's current electricity demand, depending on the technologies employed.

To develop grid infrastructure, the government has announced an interconnection project linking the southern grid to the national grid. The construction of this 700 km double 400 kV high voltage transmission line would help boost the electricity supply to the country's southern provinces.

Morocco

Diversifying electricity generation making significant progress, with a focus on renewables and flexible technologies

Electricity consumption in Morocco rose by around 2% in 2023 and is expected to grow at an average annual rate of 3.1% over the rest of the forecast period. Morocco has been striving to diversify its power supply and increase the share of renewable generation, with a target of reaching at least 52% by 2030. A series of successful tenders have resulted in a growing share of wind and solar (including PV and CSP) generation, as well as flexible technologies such as batteries and pumped storage hydro to support the integration of these new resources. Thermal generation accounted for almost 80% of generation in 2023, consisting of primarily coal-fired electricity (73%), which has steadily increased over the last five years at the expense of gas-fired generation. This comes after gas imports from Algeria ceased in November 2021 following the breakdown of diplomatic ties between the two countries.

As a result, increasing demand in Morocco over the 2024-2026 forecast period is expected to be met by growth in wind and solar PV production, also reducing the share of thermal generation in the energy mix. In July 2023, a 300 MW wind plant

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was commissioned, while the Moroccan Minister of Energy Transition and Sustainable Development (METSD), recently announced its Investment Plan for 2023–2027, which envisages the deployment of 7 GW of new renewable capacity.

Additionally, in August 2023, following the successful call for tender for the construction of a 400 MW solar PV plant with two hours of battery storage, a new call for tender was issued for an additional 400 MW solar PV plant with one hour of battery storage. This highlights not only the acceleration towards the power capacity target but also in flexibility to support the integration of these new resources. This is equally demonstrated by the recent MoU concluded between Morocco and China's telecommunications company Huawei, with the aim of harnessing innovative electricity storage technologies for the system integration of renewable generation. Morocco also adopted legislation in October 2023 that, when implemented into its regulatory framework, will both permit and encourage the broader deployment of decentralised generation.

While the focus of growth on the supply-side has been in renewables, Morocco also signed an LNG supply agreement with Shell for 0.5 bcm of LNG until 2035, which the METSD has stated would be in line with its decarbonisation goals. This would look to replace the loss of gas supply from Algeria.

Nigeria

Deterioration of power infrastructure increased dependency on backup generators for 40% of electricity consumption

In 2022, 73% of Nigeria’s population had access to electricity, an increase of more than 70 million people during the past decade. Although the country has a total installed capacity of about 13 GW, average available capacity remained around 4.5 GW in 2023 due to a combination of factors such as deteriorating units, poor maintenance and liquidity constraints. Unreliable power supply due to limited grid infrastructure, underinvestment and ineffective regulatory frameworks has resulted in an estimated 40% of all the electricity consumed in the country being produced from backup generators.

To meet increasing demand, the performance of the Nigerian Electricity Supply Industry (NESI) is being reviewed and electricity supply remains a priority of the federal government. The 240 MW Afam Three Fast Power natural gas-fired plant as well as the gas-fired 50 MW Maiduguri Emergency Thermal Power Plant were commissioned in 2023. Similarly, the 700 MW Zungeru hydropower plant was commissioned in Q4 2023, boosting the renewable generation of the country.

The country’s largest thermal power plant was announced, a 1 900 MW expansion of Egbin Power Plc (commercial operation by 2025). The 1 350 MW gas-fired

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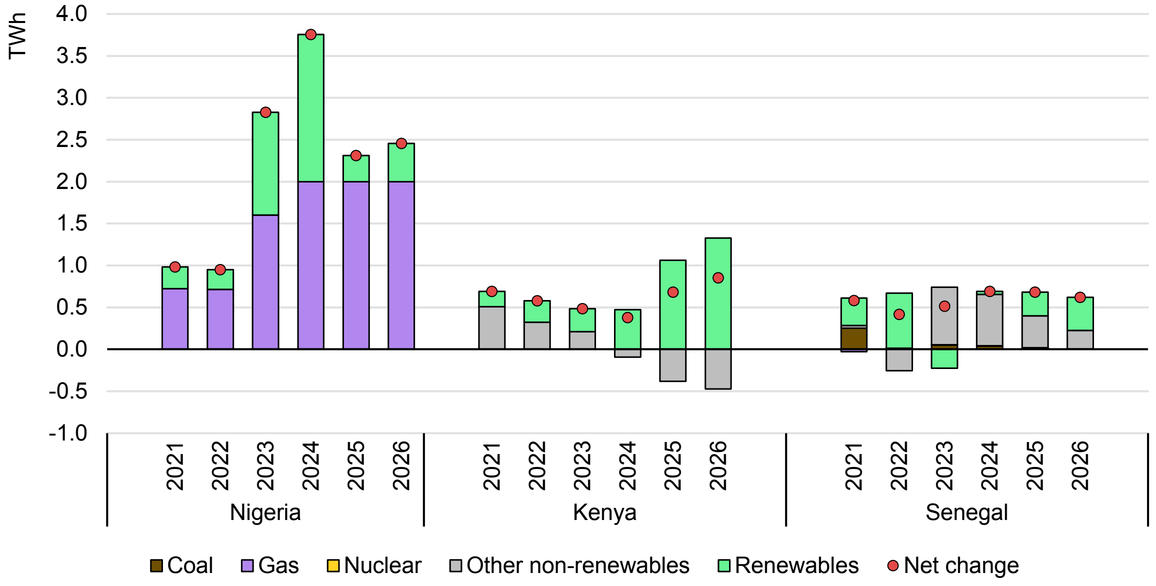
Gwagwalada Independent Power Plant is currently under construction in three phases, the first of which is to be completed in 2024. Once operational, it is expected to provide around 11% of the country's electricity.

Gas-fired generation in the country is estimated to have increased by 6% in 2023 with new plants becoming operational. We estimate that electricity demand rose by 9% in 2023 as available generation increased. From 2024-2026, electricity demand is forecast to rise by an annual average of around 7%, as new gas-fired capacities enter operation according to plan, supporting an average 6% growth rate in gas-fired generation in 2024-2026. Nevertheless, delays in commissioning of the plants and continued problems with infrastructure are sources of uncertainty in our forecast.

Year-on-year change in electricity generation in Nigeria, Kenya and Senegal, 2021-2026



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Notes: Other non-renewables includes oil, waste and other non-renewable energy sources. The figures for 2024-2026 are forecast values.

Natural gas accounted for around 75% of electricity generated on the main grid in 2023. Natural gas is expected to continue to play an important role in energy supply and grid stabilisation for Nigeria's power sector until 2030, and decline by 2050, according to the country's Energy Transition Plan (ETP).

Renewables are also forecast to increase over the 2024-2026 period, at a CAGR of around 8%, and a positive spillover in terms of GHG emission reduction (-1.8%). Hydropower accounts for most of the renewables generation during 2024-2026, largely due to the completion of the Zungeru project, with an estimated generation of 2.6 TWh per year. Hydropower is forecast to rise further in the future, thanks to the completion of the 1 650 MW Makurdi Hydropower Plant.

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Solar PV is expected to grow rapidly, with an average rate of above 50% per year over the next three years, although remaining at around 1% of generation in 2025. The off-grid space (including mini-grids, solar home systems and solar lights) represents a significant portion of solar PV electricity supply in the country, which is estimated to have reached 93 MW of installed capacity in 2021, and could drive much of the growth in the coming years. In May 2023, President Bola Tinubu announced the end of Nigeria's fossil fuel subsidies. This decision could jump-start the use of solar-based solutions to replace expensive diesel generators.

The Nigerian Rural Electrification Agency (REA) is responsible for promoting and co-ordinating rural electrification programmes and has implemented the Energizing Economies Initiative, which aims to support the rapid deployment of off-grid electricity solutions in economic clusters through private sector developers. Strong growth of off-grid solutions in Nigeria is the driver of a broader growth trend in West Africa.

In June 2023, Nigeria adopted a new Electricity Act 2023, which aims to provide a comprehensive legal and institutional framework for a privatised contract and rule-based competitive electricity market, with a view to attracting private sector investments across the power sector. While the act strengthens the role of regulatory bodies, as it introduces consumer protection measures and provides for a transparent tariff-setting process, it also opens up the possibility of multiple licensing regimes by enabling regulation at state level. Although regulation at the federal level remains the rule where no state regulation is specified, careful co-ordination and streamlining of regulatory approaches across states would be required to minimise the uncertainty of different regimes.

Other Africa

In **Kenya**, over 700 000 new customers were connected to the national grid in 2022 and 75% of the population had access to electricity (both national grid and off-grid solutions), a substantial growth compared to 47% in 2015. Electricity demand is estimated to have increased by around 4.5% in 2023, and we expect annual demand growth of 5.7% on average from 2024 to 2026. Kenya has a total installed capacity of about 3.3 GW and generated about 13 TWh, of which more than 90% was from renewable sources. The Kenyan government has an ambition of reaching a 100% share of renewables in electricity generation by 2030.

We estimate that in 2023 more than 44% of generation in Kenya came from geothermal, with the remainder of renewables coming mainly from hydropower and wind. Kenya's Lake Turkana Wind Farm is Africa's largest, with 365 turbines at 850 kWh capacity each. We anticipate the country's renewable generation to grow by around 7% per year in 2024-2026. The largest growth is anticipated in PV and wind, with 25% and 13% annual average growth, respectively. The

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government is considering the introduction of grid-scale battery energy storage systems to support increased uptake of renewable energy and displace thermal generation at peak. Kenya also aims to diversify its generation sources to include nuclear power in the future and have its first nuclear power plant up and running by 2038.

The Kenyan grid is interconnected with the Ethiopian grid through a 1 058 km line energised in 2023. The Kenya Power and Lighting Company (KPLC) started importing electricity at lower tariffs last year under a 27-year power-sharing agreement signed by the two governments. Further regional interconnections will be achieved through an interconnector with Tanzania, which is under construction, and a second line with Uganda, which is under implementation. These projects will eventually facilitate the creation of a regional power market.

According to IEA analysis, **Senegal** is well on track to achieve Sustainable Development Goal 7 (SDG7) of universal access to electricity by 2030. With some additional efforts and by deploying off-grid solutions, it can also reach its 2025 target. In 2022, 75% of the population had access to electricity, representing an increase of 17 percentage points over the past decade. Despite this rapid progress, disparities remain between urban and rural areas, where access rates are 97% and 55%, respectively. Adequacy and affordability of electricity supply to meet growing demand is a key concern for the country.

Electricity demand rose by an estimated 8% in 2023 and is forecast to grow at a slightly stronger pace of 9.% in 2024-2026. Supply is mostly dominated by fossil fuels, particularly imported heavy fuel oil (HFO). In 2021, total installed power capacity amounted to 1.62 GW, with fossil fuels accounting for 72% (1.16 GW). In 2022, renewables accounted for around 25% of total electricity generation and for 30% of installed capacity, in line with government targets.

Hoping to leverage domestic natural gas resources under development, Senegal is pursuing a gas-to-power strategy to switch from imported HFO to natural gas to reduce costs and emissions, as well as to increase security of supply. A 300 MW gas-fired combined-cycle power plant at Cap de Biches is expected to come online in 2024.

A new electricity code (Law no. 2021-31) approved in 2021 is paving the way for the unbundling of the power sector. Under this new framework, the government of Senegal is developing an Integrated Low-Cost Plan (PIMC) to enhance planning in the sector. In 2023, Senegal entered a Just Energy Transition Partnership (JETP) with France, Germany, the European Union, the United Kingdom and Canada. Under the JETP, the international partners are undertaking to mobilise up to EUR 2.5 billion to support the country in accelerating clean energy deployment for sustainable development. Senegal increased its renewable energy targets to 40% of installed capacity by 2030.

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Annexes

Summary tables

Regional breakdown of electricity demand, 2021-2026

TWh	2021	2022	2023	2026	Growth rate 2021-2022	Growth rate 2022-2023	CAAGR 2024-2026
Africa	753	765	780	887	1.6%	1.9%	4.4%
Americas	6 219	6 382	6 353	6 677	2.6%	-0.4%	1.7%
of which United States	4 170	4 277	4 208	4 404	2.6%	-1.6%	1.5%
Asia Pacific	13 193	13 733	14 394	16 459	4.1%	4.8%	4.6%
of which China	8 307	8 615	9 164	10 573	3.7%	6.4%	4.9%
Eurasia	1 302	1 316	1 335	1 386	1.1%	1.5%	1.3%
Europe	3 813	3 674	3 586	3 845	-3.6%	-2.4%	2.4%
of which European Union	2 736	2 651	2 568	2 749	-3.1%	-3.2%	2.3%
Middle East	1 172	1 210	1 235	1 347	3.3%	2.1%	2.9%
World	26 453	27 080	27 682	30 601	2.4%	2.2%	3.4%

Notes: Data for 2023 are preliminary; 2024-2026 are forecasts. Differences in totals are due to rounding. CAAGR = Compounded average annual growth rate. For the CAAGR 2024-2026 reported, end of 2023 data is taken as base year for the calculation. For the entire period European Union data is for the 27 member states.

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Breakdown of global electricity supply and emissions, 2021-2026

TWh	2021	2022	2023	2026	Growth rate 2021-2022	Growth rate 2022-2023	CAAGR 2023-2026
Nuclear	2 809	2 668	2 741	2 959	-5.0%	2.7%	2.6%
Coal	10 284	10 442	10 613	10 088	1.5%	1.6%	-1.7%
Gas	6 556	6 609	6 639	6 785	0.8%	0.5%	0.7%
Other non-renewables	852	857	782	705	0.6%	-8.8%	-3.4%
Total renewables	7 925	8 549	8 959	12 158	7.9%	4.8%	10.7%
Total Generation	28 426	29 124	29 734	32 694	2.5%	2.1%	3.2%

Mt CO_2	2021	2022	2023	2026	Growth rate 2021-2022	Growth rate 2022-2023	CAAGR 2023-2026
Total emissions	13 263	13 448	13 575	13 111	1.4%	0.9%	-1.2%

Breakdown of Asia Pacific electricity supply and emissions, 2021-2026

TWh	2021	2022	2023	2026	Growth rate 2021-2022	Growth rate 2022-2023	CAAGR 2023-2026
Nuclear	727	746	792	916	2.6%	6.1%	5.0%
Coal	8 000	8 196	8 675	8 542	2.5%	5.8%	-0.5%
Gas	1 517	1 481	1 471	1 600	-2.4%	-0.7%	2.8%
Other non-renewables	203	198	155	126	-2.2%	-21.9%	-6.7%
Total renewables	3 554	3 946	4 155	6 136	11.0%	5.3%	13.9%
Total Generation	14 001	14 568	15 248	17 321	4.0%	4.7%	4.3%

Mt CO_2	2021	2022	2023	2026	Growth rate 2021-2022	Growth rate 2022-2023	CAAGR 2023-2026
Total emissions	8 420	8 589	9 011	8 929	2.0%	4.9%	-0.3%

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Breakdown of Americas electricity supply and emissions, 2021-2026

TWh	2021	2022	2023	2026	Growth rate 2021-2022	Growth rate 2022-2023	CAAGR 2023-2026
Nuclear	942	924	924	924	-1.8%	0.0%	0.0%
Coal	1 110	1 025	844	618	-7.7%	-17.7%	-9.9%
Gas	2 204	2 291	2 421	2 422	3.9%	5.7%	0.0%
Other non-renewables	206	205	200	179	-0.4%	-2.8%	-3.6%
Total renewables	2 264	2 490	2 521	3 101	10.0%	1.2%	7.2%
Total Generation	6 726	6 934	6 909	7 244	3.1%	-0.4%	1.7%

Mt CO_2	2021	2022	2023	2026	Growth rate 2021-2022	Growth rate 2022-2023	CAAGR 2023-2026
Total emissions	2 107	2 057	1 938	1 709	-2.4%	-5.8%	-4.1%

Breakdown of Europe electricity supply and emissions, 2021-2026

TWh	2021	2022	2023	2026	Growth rate 2021-2022	Growth rate 2022-2023	CAAGR 2023-2026
Nuclear	889	750	769	827	-15.6%	2.5%	2.5%
Coal	646	686	558	402	6.2%	-18.6%	-10.4%
Gas	843	796	665	547	-5.6%	-16.4%	-6.3%
Other non-renewables	86	95	89	67	10.1%	-6.3%	-9.1%
Total renewables	1 589	1 588	1 729	2 247	0.0%	8.9%	9.1%
Total Generation	4 053	3 915	3 811	4 090	-3.4%	-2.7%	2.4%

Mt CO_2	2021	2022	2023	2026	Growth rate 2021-2022	Growth rate 2022-2023	CAAGR 2023-2026
Total emissions	1 000	1 033	856	649	3.3%	-17.1%	-8.8%

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Breakdown of Eurasia electricity supply and emissions, 2021-2026

TWh	2021	2022	2023	2026	Growth rate 2021-2022	Growth rate 2022-2023	CAAGR 2023-2026
Nuclear	225	211	208	220	-6.3%	-1.4%	1.9%
Coal	261	279	289	285	6.8%	3.6%	-0.4%
Gas	666	678	687	712	1.8%	1.3%	1.2%
Other non-renewables	18	12	12	14	-33.6%	-0.7%	5.3%
Total renewables	284	289	293	308	1.8%	1.4%	1.6%
Total Generation	1 454	1 469	1 489	1 539	1.0%	1.4%	1.1%

Mt CO_2	2021	2022	2023	2026	Growth rate 2021-2022	Growth rate 2022-2023	CAAGR 2023-2026
Total emissions	548	565	578	589	3.3%	2.2%	0.6%

Breakdown of Middle East electricity supply and emissions, 2021-2026

TWh	2021	2022	2023	2026	Growth rate 2021-2022	Growth rate 2022-2023	CAAGR 2023-2026
Nuclear	13	26	39	57	95.3%	51.6%	13.6%
Coal	21	18	17	4	-14.6%	-4.2%	-38.3%
Gas	956	985	1 004	1 078	3.0%	2.0%	2.4%
Other non-renewables	284	278	261	256	-1.8%	-6.1%	-0.7%
Total renewables	43	49	59	98	14.4%	21.1%	18.2%
Total Generation	1 316	1 355	1 381	1 493	3.0%	1.9%	2.6%

Mt CO_2	2021	2022	2023	2026	Growth rate 2021-2022	Growth rate 2022-2023	CAAGR 2023-2026
Total emissions	716	725	721	741	1.2%	-0.5%	0.9%

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Breakdown of Africa electricity supply and emissions, 2021-2026

TWh	2021	2022	2023	2026	Growth rate 2021-2022	Growth rate 2022-2023	CAAGR 2023-2026
Nuclear	12	10	9	13	-20.7%	-11.5%	15.2%
Coal	246	238	229	238	-3.0%	-4.0%	1.2%
Gas	371	379	391	425	2.2%	3.3%	2.8%
Other non-renewables	56	69	66	63	22.7%	-4.4%	-1.2%
Total renewables	191	187	201	268	-2.0%	7.6%	10.0%
Total Generation	876	883	896	1 007	0.8%	1.5%	4.0%

Mt CO_2	2021	2022	2023	2026	Growth rate 2021-2022	Growth rate 2022-2023	CAAGR 2023-2026
Total emissions	473	479	471	493	1.3%	-1.6%	1.5%

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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] Czechia, Denmark, Estonia, Finland, France, Germany, Gibraltar, Greece, Hungary, Iceland, Ireland, Italy, Kosovo[7] 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] Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain and Sweden.

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Middle East – Bahrain, Islamic Republic of Iran, Iraq, Israel[8], 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 the Republic of 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 the United Nations, Türkiye shall preserve its position concerning the "Cyprus issue".

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.

[7] 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.
[8] 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.

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Abbreviations and acronyms

ACER	European Union Agency for the Cooperation of Energy Regulators
AEMO	Australian Energy Market Operator
AI	artificial intelligence
BESS	battery energy storage system
BIL	Bipartisan Infrastructure Law
BMWK	Federal Ministry for Economic Affairs and Climate Action
BNetzA	Bundesnetzagentur - German Federal Network Agency
CAISO	California Energy Market Operator
CBAM	Carbon Border Adjustment Mechanism
CCRG	compound average growth rate
CERC	Central Electricity Regulator Commission
CFDs	contracts for difference
CO2	carbon dioxide
CSP	concentrated solar power
DRE	distributed renewable energy
DSOs	distribution system operators
ERCOT	Electric Reliability Council of Texas
EU-ETS	EU Emission Trading System
FERC	Federal Energy Regulatory Commission
FFR	fast frequency response
GDP	gross domestic product
GEC	Green Electricity Certificates
HFO	heavy fuel oil
HP-DAM	High-Price Day-Ahead Market
HVDC	high-voltage direct current
IAEA	International Atomic Energy Agency
ICT	Information and Communications Technology
IMF	International Monetary Fund
IPP	independent power producers
IRA	Inflation Reduction Act
JETP	Just Energy Transition Partners
METDS	Moroccan Minister of Energy Transition and Sustainable Development
NERC	North American Electricity Reliability Corporation
NETR	National Energy Transition Roadmap
NIS	Network and Information Directive
NPK	Nitrogen, Phosphorus and Potassium
NZE	Net Zero Emissions by 2050 Scenario
PDP	Power Development Plan
PPA	power purchase agreement
PPP	purchasing power parity
SHS	Solar home systems
SIR	Synchronous Inertia Response

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SMP	System Marginal Price
SMR	small modular reactors
STEPS	Stated Policies Scenario
TSOs	transmission system operators
VGF	Viability GAP Funding
VRE	variable renewable energy

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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
g CO_2	gramme of carbon dioxide
g CO_2/KWh	grammes of carbon dioxide per kilowatt hour
GJ	gigajoule
Gt/yr	gigatonnes per year
GW	gigawatt
kt	kilo tonnes
MW	megawatt
MWh	megawatt-hour
Mt	million tonnes
Mt CO_2	million tonnes of carbon dioxide
Mt CO_2/yr	million tonnes of carbon dioxide per year
GW	gigawatt
GWh	gigawatt hour
TWh	terawatt-hour

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