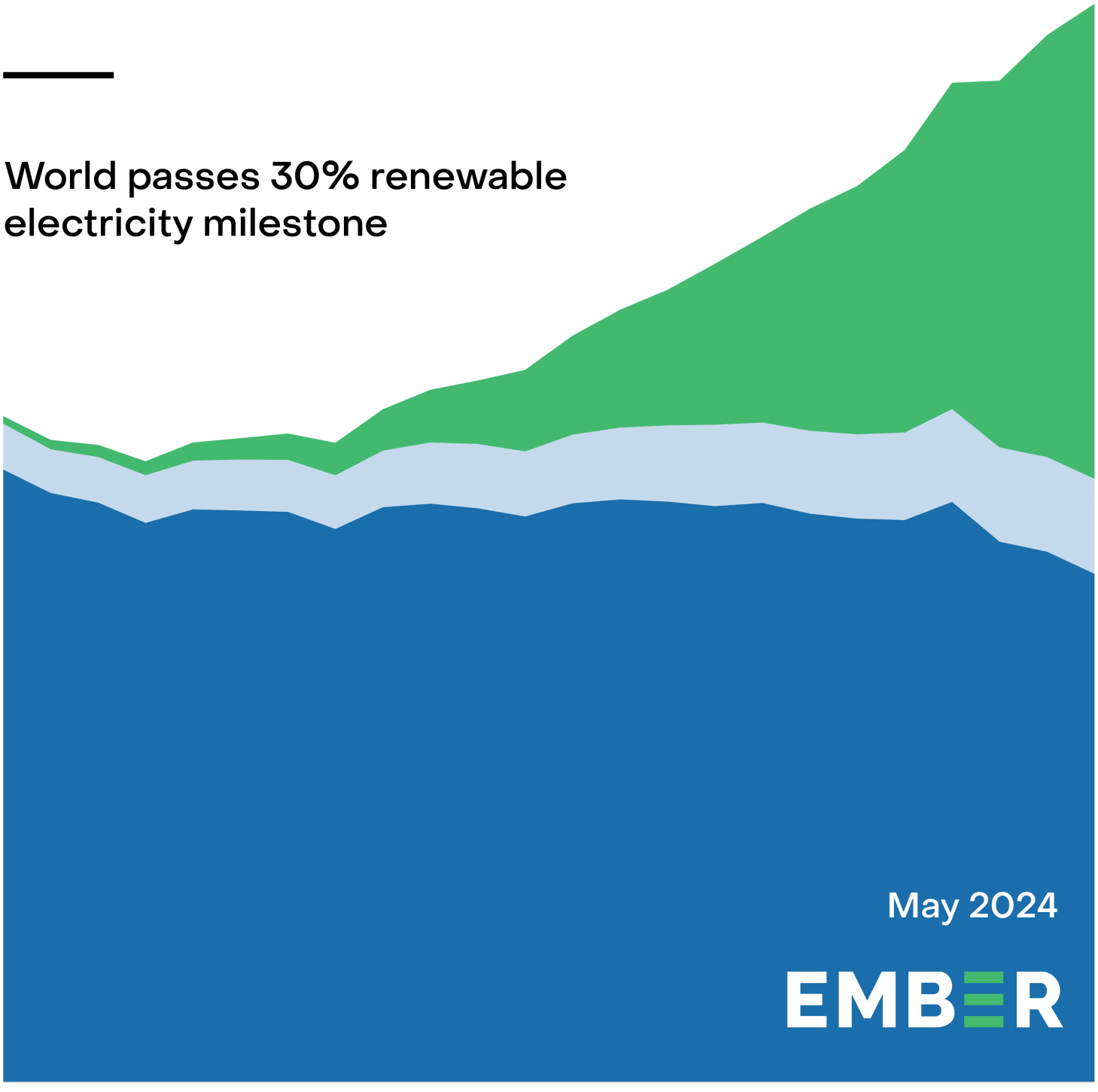
Global Electricity Review 2024

World passes 30% renewable electricity milestone



May 2024

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About

Ember's fifth annual Global Electricity Review provides the first comprehensive overview of changes in global electricity generation in 2023, based on reported data. It presents the trends underlying them, and the likely implications for energy sources and power sector emissions in the near future. With the report, Ember is also releasing the first comprehensive, free dataset of global electricity generation in 2023.

The report analyses electricity data from 215 countries, including the latest 2023 data for 80 countries representing 92% of global electricity demand. The analysis also includes data for 13 geographic and economic groupings, such as Africa, Asia, the EU and the G7. It also dives deeper into the top six CO2 emitting countries and regions, which account for over 72% of global power sector emissions, and the Annex gives an overview of 25 other countries that are significant polluters.

We make all of the data freely accessible to empower others to do their own analysis and help speed the switch to clean electricity.

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+23%

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+10%

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+0.8%

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Record renewables propel the world towards a new era of falling fossil generation

Renewables generated a record 30% of global electricity in 2023, driven by growth in solar and wind. With record construction of solar and wind in 2023, a new era of falling fossil generation is imminent. 2023 was likely the pivot point, marking peak emissions in the power sector.

The renewables revolution – led by solar and wind – is breaking records and driving ever-cleaner electricity production. The world is now at a turning point where solar and wind not only slow emissions growth, but actually start to push fossil generation into decline.

Indeed, the expansion of clean capacity would have been enough to deliver a fall in global power sector emissions in 2023. However, drought caused a five-year low in hydropower, which created a shortfall that was met in large part by coal. Nonetheless, the latest forecasts give confidence that 2024 will begin a new era of falling fossil generation, marking 2023 as the likely peak of power sector emissions.

01 Renewables provided 30% of global electricity for the first time

In 2023, growth in solar and wind pushed the world past 30% renewable electricity for the first time. Renewables have expanded from 19% of global electricity in 2000, driven by an increase in solar and wind from 0.2% in 2000 to a record 13.4% in 2023. China was the main contributor in 2023, accounting for 51% of the additional global solar generation and 60% of new global wind generation. Combined with nuclear, the world generated almost 40% of its electricity from low-carbon sources in 2023. As a result, the CO2 intensity of global power generation reached a new record low, 12% lower than its peak in 2007.

02

Solar was the main supplier of electricity growth in 2023

Solar is leading the energy revolution. It was the fastest-growing source of electricity generation for the 19th year in a row, and surpassed wind to become the largest source of new electricity for the second year running. Indeed, solar added more than twice as much new electricity as coal in 2023. The record surge in installations at the very end of 2023 means that 2024 is set for an even larger increase in solar generation.

03

Hydropower fell to a five-year low, preventing a fall in emissions in 2023

Drought conditions resulted in a record fall in hydropower generation, which dropped to a five-year low. Under normal conditions, the clean capacity added during 2023 would have been enough to enable a 1.1% fall in fossil generation. However, the shortfall in hydropower was met by an increase in coal generation, which led to a 1% increase in global power sector emissions. 95% of the coal generation rise in 2023 occurred in four countries that were severely affected by droughts: China, India, Viet Nam and Mexico.

04

Demand growth slowed in 2023, but in future it will only go up

Global electricity demand rose to a record high in 2023, with an increase of 627 TWh which is equivalent to adding the entire demand of Canada (+607 TWh). Nevertheless, the 2023 increase of 2.2% was below the average for recent years, due to a pronounced decrease in demand in OECD countries, notably the US (−1.4%) and the EU (−3.4%). In contrast, the rapid demand growth in China (+6.9%) was equivalent to the total global growth in demand in 2023. More than half of the electricity demand rise in 2023 was from five technologies: electric vehicles (EVs), heat pumps, electrolysers, air conditioning and data centres. The spread of these technologies will accelerate the growth in electricity demand, but overall energy demand will decline as electrification is much more efficient than fossil fuels.

05

A new era of declining power sector emissions is about to begin

Ember forecasts fossil generation to fall slightly in 2024, leading to larger falls in subsequent years. Demand growth in 2024 is expected to be higher than in 2023 (+968 TWh) but clean generation growth is forecast to be even greater (+1300 TWh), leading to a 2% fall in global fossil generation (−333 TWh). Already the rollout of clean generation, led by solar and wind, has helped to slow the growth in fossil fuels by almost two-thirds in the last ten years. As a result, half the world's economies are already at least five years past a peak in electricity generation from fossil fuels. OECD countries are at the forefront of this, with power sector emissions collectively peaking in 2007 and falling 28% since then.

The decade ahead will see the energy transition enter a new phase. A permanent decline in fossil fuel use in the power sector at a global level is now inevitable, leading to falling sector emissions. Clean electricity additions – led by solar and wind – are already forecast to outpace demand growth in the coming decade, securing moderate reductions in fossil fuel use and hence emissions, even as demand accelerates to meet the growing needs of electrification and other booming technologies.

For the goal of achieving international climate change targets, this is critical, with multiple analyses finding that the power sector should be the first to decarbonise – by 2035 in OECD countries, by 2045 in the rest of the world. The sector is currently the highest emitting of all, producing more than a third of energy-related carbon dioxide emissions. Clean electricity is also key to decarbonising transport, heating and much of industry, by replacing the fossil fuel burning that currently takes place in car and bus engines, boilers, furnaces and other applications. An accelerating transition to a clean electrified economy powered by wind, solar and other forms of clean energy will also unlock benefits in areas such as economic growth, jobs, air quality and energy sovereignty.

The pace of emissions declines will be shaped by how quickly the build-out of clean power continues. There is a global consensus on the scale of ambition needed. At the UN's COP28 climate change conference in December, world leaders reached a historic agreement to triple global renewables capacity by 2030. The target would see the world reach 60% renewable electricity by 2030, almost halving power sector emissions and putting the world on a pathway aligned with the 1.5C climate goal. Leaders also agreed at COP28 to double annual energy efficiency improvements by 2030, which will be crucial to delivering the full potential of electrification and avoiding runaway growth in electricity demand.

Countries are already demonstrating the key enablers that galvanise rapid growth in solar and wind, including high-level policy ambition, incentive mechanisms and flexibility solutions. The report highlights three countries – China, Brazil and the Netherlands – which show that despite very different starting points, the combination of these approaches is delivering rapid transformations of their electricity systems and preparing the way for a clean, electrified economy.

“The renewables future has arrived. Solar in particular is accelerating faster than anyone thought possible.

The decline of power sector emissions is now inevitable. 2023 was likely the pivot point – peak emissions in the power sector – a major turning point in the history of energy.

But the pace of emissions falls depends on how fast the renewables revolution continues. The good news is we already know the key enablers that help countries unleash the full potential of solar and wind.

There’s an unprecedented opportunity for countries that choose to be at the forefront of the clean energy future. Expanding clean electricity not only helps to decarbonise the power sector. It also provides the step up in supply needed to electrify the whole economy; and that’s the real game-changer for the climate.”

Dave Jones

Global Insights Programme Director, Ember

World hit 30% renewable electricity in 2023, driving carbon intensity to record low

Strong growth in wind and solar drove the share of renewables in the global electricity mix above 30% and total clean generation to almost 40%. As a result, the carbon intensity of the world's electricity reached a new record low.

However, clean sources were unable to meet all of the rise in demand, and a record fall in hydropower created a further shortfall, so fossil generation increased to meet the gap. Therefore, total power sector emissions rose to a new record high.

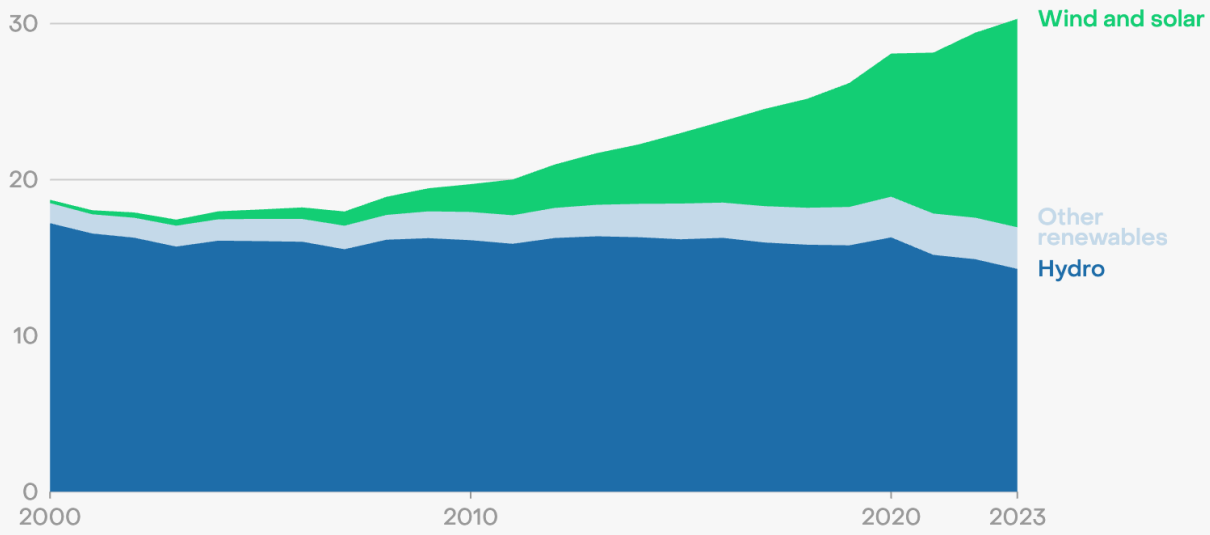
Chapter contents

1.1 Renewables hit 30% of global electricity

Strong growth in wind and solar drove the share of renewables in the global electricity mix above 30% for the first time. 102 countries had a renewable generation share of 30% or higher, up from 98 in 2022 and for 69 countries the renewables share exceeded 50%, up from 66 in 2022. Combined with nuclear, 39.4% of global electricity now comes from low-carbon sources.

Global growth in wind and solar pushed renewables to make up more than 30% of the global electricity mix in 2023

Share of global electricity generation from renewable sources (%)



Source: Annual electricity data, Ember

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Record solar and wind generation

Wind and solar generation continued to expand faster than any other source of electricity. Together they reached a new record high of 13.4% (3,935 TWh) in 2023, gaining another 1.5 percentage points of the global electricity mix compared to 2022 (11.9%, 3,422 TWh).

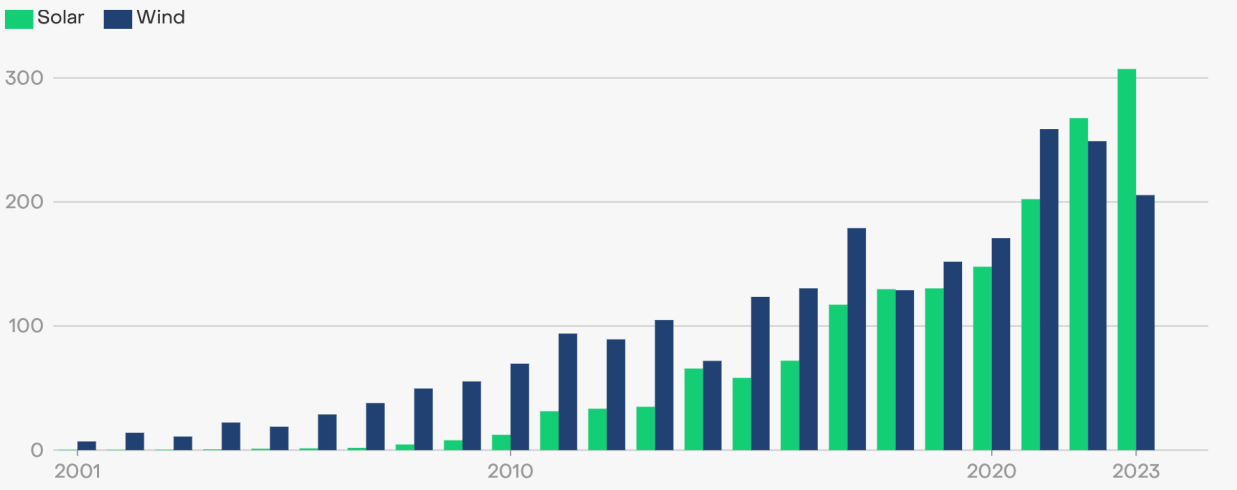
China was the main contributor, accounting for 51% of the additional global solar generation in 2023 and 60% of new global wind generation. Other major contributors to global wind growth include the EU (24%) and Brazil (7%), while global solar growth was provided by the EU (12%) and the US (11%). Together the top four solar growth economies – China, the EU, the US and Brazil – accounted for 81% of solar power growth in 2023.

Solar growth outpaced wind, but both were slower than expected

Solar is leading the energy revolution, adding more than twice as much new electricity as coal in 2023. It was the fastest-growing source of electricity generation for the 19th year in a row. 2023 was the second consecutive year in which global growth in solar generation (+307 TWh, +23%) outpaced wind (+206 TWh, +9.8%). Solar reached a 5.5% share of the global electricity mix (1,631 TWh), up from 4.6% in 2022. Wind still provides a higher share of global electricity, at 7.8% in 2023 (2,304 TWh).

Solar outpaced wind generation growth in 2023 for the second year running

Annual change in electricity generation (TWh)



Source: Annual electricity data, Ember

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Despite reaching new record highs, the absolute growth in wind and solar (+513 TWh) was below expectations and slightly smaller than in 2022 (+517 TWh). This was mainly due to lower-than-expected wind growth, which was 18% lower compared to the 249 TWh increase in 2022.

The US was a key contributor to the wind slowdown, experiencing a fall in wind generation for the first time since at least 2001 (-9.1 TWh, -2.1%). Low wind conditions kept load factors close to the lowest levels seen in the past five years, while capacity additions slowed before an anticipated uplift from the Inflation Reduction Act. These were likely short-term factors, bringing confidence in a return to growth levels similar to those from 2020-2021.

Solar generation growth was also lower than expected, lagging behind record high capacity additions (+36%) in 2023. The biggest reasons (further examined in Chapter 2.2) are the higher share of capacity additions in areas like China which experienced lower sunlight in 2023, and the underreporting of solar generation in some countries. When correcting for temporary factors – underreporting, sunniness and the timing of additions – the 2023 increase in generation could have been as high as 29% instead of 23%, bolstering our confidence in a larger increase in 2024.

A record fall in global hydropower generation led to a five-year low

Following a record annual fall (-88 TWh), global hydropower generation fell to a five-year low of 4,210 TWh. Although it remained the largest source of clean power globally, its share in the world's electricity mix dropped 0.6 percentage points to 14.3% – the lowest level since at least 2000 and just 1 percentage point above wind and solar. This occurred despite the construction of new dams, with 7 GW of hydro capacity added in 2023 according to IRENA.

Droughts affected hydro output in different regions, including Asia (-5.9%) and North America (-7.4%) – especially Mexico which saw a fall of 42%. Meanwhile, EU hydro generation recovered only partially from the 2022 multi-decade low (+14%).

China saw the largest absolute drop in hydro of 59 TWh (-4.5%), with the fall concentrated in the first half of the year as generators were instructed to save water for the winter period to avoid power shortages. Other Asian economies were even more severely affected, with hydro generation falling 15% in India and 20% in Viet Nam.

Nuclear remained the same

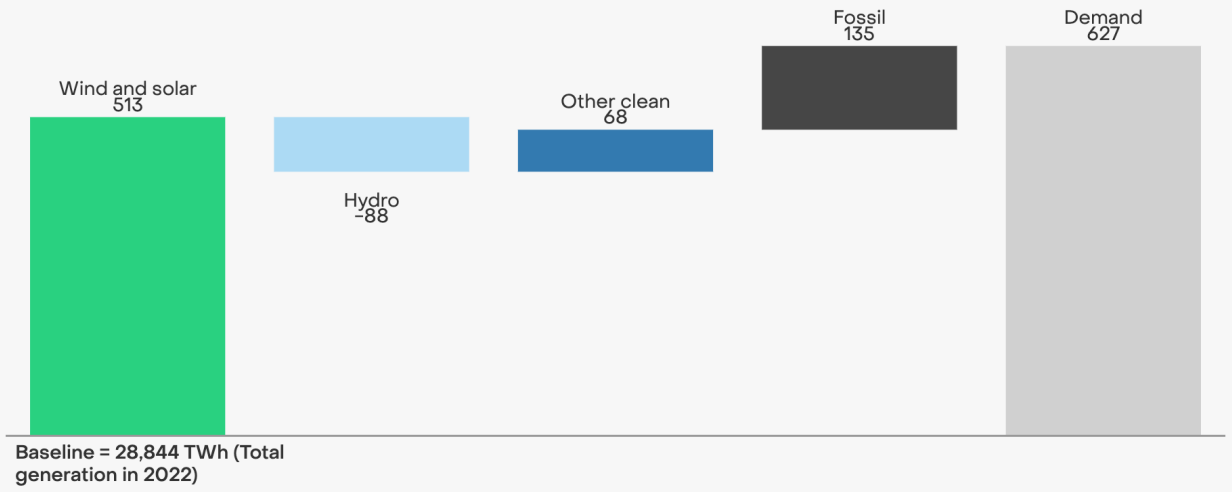
Nuclear provided 9.1% of global electricity in 2023, unchanged from the previous year. Global nuclear power generation increased by a marginal 46 TWh (+1.8%) to 2,686 TWh, recovering less than 40% of its fall in 2022 (−123 TWh, −4.4%). The partial recovery of French nuclear power from 2022 contributed strongly (+41 TWh), together with restarts in Japan's nuclear fleet (+26 TWh). Elsewhere in the world, new reactors in Finland, the US and China came online and helped offset the effect of voluntary early closure of reactors in Germany and Belgium.

Bioenergy showed a small increase

Global bioenergy electricity generation increased by 21 TWh (+3.1%), mainly due to growth in China (+28 TWh, +15.6%), while in OECD countries it fell by 8.9 TWh (−2.6%). As a result, its share in the global mix remained at just 2.4%. The risk of emissions, plus wider social and ecological impacts, constrains the use of bioenergy for decarbonising the power sector (see Chapter 4.7).

Wind and solar power grew most in 2023, but other clean electricity sources underperformed

Annual change in electricity generation (TWh)



Source: Annual electricity data, Ember

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1.2 Demand growth was below trend but clean growth still fell short

Demand growth was lower than usual in 2023, but despite this, clean growth was not able to meet all of the increase and so fossil generation grew marginally to meet the shortfall.

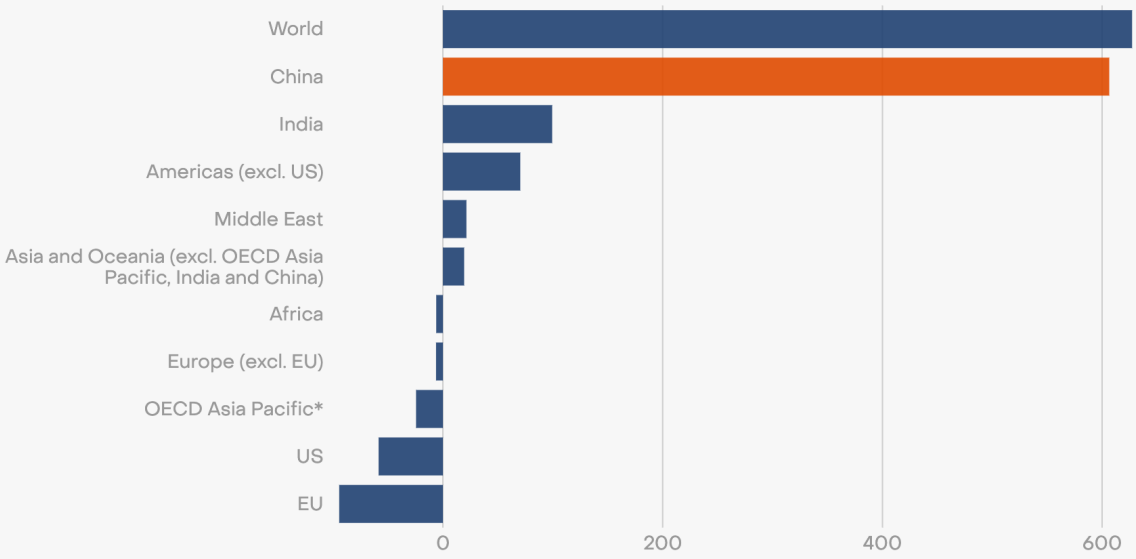
Demand growth was below trend

In 2023, global electricity demand increased by 627 TWh (+2.2%), the equivalent of adding the entire electricity demand of Canada (607 TWh). This brought total global demand to a new record high of 29,471 TWh. Nevertheless, 2023's growth rate was lower than the 2.5% average growth of the past decade (2012–2022).

China remained the main engine of global electricity demand growth. China's rapid growth (+606 TWh, +6.9%) was just 21 TWh lower than the net global increase. India's growth (+99 TWh, +5.4%) was the next largest contributor.

China was the main driver of global electricity demand growth, while the EU and US saw sharp falls

Change in electricity demand in 2023 (TWh)



Source: Annual electricity data, Ember
*South Korea, Japan, Australia and New Zealand

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The increase in global electricity demand was limited primarily by a pronounced decrease in OECD countries. The largest demand falls were seen in the US (–1.4%) and the EU (–3.4%), amid milder weather and – mainly in the case of the EU – a temporary downturn in industrial activity and demand reduction measures. Demand also fell in Japan (–1.9%) amid economic headwinds in the manufacturing sector and demand reduction measures.

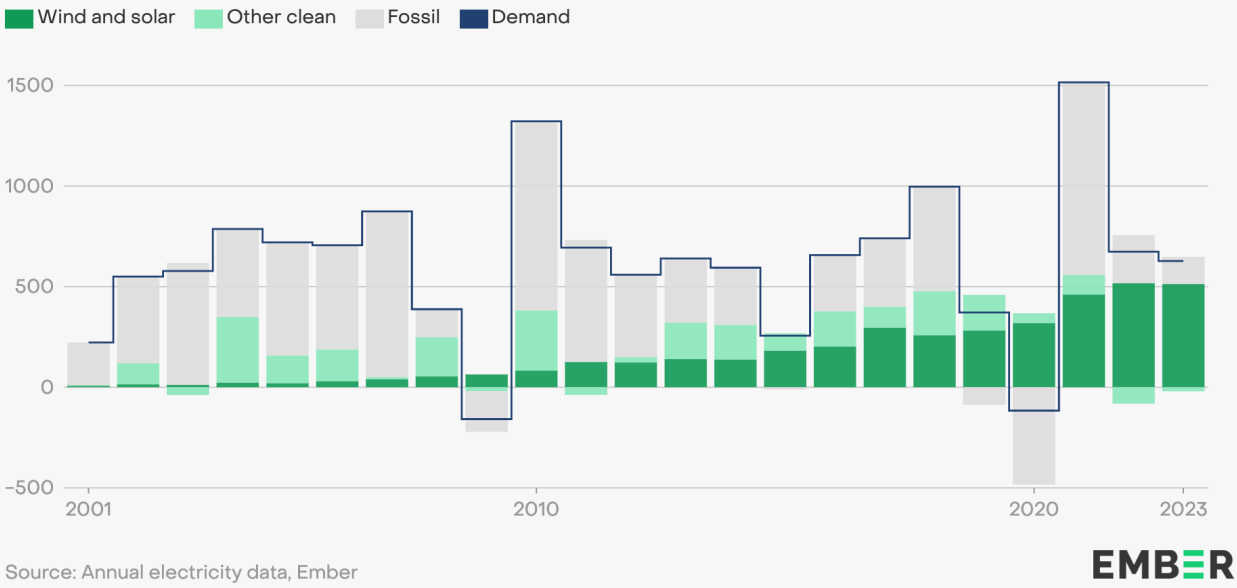
Demand growth is expected to accelerate going forward as electrification picks up speed alongside growing pressures from technologies like AI and greater demand for cooling (as explored in Chapter 2.3), raising the question of whether clean power growth will accelerate fast enough to meet it.

Wind and solar met most of the electricity demand rise

Wind and solar rose by 513 TWh, slightly less than in 2022 (+517 TWh) but they met 82% of the 2023 global electricity demand growth, compared to 77% in 2022. The higher share was due to the smaller demand increase in 2023 (+627 TWh) compared to 2022 (+674 TWh).

Growth in wind and solar met 82% of the global electricity demand rise in 2023

Annual change in electricity generation (TWh)



Source: Annual electricity data, Ember

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Despite their lower-than-expected growth, solar and wind were the powerhouses of newly added clean electricity. In aggregate, all other clean electricity sources fell – small rises in bioenergy and nuclear were not enough to counter the large fall in hydro generation caused by extensive droughts. Together, all clean sources met 79% of the increase in electricity demand, creating a shortfall that was met by fossil generation.

1.3 Carbon intensity fell, but emissions narrowly hit another record high

2023 marked another major leap forward in reducing the CO2 intensity of global power generation, reaching a new record low of 480 gCO2/kWh, down 1.2% from 486 gCO2/kWh in 2022, as the share of clean sources reached a record high.

However, absolute fossil generation increased 135 TWh (+0.8%) to meet the remainder of demand growth not met by clean sources, with small increases in coal and gas. As a result, global emissions rose by 1% (+135 million tonnes of CO2) in 2023, reaching 14,153 million tonnes of CO2 – a record high.

2023 came very close to becoming the first year of a new era of falling power sector emissions. As clean electricity growth continues, we have growing confidence that in 2024, it will rise above electricity demand and lead to a fall in emissions (as explored in Chapter 2.1).

Small increases in coal and gas

Global coal generation increased by 1.4% from 10,288 TWh in 2022 to 10,434 TWh in 2023, but its share in the global electricity mix fell by 0.3 percentage points from 35.7% to 35.4%. Although it is a relatively small decrease it is a positive sign of the progress in the global energy transition. As explored below, coal generation is in rapid decline in mature economies, while coal increased mainly in four emerging economies hit by droughts in 2023.

Global gas generation increased only slightly (+53 TWh, +0.8%) and its share in the mix fell 0.3 percentage points to 22.5%. The increase in the US (+115 TWh, +6.8%) was more than 2.5 times the growth recorded at the global level, but was largely offset by sizable falls in the EU (−86 TWh, −16%), the UK (−25 TWh, −20%) and Japan (−27 TWh, −7.4%), where falling demand and rising clean power pushed out both coal and gas. The EU has now seen gas generation fall for four years in a row.

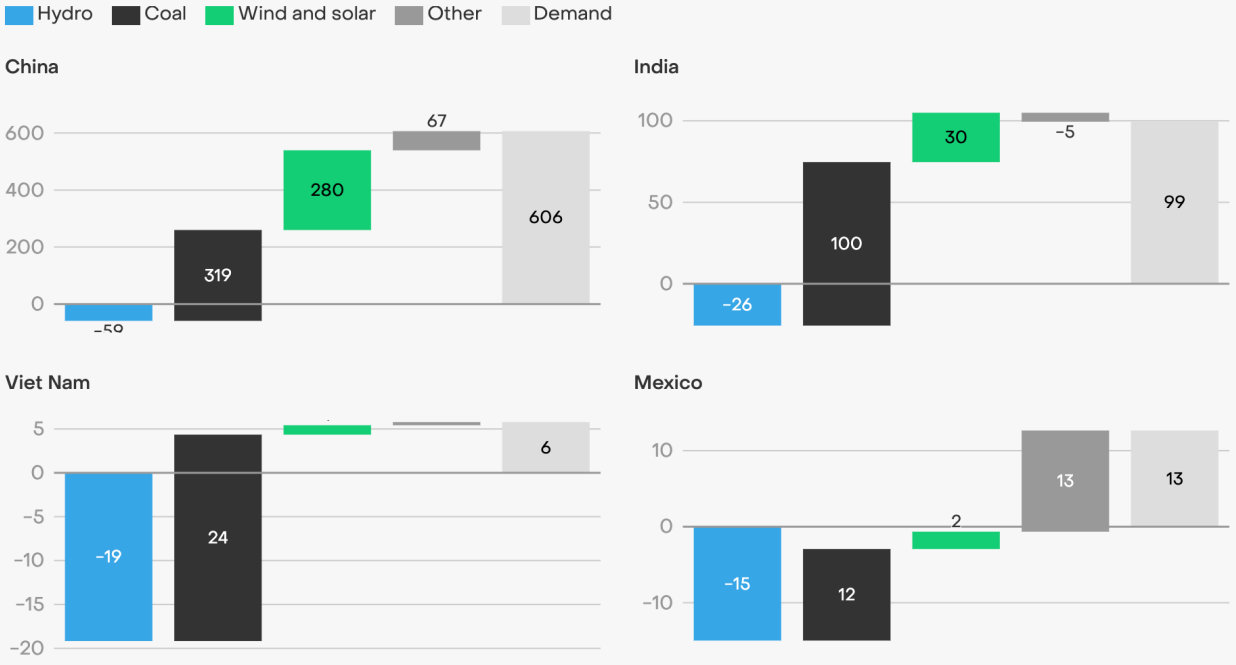
Droughts and high demand drove coal rises in key emerging markets

The hydro deficit in 2023 was a major factor behind the increase in fossil generation at a global level. 95% of the coal generation rise occurred in four countries that were severely affected by droughts, while also having above-average demand growth, in part boosted by heatwaves and greater cooling requirements. Coal generation increased by 319 TWh (+5.9%) in China, by far the largest contributor, followed by India (+100 TWh, +7.3%), Viet Nam (+24 TWh, +23%) and Mexico (+12 TWh, +55%).

In China and India, lower hydro accounted for 18% and 26% of the rise in coal, respectively. The rest of the coal increase in these two countries was to meet the shortfall in additional electricity demand. In Viet Nam, lower hydro accounted for 81% of its coal rise and the country struggled to meet the rise in demand, experiencing rolling black-outs. In Mexico, both coal and gas generation had to increase to meet the hydro shortfall.

95% of the global rise in coal generation in 2023 occurred in four countries that were severely affected by droughts

Annual change in electricity generation, 2023 (TWh)



Source: Annual electricity data, Ember
'Other' includes gas, bioenergy, other renewables, other fossil generation and net imports; the majority of Mexico's 'Other' generation is from an increase in gas power

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Coal generation and emissions fell strongly in many mature economies

The increase in coal generation in key emerging markets was partly offset by large falls in mature economies. 86% of the fall in global coal generation came from OECD economies. The largest falls were registered in the US (−156 TWh, −19%), the EU (−113 TWh, −25%) and Japan (−22 TWh, −6.3%). Demand reduction and clean power generation contributed to these coal falls. In Europe, this was mainly thanks to wind and solar. In the US, it was coal to gas switching, while in Japan nuclear was the main contributor.

The mega-trends shaping the electricity transition in 2024

This section explores four trends that define today's electricity transition.

The world is entering a new era of falling power sector emissions. This chapter begins by examining why power sector emissions are likely to fall in 2024 – leaving 2023 as the peak of fossil generation – and then examines how fast global power emissions may fall this decade, as policymakers gear up to triple global renewable capacity and expand other clean sources.

Solar energy is leading the energy revolution, unlocking the possibility of achieving the tripling goal, and putting the electricity sector on course towards climate targets. We look at how the rise in new solar capacity in 2023 surpassed expectations and how growth in 2024 will continue.

We then contrast the weak electricity demand growth in 2023 – especially in OECD countries – with the big rise expected in 2024 and beyond. The future expansion of electrification – with China leading on this – and also the growth in data centres and rising use of air conditioning are significantly adding to electricity demand. We highlight just how important it is to avoid wastefulness and inefficiency, which reduce our ability to quickly reduce emissions.

Finally, we look at case studies of policies that have helped three very different countries – China, Brazil and the Netherlands – achieve rapid growth in solar and wind in the last few years.

Through these four trends, we explore the factors behind the rapid and profound changes rippling through the electricity sector, and set out the reasons why these changes will only accelerate in the coming years.

Chapter contents

2.1 Past the peak: A new era of falling power emissions

2023 was likely the peak of fossil generation, unlocking a new era of falling power sector emissions. Solar and wind have dramatically slowed emissions growth, and many countries are already past peak power emissions. We forecast that power sector emissions will likely fall in 2024 – and would likely have done so already in 2023 had it not been for droughts reducing hydro generation. In last year's report, Ember estimated that there would be a 0.4% reduction in power sector emissions in 2023, but because of the record fall in hydropower generation emissions instead grew by 1%.

In the years ahead, solar and wind additions are forecast to be sufficient to reduce power emissions, even under scenarios of high electricity demand growth. The fact that solar and wind will continue to increase gives confidence that power sector emissions will not just plateau, but will in fact fall. Tripling global renewable electricity capacity by 2030 could supercharge the transition, and has the potential to help halve power sector emissions by 2030.

Now is the time to look past the peak, and to focus on how clean power could force emissions into a fast decline.

The scene is set for falling emissions

The growth of solar and wind have set the conditions for a peak and decline in power sector emissions. Solar and wind have already dramatically slowed emissions growth and many countries are past the peak.

Solar and wind have slowed the rise in emissions

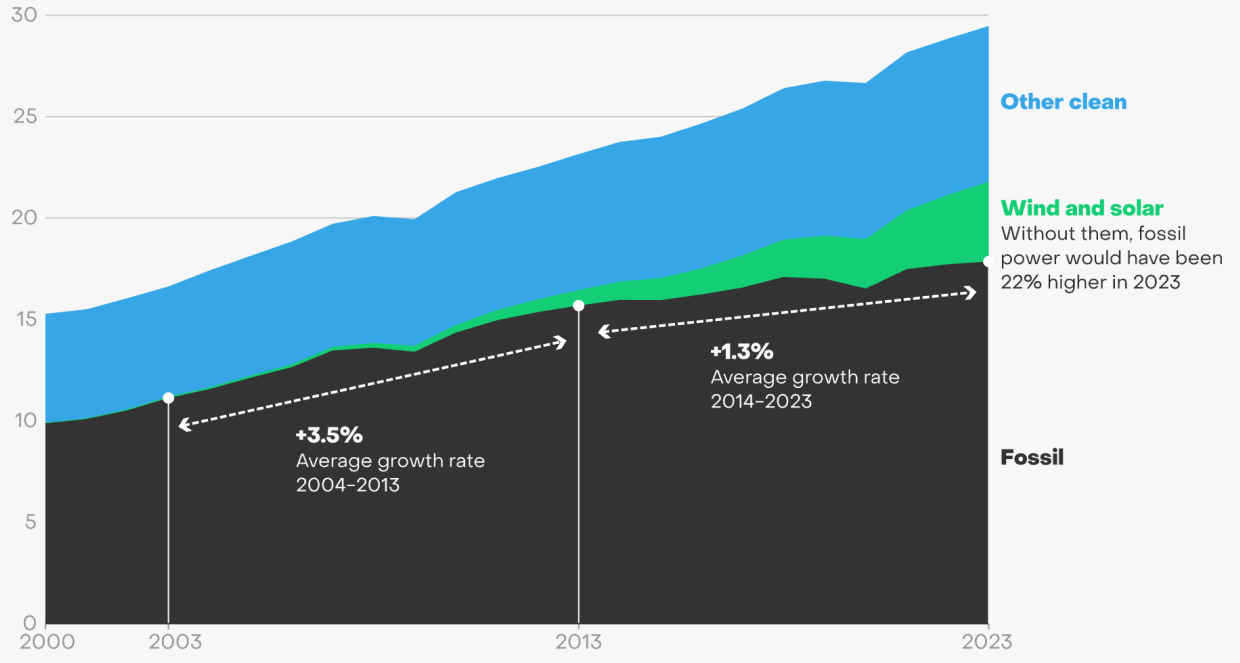
Clean electricity growth – led by solar and wind – has helped to slow the growth in fossil fuels by almost two-thirds in the last ten years. Fossil fuel generation rose on average by 3.5% per year from 2004 to 2013, slowing to 1.3% per year from 2014 to 2023.

Fossil fuel electricity generation was 22% lower in 2023 than it would have been if solar and wind generation hadn't been built. Between 2005 and 2023, wind and solar have avoided 19 gigatonnes of CO2 emissions, which is over half of 2023's total global CO2 emissions.

Although power sector emissions reached an all-time high in 2023, solar and wind have prevented emissions rising even faster.

Wind and solar power have already slowed fossil fuel growth substantially

Global electricity generation (TWh, 000s)



Source: Annual electricity data, Ember

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More than half of the world is already past the peak

More than half of economies are already at least five years past a peak in electricity generation from fossil fuels. Emissions from these 118 power sectors have fallen by a quarter in the last decade. Collectively, they represent 43% of global electricity demand.

Many developed economies peaked over a decade ago. European countries have seen the biggest falls – fossil generation in the UK has fallen by 63% since its peak in 2008, Greece by 57% (having peaked in 2007), Spain by 59% (2005) and Germany by 42% (2007). The biggest falls have happened in the last few years as solar and wind power have accelerated.

Other key developed economies have peaked, and seen smaller falls. Fossil generation in the US has fallen by 16% since its peak in 2007, Canada by 26% (having peaked in 2001), Australia by 24% (2009), Japan by 29% (2012) and South Korea by 13% (2018).

Collectively, OECD countries saw power sector emissions peak in 2007, with a fall of 28% since then.

Falling power sector emissions is already the reality for many countries, and the scene is now set for global emissions to start falling.

More than half of economies are already at least five years past a peak in fossil generation

Electricity generation from fossil fuels as a share of countries' peak in the period 2000–2023 (%)

Source: Annual electricity data, Ember
Graphic excludes countries which have not generated electricity using fossil fuels since the year 2000

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The world is past the peak

Looking back in time, it is likely that 2023 will have been the peak of power sector emissions.

Clean capacity growth was already enough to deliver an emissions decline in 2023, but a record fall in hydro generation prevented that. We forecast that power sector emissions will likely fall in 2024, due to solar surging and a rebound in hydro generation, even as electricity demand picks up.

A signal is emerging from the noise of year-on-year variability: the world is at the peak, and about to enter a new era of falling power sector emissions.

Clean capacity growth was enough to drive down emissions in 2023, but a fall in hydro generation prevented that

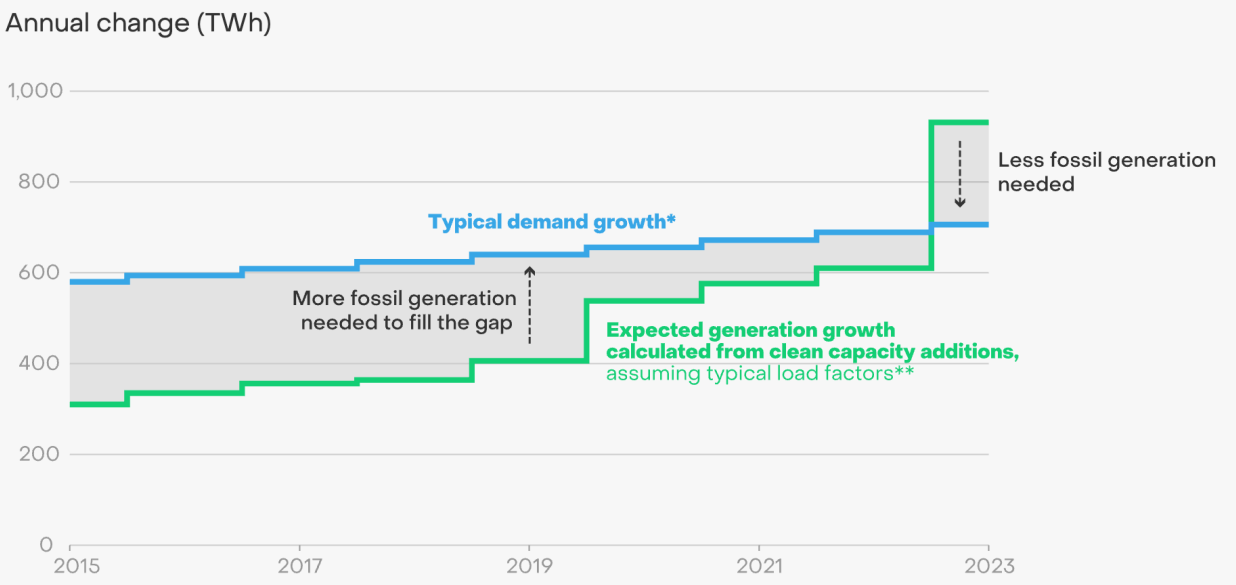
Clean power capacity growth reached a critical point in 2023 where, for the first time, it was enough to more than exceed typical demand growth and lead to a fall in emissions.

Clean power capacity additions increased in 2023. Solar capacity additions were 74% higher in 2023 than in 2022. Wind additions were 47% higher. This new clean capacity added during 2023 should have led to an increase of 930 TWh of electricity generation at typical load factors. This expected growth would have been more than the average annual rise in electricity demand of 2.5% over the last 10 years, which for 2024 would have been 730 TWh. This means the capacity added during 2023 would have been expected to deliver a 1.1% (200 TWh) fall in fossil electricity generation.

However, instead of falling, emissions rose slightly in 2023 because only half (493 TWh) of the expected rise in clean generation was recorded. This was predominantly because of a shortfall in hydro generation. Despite lower-than-expected demand growth, the clean growth was still not sufficient to meet all the rise in demand, which created a shortfall that was met by fossil generation.

The factors preventing a fall in 2023 masked the fact that clean growth was already fast enough to deliver falling emissions.

Clean power capacity growth in 2023 was - for the first time - enough to more than exceed typical demand growth and lead to a fall in emissions



Sources: *Based on the average global electricity demand growth of 2.5% from 2013 to 2023 (annual electricity data, Ember) **Ember calculations based on solar capacity additions from BNEF (assuming a 13% load factor), wind capacity additions from GWEC (assuming a 29% load factor); hydro, bioenergy and nuclear generation are sourced from the IEA

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Ember forecasts that power sector emissions will fall slightly in 2024

We forecast that 2024 will likely see a fall in power sector emissions, as bumper growth in clean generation outweighs higher electricity demand growth.

We forecast that electricity demand will increase significantly by 968 TWh in 2024. But clean generation will likely grow even faster, adding an estimated 1300 TWh in 2024, which is more than double the increase in 2023 (+493 TWh). As a result, Ember estimates fossil generation is set to decline slightly by 333 TWh or 2% in 2024.

The latest forecasts give confidence in the projected growth in clean generation in 2024. Hydro generation should see a large rise, most importantly in China, even as a warmer climate increases the risk of droughts in future years. As demonstrated in Ember's Mid Year Insights, long term trends on hydro capacity factors vary significantly across regions and years. Solar and wind additions will hit new records. BloombergNEF (BNEF) forecasts a 29% rise in solar additions from 444 GW in 2023 to 574 GW in 2024, and the Global Wind Energy Council (GWEC) forecasts a 9% increase in wind additions from 115 GW in 2023 to 125 GW in 2024.

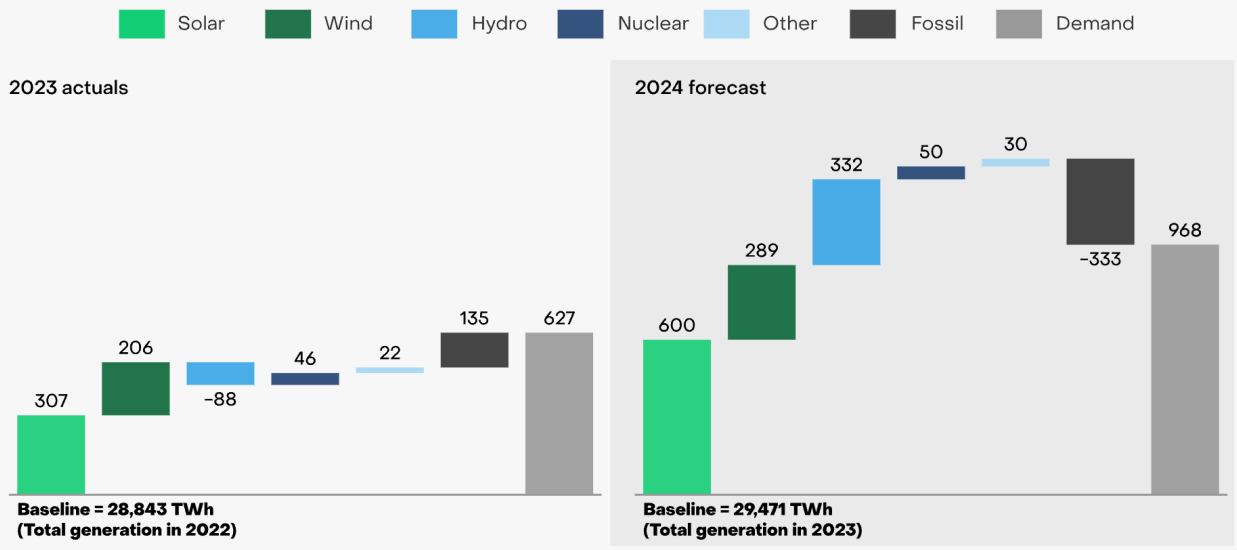
Electricity demand will also grow. We forecast the rise in electricity demand in 2024 will be around 3.3% (+968 TWh), compared to 2.2% (+627 TWh) in 2023, and well above the last 10 years' trend growth of 2.5%. The expected increase is driven by a bounceback in OECD electricity demand from low levels in 2023, and spurred on by a step-rise in electric cars, heat pumps and data centres, and strong industrial growth in China and India. Ember forecasts a 2-3% rise in the EU, compared to a 3% fall in 2023. The US Energy Information Administration (EIA) forecasts a 3% rise in the US, compared to a 1% fall in 2023.

Ember's 2024 forecast assumes much faster electricity demand growth worldwide (+3.3%) than in 2023, and January–February data already indicates strong industrial production in China, and stronger than expected GDP growth in India. As the IMF and others upgrade industrial growth in China and India for 2024, it remains possible that electricity demand overshoots our forecast, which could result in power sector emissions registering another small rise in 2024, especially if droughts do not come to an end.

Most significantly, China is set to see a decline in fossil fuels in 2024. China's strong growth in solar and wind power deployment in the last months of 2023 led the IEA to forecast a 3% fall in coal generation in China for 2024, which is a substantial change from their previous forecast of a coal rise. China added 37 GW of new solar and 10 GW of new wind capacity in January and February alone, surpassing previous record additions. Furthermore, early signs point to the drought relenting in 2024, which should boost hydro generation. This sets the country on a path to achieve new record additions of clean electricity in 2024.

Bumper renewables growth forecast for 2024 will reduce fossil generation, even as demand picks up

Annual change in electricity generation (TWh)



Source: Annual electricity data, Ember, Ember calculations (see Methodology)
'Other' includes bioenergy and other renewables

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The choices we make now will determine how rapidly emissions fall

Power sector emissions will fall, but the pace of the decline depends on how fast the world embraces clean electricity.

Power sector emissions will inevitably reduce given current forecasts for solar and wind, but the step up to tripling renewables would almost halve them.

Solar and wind forecasts are already big enough to enable emissions to fall

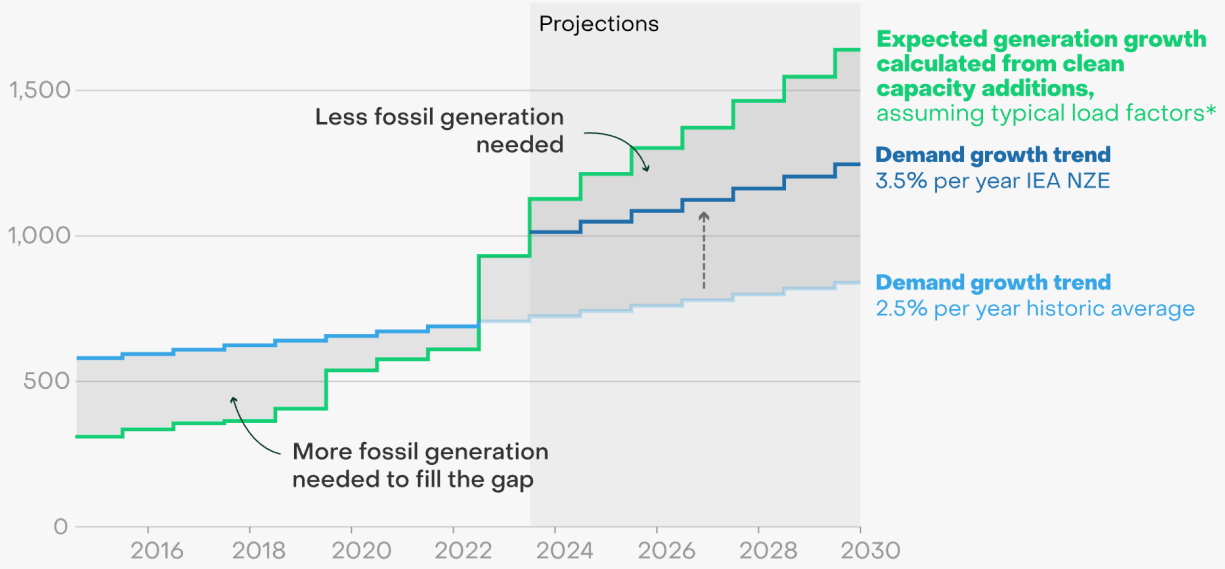
The latest industry forecasts give confidence that clean electricity deployment will provide enough electricity generation to meet even accelerated electricity demand growth throughout this decade.

The latest solar forecast from BNEF and wind forecast from GWEC are for annual additions to continue to rise from the record levels in 2023, throughout this decade. Almost 90% of the forecast rise in clean generation is driven by solar and wind additions, with nuclear, hydro, bioenergy and geothermal making up most of the rest.

Even if the annual increase in demand rises from the historic 2.5% per year to the 3.5% increase envisaged by 2030 in the IEA Net Zero Emissions scenario, clean generation is forecast to rise even more, reducing fossil fuel consumption and power sector emissions.

Strong solar and wind industry forecasts give confidence that power sector emissions will fall, even with accelerated demand growth

Annual change (TWh)



Source: Demand trends are based on annual electricity data from Ember *Ember calculations based on solar capacity additions from BNEF (assuming a 13% load factor), wind capacity additions from GWEC (assuming a 29% load factor); hydro, bioenergy and nuclear generation are sourced from the IEA

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Tripling renewables would bend the curve on emissions

Tripling global renewable electricity capacity by 2030 – as countries committed to do at COP28 in 2023 – has the potential to almost halve power sector emissions by 2030.

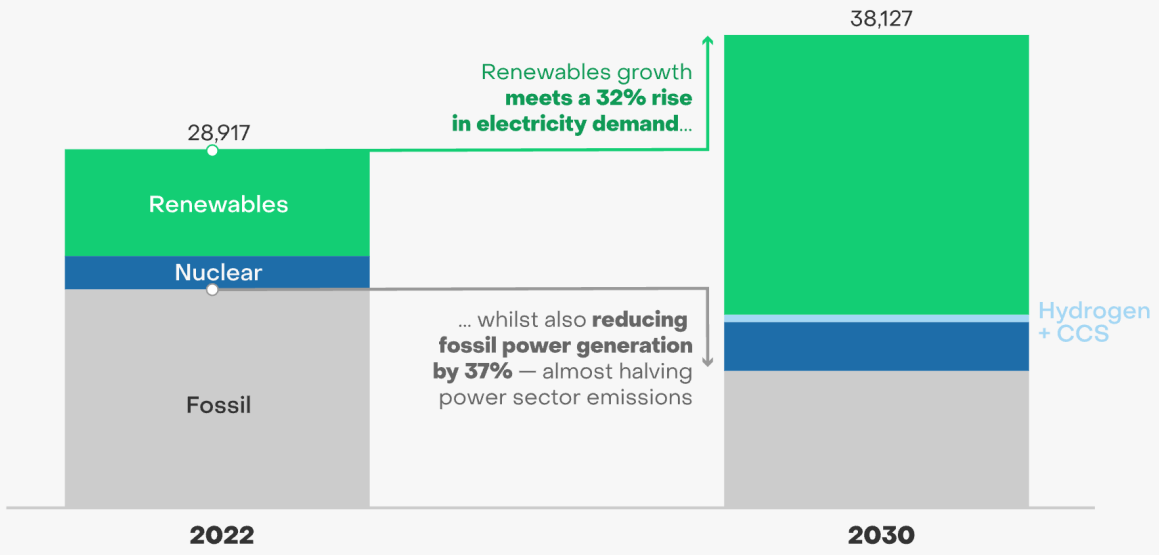
Tripling renewable electricity means adding 14,000 TWh of annual generation by 2030, compared to 2022. This would help cut fossil power generation by 6,570 TWh (-37%).

And because generation from coal, the most carbon-intensive fossil fuel, falls fastest, that leads to a 45% fall – an almost halving – in power sector emissions, according to the IEA Net Zero Emissions scenario.

Furthermore, renewables will not only replace fossil fuels in the power sector, but also across the energy system. Under the IEA scenario, over half of the rise in renewable electricity generation is used to meet a 32% rise in electricity demand, which adds 9,000 TWh to global electricity demand by 2030. Much of this is due to electrification, where renewable electricity would cut oil and gas from sectors like transport and buildings, and therefore reducing CO2 emissions outside the power sector.

Tripling renewables would simultaneously meet significant electricity demand growth and almost halve power sector emissions

Global electricity generation (TWh)



Source: IEA Net Zero Roadmap (2023)

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The tripling of renewable capacity would provide a massive boost in clean energy. In the IEA NZE scenario, renewables leapfrog past oil, coal and gas to become the world's largest primary energy source by 2030, from fourth place today. Already, renewables are the second largest source of electricity, after coal.

Ember's research shows that government plans to 2030 already align with a doubling of global renewable capacity. The analysis showed that many national plans are behind the curve of current renewables growth and need updating to keep up; this would then make a global tripling a real possibility. Many OECD countries – including the US, Canada, the UK, Netherlands and Germany – are already aiming for net zero power by 2035.

Power was the biggest emitting energy sector in 2023. It is possible that it could become the first sector to reach net zero, while unlocking emissions reductions across the global economy as the world moves towards a clean, electric future. Power sector emissions will fall this decade. But how rapidly they fall depends on the actions taken now.

2.2 Solar is leading the energy revolution – and there is more to come

In recent years, solar's rapid capacity additions have surpassed all expectations, positioning it at the forefront of the clean energy revolution. Solar generation rose more slowly than capacity in 2023, but will see a huge increase in 2024, with projections of a bumper year for solar generation. 2023 brought an unprecedented rise in supply – and fall in price – of solar panels, making them cheaper and more plentiful than ever. Given the excess of supply, and the rapid drop in battery storage costs, solar is increasingly limited only by how fast it can be connected to the grid.

Solar capacity has been growing fast

Solar growth has taken the world by surprise. Solar capacity additions have been growing exponentially since 2000. From 2000 to 2010 cumulative global capacity doubled every two years, then from 2010 to 2023 the rate slowed to doubling every three years. This move to a slower pace of exponential growth is not a cause for concern, and the path to a global tripling of renewables or meeting the IEA NZE scenario for 2030 does not require exponential growth to continue. A doubling every 3.8 years from 2023 to 2030 is consistent with the IEA's NZE scenario.

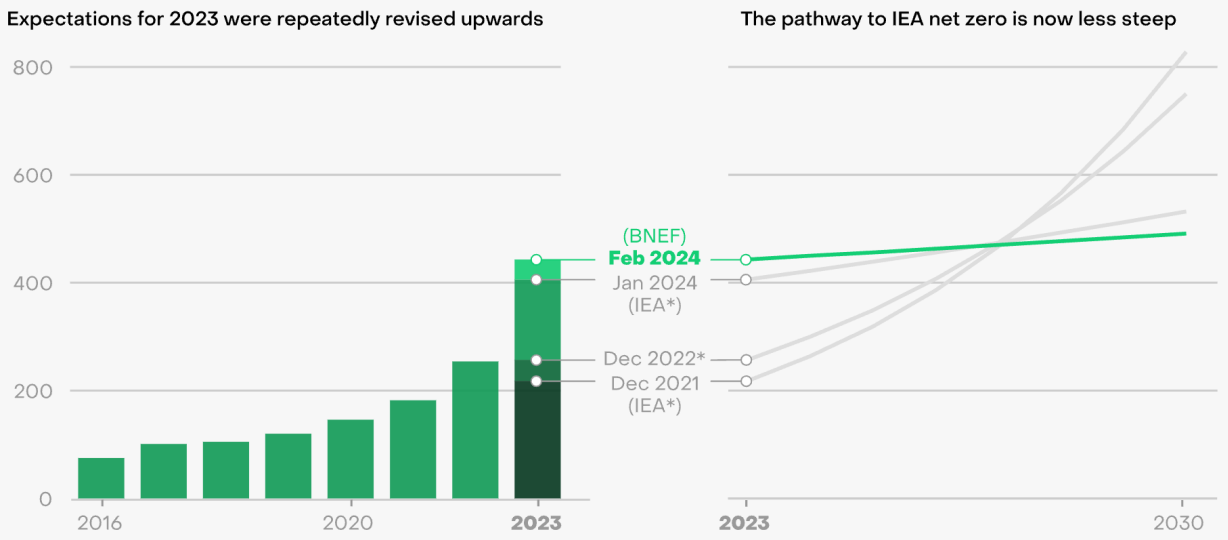
Record-setting solar capacity additions exceeded expectations in 2023

Record-setting annual capacity additions were 76% higher in 2023 than in 2022, and continue to exceed predictions. Each year the IEA has upgraded predictions: from 2021 to 2022 to 2023 the IEA's accelerated case scenario predicted that 2023 annual additions would be 218 GW, 257 GW, and 406 GW, respectively. With recent updates from China, the actual additions for 2023 are 444 GW according to BNEF. To put the scale of additions in 2023 into context, annual additions of solar capacity had not broken 200 GW per year until 2022, which itself was a record year.

A record year for solar capacity additions in 2023 puts the global scale-up for net zero in a strong position

Capacity additions: actual and projected (GW)

2023 figures are by date of estimate



Source: 2016–2022 data from BNEF (DC), 2024–2030 data are projections to meet IEA NZE 2030 cumulative solar capacity of 6,101 GW · *IEA accelerated case

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Solar capacity has boomed due to steep declines in costs, supportive policy environments, technology efficiency improvements, and increased manufacturing capability. A key to the rapid rise is Wright's law of technology learning curves, whereby the technology gets cheaper as it is deployed more and it is deployed more as it gets cheaper. Increased deployment is evident as there are now 33 countries with more than 10% share of solar generation, including Chile (20%), Australia (17%) and the Netherlands (17%), as well as the state of California at 28% (itself the world's fifth largest economy).

The growth in annual solar additions unlocks a plausible pathway to tripling renewables

According to the IEA NZE scenario, a global tripling of renewables from 2022 to 2030 means a quintupling of global solar capacity from 1,223 GW in 2022 to 6,101 GW in 2030. Solar has been so successful that its contribution to renewables capacity in 2030 was revised upwards from 48% in the 2021 IEA NZE scenario to 55% in the 2023 update.

Given 2023's record additions, meeting this goal means annual solar additions need to increase at a compound annual growth rate of 9% through to 2030, which is just over a third of the historic growth rate of 23% from the prior decade (2012 to 2022). According to the IEA NZE scenario, the land resources needed to support this level of growth are a fraction of the available suitable land.

Solar generation rose less than expected in 2023, but 2024 will see a big increase

Solar generation did not rise as much as solar capacity did in 2023, primarily because of the location of additions and growing underreporting. Nonetheless, solar generation in 2024 should reflect the capacity boom of this year and next.

Cumulative global solar capacity rose 36% in 2023, but solar generation rose only 23%

Global solar generation increased by 23% (+307 TWh) in 2023, with the share of solar reaching 5.5% in 2023 (1,631 TWh), up from 4.6% in 2022 (1,324 TWh). While impressive, this growth is not as fast as expected given the large amount of capacity installed.

There has been a strong linear relationship between capacity and generation over the past seven years, which shows 1 GW of solar capacity yields 1.09 TWh of generation. Based on that strong relationship, generation in 2023 was 182 TWh less than expected.

The shortfall is primarily explained by the location of capacity additions, under-reporting of generation, the timing of installations and weather.

1. 60% of solar capacity added was in China, and 14% in Europe. These regions receive relatively little sunlight by global standards.

2. There were large additions in countries that do not report up-to-date generation, particularly in Asia and the Middle East and North Africa. There are also growing challenges with reporting distributed generation, including behind-the-metre rooftop solar, and underreporting in large markets like the EU and Japan.

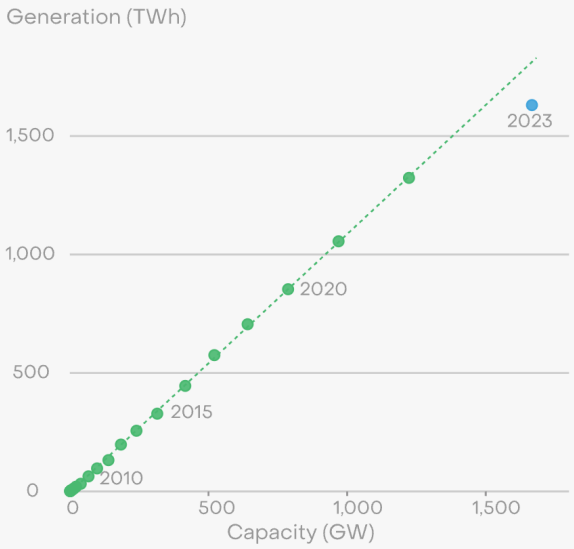
3. Installations occurred unusually late in the year, and therefore contributed less to 2023 generation. Some of this effect will be persistent: Chinese installations always spike in December to meet targets. 2023 was particularly extreme however, with almost a quarter of China's capacity additions happening in December.

4. Solar insolation varies year to year, with the EU in particular experiencing less than average insolation in 2023.

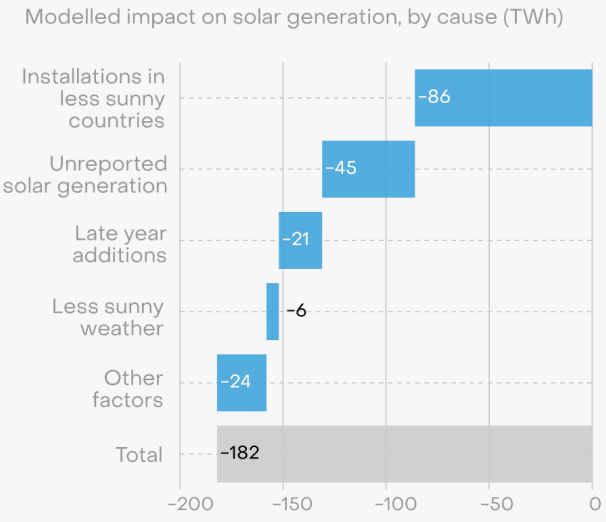
5. A number of factors contributed to the remaining shortfall. Curtailment increased in some markets, particularly in Japan, the Netherlands and Australia, though it remained consistent with recent years in China and most of the EU. Other possible explanations include the increasing proportion of rooftop solar in China, temperature-related efficiency changes, the use of less optimal sites, and patterns in the location and timing of installations that could not be measured from available data.

Global solar power generation in 2023 was relatively low given the significant capacity additions

Solar generation was well below the trend...



...but much of this effect is temporary



Source: Annual electricity data, Ember, BNEF
Late year additions includes intra- and inter-regional effects. Other factors includes curtailment, lower rooftop solar efficiency, site availability, and unmeasured locational and installation timing effects

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Generation is still growing but deeper integration of solar requires proactive planning

Although the increase in generation was lower than expected in 2023, the boost will be seen in 2024 generation figures. The additional electricity generation from panels installed late in 2023 (+21 TWh), less sunny weather (+6 TWh) and the under-reported generation (+45 TWh) would have brought total solar generation to 1,703 TWh in 2023, representing an increase of 29% compared to 2022.

Based on 2023 additions and BNEF's 2024 Q1 solar installation outlook, we expect recorded solar generation in 2024 to be between 2,150–2,350 TWh, depending on how accurate installation forecasts are. This change represents at least a 32% increase compared to 2023, and provides reassurance that solar remains on track with the 26% average growth rate required for net zero.

Nonetheless, challenges must be addressed. Grid congestion is already a major bottleneck to solar deployment around the world, with suitable connection points becoming rarer. In 2024, curtailment is expected to increase in China and California due to insufficient storage. With long construction lead times, investing in new transmission capacity now will maximise the benefits of solar. In the meantime, connect-and-manage approaches to planning – ensuring a quick grid connection with some curtailment risk in exchange – can ensure congestion does not unnecessarily slow the energy transition.

Harnessing the full potential of solar

2023 brought an unprecedented rise in supply of solar panels, yet many countries – even many sunny countries – still have a low amount of solar generation.

Global solar supply can meet global tripling goal and then some

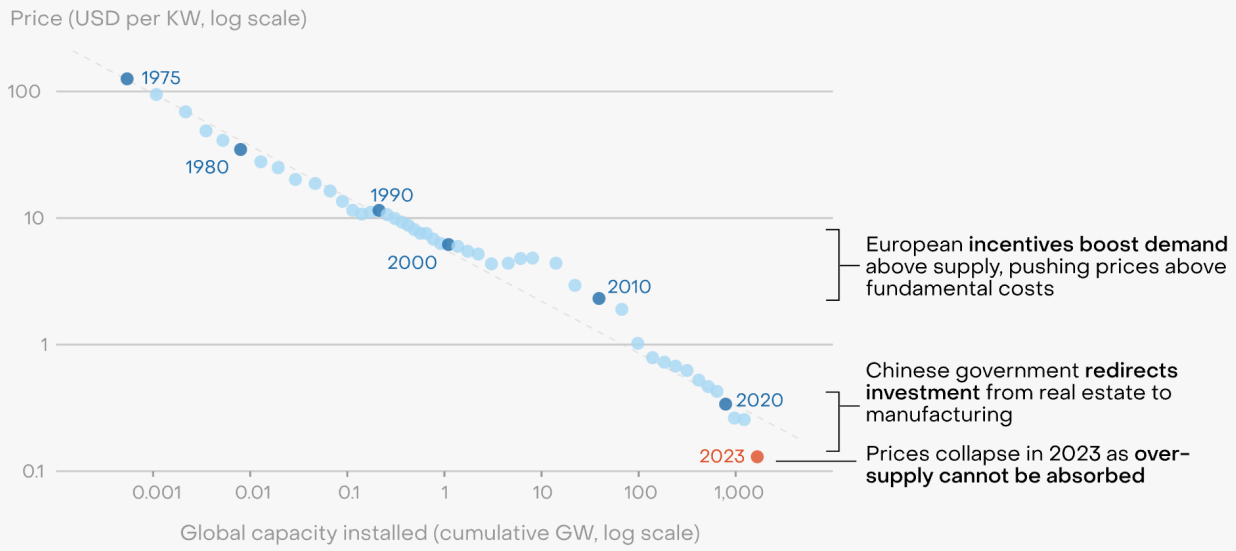
Global solar PV manufacturing capacity is forecast to reach 1,100 GW by the end of 2024. According to the IEA market update in June 2023, this is more than sufficient to meet the needs of the IEA NZE scenario. This suggests that solar can potentially play an even bigger role in the global clean energy transition if needed.

In 2023, the amount of solar manufactured in China outpaced global demand, with module spot prices collapsing by more than 50% in the second half of the year and pushing domestic installations higher and higher. Solar module prices are now significantly lower than would be expected based on Wright's law of technology learning curves. As Chinese state lending has been increasingly redirected from the residential sector to manufacturing, the country now accounts for 80–85% of global solar module production.

Oversupply of modules will persist into 2024. EU demand remains large, but with inventories high, electricity prices falling and barriers to installation, exports to the EU are unlikely to be larger than in 2023. Meanwhile China's solar exports to India, which grew rapidly in the last four months of 2023 as prices fell, will shrink drastically, as from April onwards any government supported solar projects will be required to use domestically manufactured solar panels. China's need to find new export markets is a tremendous opportunity for countries around the world to take advantage of how cost competitive and available solar is compared to other generation sources.

Solar prices fell much faster than the historic trend in 2023

Prices have been declining consistently as manufacturing of solar PV modules has increased – as per Wright's law*



Source: Our World in Data, Infolink Consulting, BloombergNEF
*Wright's law is also known as a technology learning curve, whereby a technology gets cheaper as it is deployed more and it is deployed more as it gets cheaper

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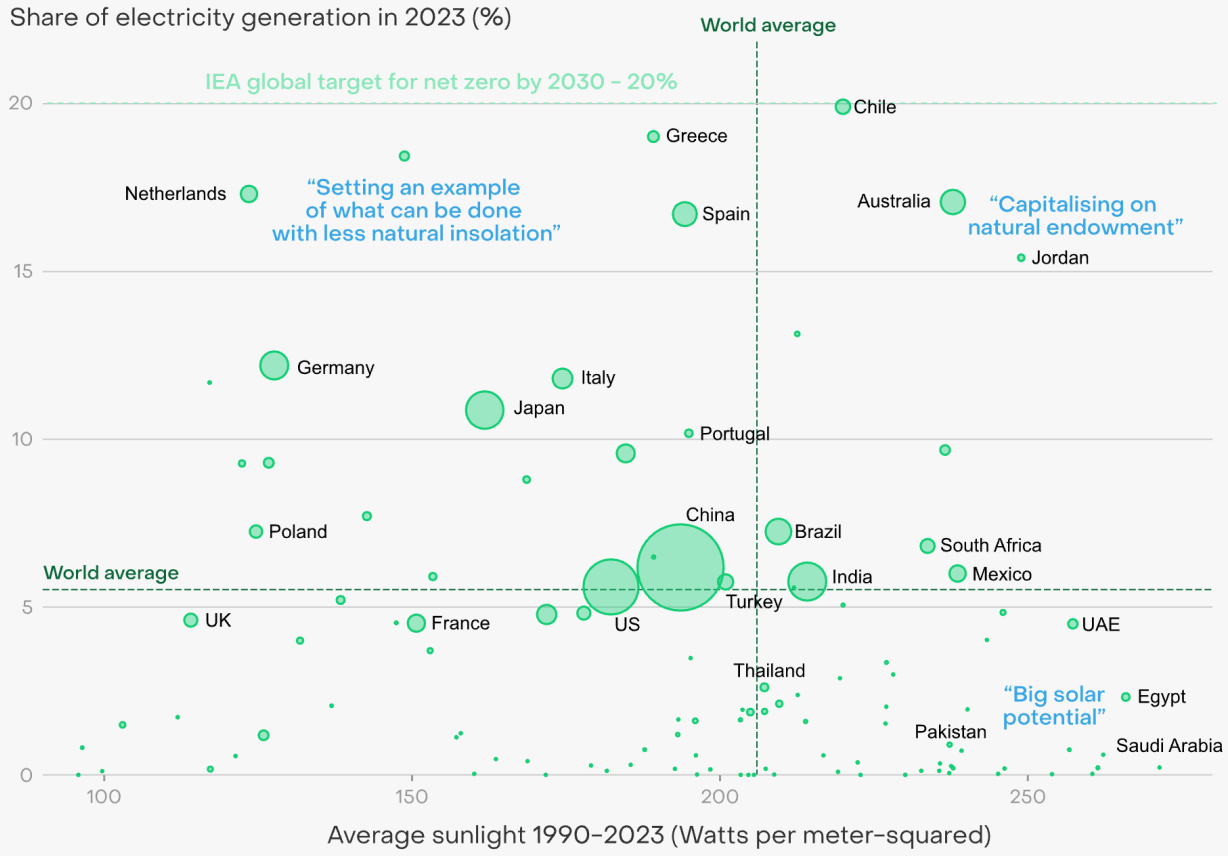
Promising solar regions remain untapped

There is not a clear relationship between sunshine and solar uptake, with many sunny countries yet to tap the potential of solar. While a few leaders like Australia and Spain are producing almost 20% of their power from solar, 66% of countries get less than 5% of electricity from solar. The presence of high solar generation even in countries with relatively poor insolation like Germany (12%) and the Netherlands (17%) highlights the potential solar has for meeting generation needs regardless of natural endowments.

There are promising signs in some regions, with module imports to the Middle East rising in 2023. Many countries across the globe face financial and logistical challenges, and it is important to enable development in high potential countries through the appropriate financing and de-risking mechanisms. Africa alone accounts for one-fifth of the global population and has huge solar potential, and yet the region currently attracts just 3% of global energy investment.

The untapped potential of solar power

Bubble sizes represent total solar generation in 2023 (TWh)



Source: Annual electricity data, Ember, IEA Net Zero Scenario (2023), ERA5 reanalysis data extracted from Teal
Graphic only includes countries or regions with demand over 10 TWh in 2023

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2.3 Demand growth in 2023 was below trend, but in future it will only go up

Global electricity demand growth was particularly weak in early 2023, mostly due to falls in OECD countries, but the latest monthly evidence shows growth is already picking up.

Five fast-growing technologies accounted for over half of the demand growth, and all could benefit from a focus on efficiency – EVs, heat pumps, electrolysers for green hydrogen, data centres and air conditioners. As electrification picks up speed, OECD demand growth will begin to rise for the first time in two decades. But as of 2023, China is ahead of the world in beginning electrification of its economy.

Demand growth will not just bounce back from the weak levels in 2023, it will enter a new era of faster growth – just how fast will depend, in part, on a focus on efficiency.

Global demand growth was below trend in 2023 but acceleration is already underway

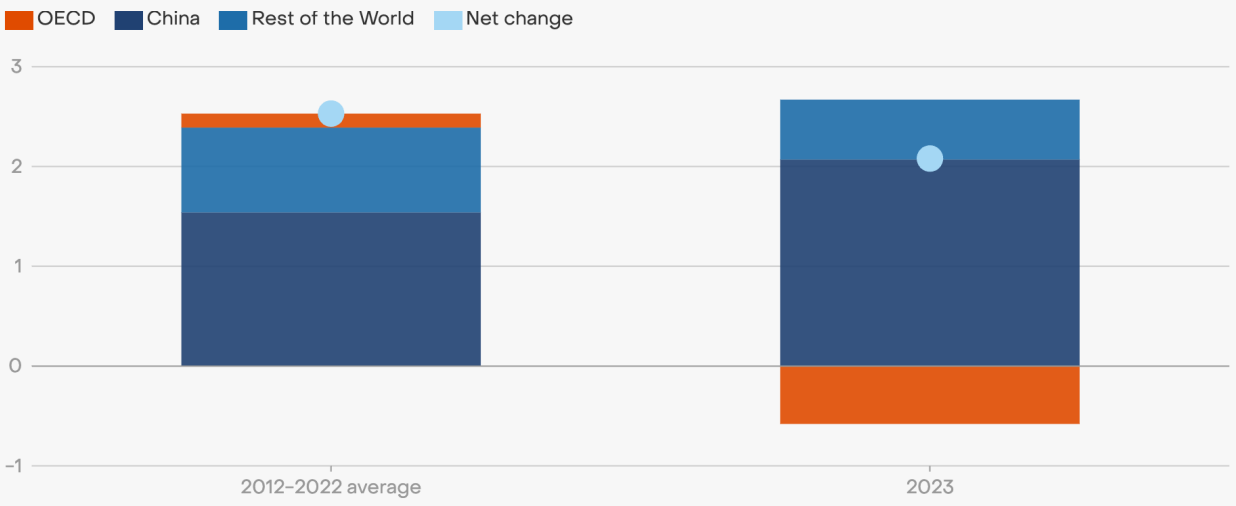
Global electricity demand increased by 627 TWh in 2023, mostly due to strong growth in China and other developing countries. Falls in OECD countries were due to short-term non-structural factors and the latest monthly evidence shows growth is already picking up.

Global electricity demand was weak in 2023 due to falls in OECD countries

Global electricity demand rose by 2.2% in 2023, which was 0.3 percentage points below the average annual increase from the past ten years (+2.5%). The slowdown was caused mainly by a fall in electricity demand in OECD countries, which shaved 0.6 percentage points from global demand.

The drop in OECD electricity demand in 2023 kept global growth below average

Percentage point contribution to the annual change in global electricity demand



Source: Annual electricity data, Ember

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The downturn in EU electricity demand was due to multiple factors, including a drop in industrial electricity consumption, mild weather and energy savings and efficiency. The US saw a dramatic shift in weather conditions from a particularly cold winter and hot summer in 2022 to unusually mild temperatures in 2023. Among OECD countries in Asia Pacific, especially in Japan, high energy prices incentivised the adoption of energy saving measures and put pressure on industrial consumption.

Many South Asian countries experienced economic headwinds and power shortages, especially Pakistan and Bangladesh, where severe gas shortages spiralled into power shortages.

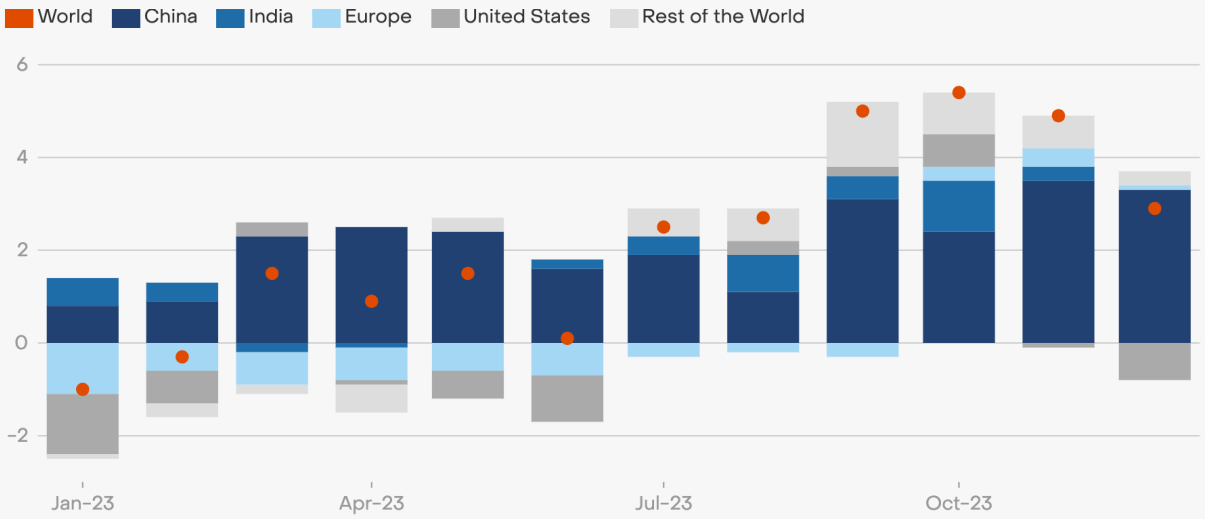
This left China as the main driver of global demand growth, contributing 2.1 percentage points to global demand growth in 2023.

Electricity demand was already picking up by the end of the year

The main factors weighing on global electricity demand had already subsided towards the end of the year, leading to a gradual acceleration of demand growth over the second half of 2023. Global electricity demand from January to August 2023 was 1% higher than the same period in 2022. In the last four months of 2023, demand was 4.5% higher than the same period in 2022.

Growth in global electricity demand was slow at the start of 2023 but accelerated over the course of the year

Year-on-year change in electricity demand (%) and percentage point contribution by country



Source: Monthly electricity data, Ember

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In the EU, the energy crisis that followed Russia's invasion of Ukraine had already eased as electricity prices fell to pre-war levels and heavy industry started to recover; so demand has been on a mild recovery path since October 2023.

In the US, the demand fluctuations were driven by extreme weather. January 2022 was colder than usual, followed by an extremely hot spring and summer, especially in May, contributing to spikes in electricity demand, while the winter of 2023 was milder than usual.

Meanwhile, demand growth in the rest of the world accelerated after a relatively slow start to the year. Strong growth in China in Q4-2023 was anticipated by national authorities as a result of increased economic activity after the easing of Covid-19 restrictions, although colder-than-average weather in November and December made the rise particularly large.

The evidence suggests the slowdown in global demand growth has now likely come to an end.

Electrification, data centres and air conditioning are driving demand growth

Five fast-growing technologies are already noticeably contributing to electricity demand growth, accounting for over half of the world's demand growth in 2023 – EVs, heat pumps, electrolysers for green hydrogen, data centres and air conditioners. All these technologies require a strong focus on efficiency to avoid wasteful demand growth in a world of limited clean electricity.

29% of global electricity demand growth was from electrification of transport and heating and green hydrogen

The contribution of key electrification technologies, which replace fossil fuels with electricity, is already significant at the global level. EVs and heat pumps have added an estimated 0.6% to global electricity demand in 2023 – 27% of total growth.

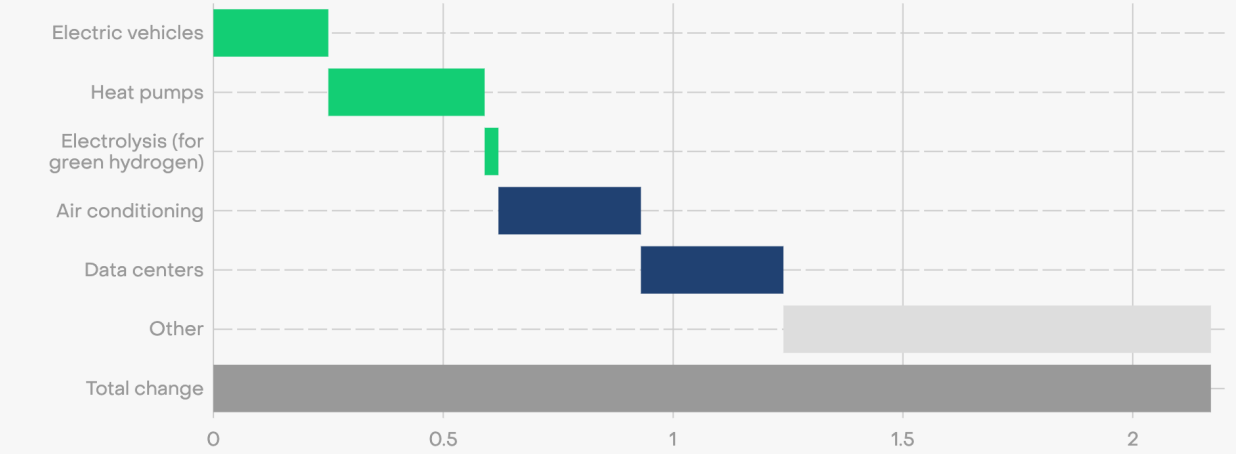
The contribution of heat pumps to global electricity demand is substantial, although it has eased slightly in 2023 – an estimated 100 TWh compared to 103 TWh in 2022, mainly due to slower heat pump sales in the US and the EU amid falling gas prices and uncertainty regarding policy support. Meanwhile, the contribution of EVs has increased, as strong EV sales in China, Europe, the US, Japan, and India created additional demand for an estimated 72 TWh of electricity, a 50% increase compared to 2022, bringing the share of EVs in global electricity demand to an estimated 0.7% from 0.5% in 2022.

The acceleration of electricity demand growth coming from EVs and heat pumps has contributed not only to reducing fossil fuel demand outside the power sector, but also to considerable efficiency gains and CO2 savings. The 72 TWh of additional demand from EVs in 2023 was enough to displace over 260,000 barrels of oil equivalent per day, had it been burned in ICE vehicles. This is comparable to Australia's total gasoline consumption in 2021. The 100 TWh of additional demand coming from the new heat pump sales in 2023 would have required around 300 TWh of gas, if burned in a conventional boiler to produce the same amount of heat. This is similar to the total gas consumption of France.

As the world continues to electrify, the efficiency gains will mean that less overall energy is needed, even as demand for electricity increases. The benefits to electrification are many: cutting energy waste delivers cost savings, in addition to reducing emissions.

Five fast-growing technologies are already noticeably contributing to electricity demand growth

Share of global electricity demand growth attributed (percentage points)



Source: Ember calculations (see Methodology)

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28% of electricity demand growth was from air conditioning and data centres

Another major source of global electricity demand growth has come from two key sectors – space cooling and data centres. Efficiency in these two sectors is particularly important to ensure the success of the energy transition.

Air conditioning added an estimated 0.3% to global electricity demand in 2023, assuming a continuation of the 4% per year on average since 2000 (+5% in 2022).

These high growth rates are influenced by poor efficiency standards: most air conditioners sold globally tend to be half as efficient as the best available technology, despite the limited difference in costs.

Data centres contributed as much as air conditioning to global demand growth in 2023 (+90 TWh, +0.3%), with an average annual growth rate of electricity demand from this sector of almost 17% since 2019. State-of-the-art cooling systems can improve energy efficiency of data centres by at least 20%.

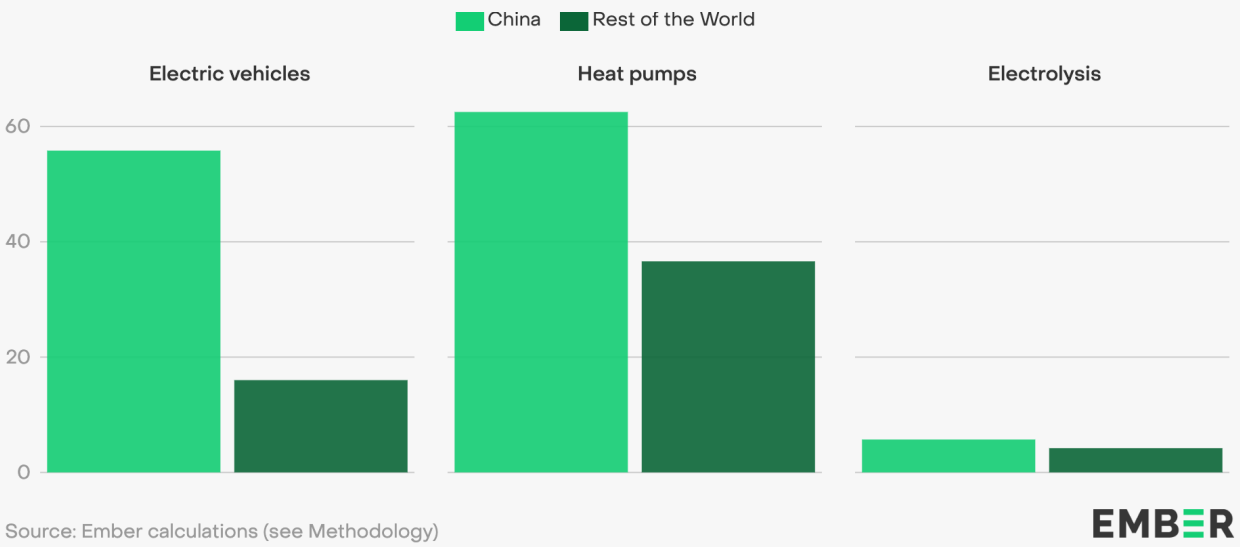
Even with electrification, there needs to be a focus on efficiency, as the least efficient EVs on the market have double the consumption of the most efficient models. Heat pump efficiency can be improved by 10% or more, depending on refrigerants.

China is ahead of the curve, but even here electrification is still in its infancy

China is ahead of the curve in electrifying heating and transport and building electrolyser capacity. In 2023, China's electricity demand from the charging and battery swapping service industry grew by 78% and added an estimated 56 TWh to China's electricity demand – 3.5 times more than the rest of the world. While China accounts for 60% of electric light-vehicle sales, this segment represents only an estimated 18 TWh of the 56 TWh demand increase, with the rest coming from electric vans, trucks, buses and two-wheelers, which China dominates globally. It is also the largest heat pump market in the world with more installations per year than any other country. Electrolysers, used mostly in demonstration plants by chemical and petrochemical companies, have also grown faster in China than the rest of the world. As a result, China accounted for 50% of global electrolyser capacity in 2023.

China deployed key low-carbon technologies far more quickly than the rest of the World combined in 2023

Additional demand per technology (TWh)



Source: Ember calculations (see Methodology)

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Even in China, electrification is still in its infancy. Only a fifth of China's electricity demand growth in 2023 (124 TWh of 606 TWh) was from the three electrification technologies, but this share will rise in time. These technologies added 1.4% to China's electricity demand in 2023, up from 1.1% in 2022. Meanwhile in the rest of the world, electrification added 0.25% to electricity demand in 2022 and 0.28% in 2023.

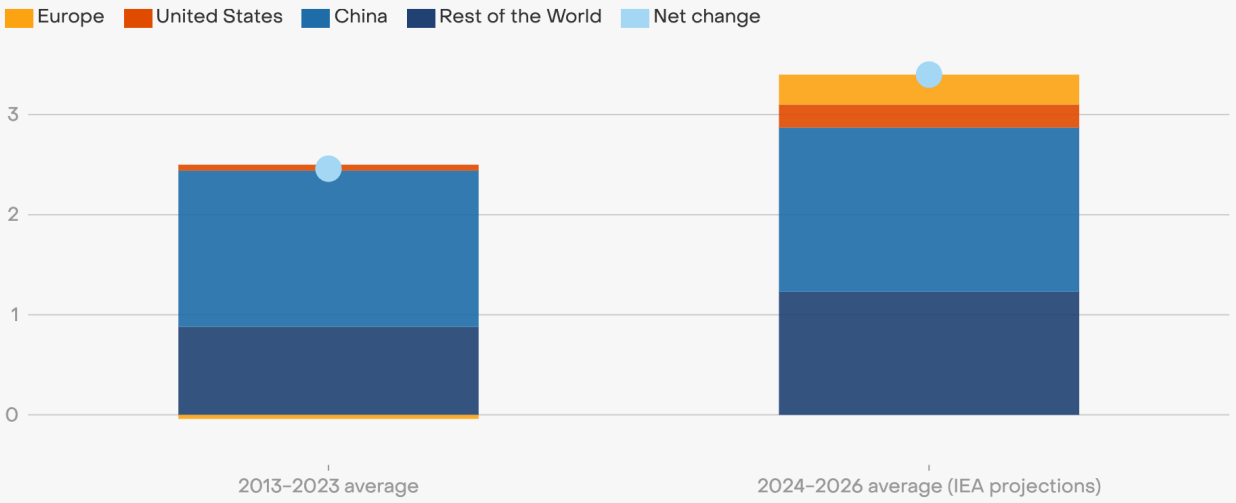
As China further accelerates the deployment of key electrification technologies and the world continues to catch up, the contribution of electrification will expand even further.

Demand is now entering an era of faster growth

As electrification continues to accelerate, global electricity demand is entering a new era of stronger growth and at 3.4% annual growth over 2024–2026 is even expected to exceed global GDP growth (+3.1%).

Global electricity demand will speed up in the coming years, as more industries switch to electricity

Percentage point contribution to the annual change in global electricity demand



Source: Annual electricity data, Ember, IEA

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Mature economies such as the US and the EU will see electrification underpin stronger electricity demand growth, leading to a greater contribution to global growth. In emerging economies, where demand will grow the fastest, wind and solar are ideal enablers for accelerating electricity access and economic growth, as already demonstrated by China's experience. Even as global electricity demand increases from electrification in transport, buildings and industry – accounting for 54% of demand growth by 2030 in the IEA Net Zero Emissions scenario – this will lead to lower overall energy demand due to considerable efficiency gains.

The IEA NZE scenario forecasts an annual increase in demand of 3.5% until 2050, assuming ambitious efficiency improvements across sectors and technologies, so even faster growth is possible if efficiency improvements disappoint. In a world of limited clean generation, wasteful demand growth would slow CO2 cuts in the power sector.

Without a strong move towards adopting the best available air cooling technologies, a continuing 4% annual growth rate in electricity demand from this sector would add 117 TWh per year by 2030. Cumulatively, this would add 730 TWh in total from 2023 levels – the equivalent of Brazil's total electricity demand. Meanwhile, electricity demand from data centres could nearly double to 1,050 TWh within the next three years if the fast expansion of this sector continues without efforts to introduce more efficient cooling solutions.

The world is moving towards an electric economy, and governments need to embrace electrification, plan for fast renewables growth to meet electricity demand, and prevent wastefulness by having a strong focus on efficiency.

2.4 The countries showing how to rapidly transition to clean energy

Transforming an electricity system requires a variety of actions, but some common key enablers are galvanising the rapid growth in solar and wind around the world: high-level policy ambition, incentive mechanisms to unlock residential and utility-scale deployment and removing technical barriers to deployment. The following examples of three countries – China, Brazil and the Netherlands – show that despite very different starting points, the combination of these approaches is delivering rapid transformations of their electricity systems.

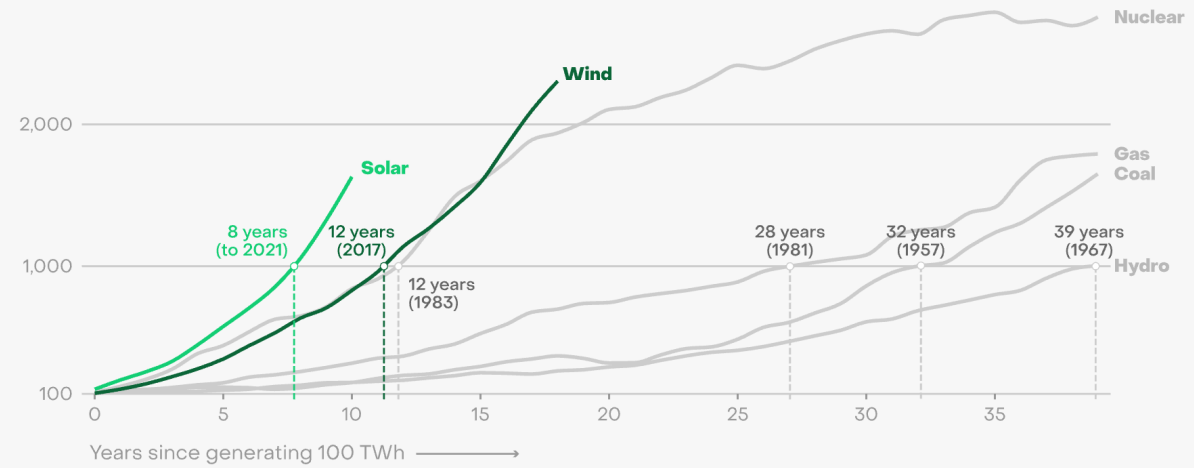
Different pathways, shared enablers

The power sectors of many countries are changing rapidly, largely due to the rise of wind and solar generation. Since the Paris Agreement in 2015, the combined share of wind and solar in the global electricity mix has increased from just 4.5% to 13.4%. This progress has made wind and solar the key solutions to combat climate change.

No other sources of electricity have ever grown from 100 TWh of generation to 1000 TWh faster. Solar and wind took just 8 and 12 years respectively, far ahead of gas (28 years), coal (32 years) and hydro (39 years). Like wind and solar, nuclear power also saw fast growth after it first passed 100 TWh in 1971, taking 12 years to pass 1000 TWh. However, now we have two clean sources growing even faster, and doing so at the same time.

Wind and solar have scaled up faster than any other sources of electricity in history

Global electricity generation, by technology (TWh)



Source: Wind and solar generation data from Ember annual electricity data, nuclear, gas, coal and hydro generation data from Pinto et al. (2023)
This graphic is based on a chart by Nat Bullard https://www.nathanielbullard.com/presentations

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Rapid wind and solar scale-up has been achieved by countries with different geographies, stages of economic development and political systems, demonstrating that we have all the tools necessary to make this fast change happen in power sectors across the globe.

There are many paths to a successful transition of the power sector and each country has different challenges to overcome. However, effective approaches have many things in common. Geography can be important, but it alone does not determine the ability to deploy wind and solar. Rapid large-scale deployment is driven by national or regional policy ambition, incentive mechanisms to increase demand and the removal of technical barriers to enable integration into the electricity mix.

Ambition

Ambition is often expressed through targets or commitments. Whether on a regional or national basis, these can be an effective tool for guiding long-term planning and driving deployment of renewables. They give customers, businesses and investors confidence in wind and solar.

Incentive mechanisms

Policies that incentivise the adoption of wind and solar drive up demand and investment for these technologies. Feed-in tariffs and net metering schemes that reward customers for excess generation are particularly effective in driving residential solar adoption. Tenders and auctions for large-scale installations ensure competition and push prices lower. Tax incentives and power purchase agreements (PPAs) make utility-scale deployment more attractive.

Removing barriers

For a fast transition to happen, there are many technical barriers to overcome. Integrating large proportions of variably-generating renewables into a power system requires efficient planning processes and grid connection, and ensuring a focus on flexibility. Maximising flexibility means creating a portfolio of actions, including ensuring fossil plants are flexible, building energy storage, building stronger, more efficient and smarter grids, redesigning electricity market rules and encouraging demand-side participation.

Furthermore, using natural resources effectively means facilitating the development of wind and solar in regions where conditions are more suitable through long distance transmission. With the electrification of transport, heating and industry, smart demand strategies, for example for electric vehicle charging or heat pump use, can match demand with wind and solar generation patterns and ease integration.

Case studies

Three leaders in the fast deployment of wind and solar – China, Brazil and the Netherlands – offer crucial insights on how countries are successfully applying these tools.

1. **China** is the global leader in wind and solar, with both the largest absolute generation and the highest annual additions for over a decade. It has delivered wind and solar additions at breakneck speed, transforming the world's largest electricity system.

2. **Brazil** is using wind and solar to meet growing electricity demand. The country is taking advantage of the low costs of wind and solar and has made its power system more resilient, enabling it to be a leader in renewable electricity and avoid building up a reliance on gas or coal as electricity demand rises.

3. **The Netherlands** has reshaped its power system as it seeks to rapidly phase out coal power and phase down gas power. The rapid build-up of wind and solar has reduced fossil generation from more than 80% of the power mix to less than 50% in just five years, putting the country on a path to rapid decarbonisation.

All three countries have used both wind and solar to deliver this transformation of their power sectors.

China

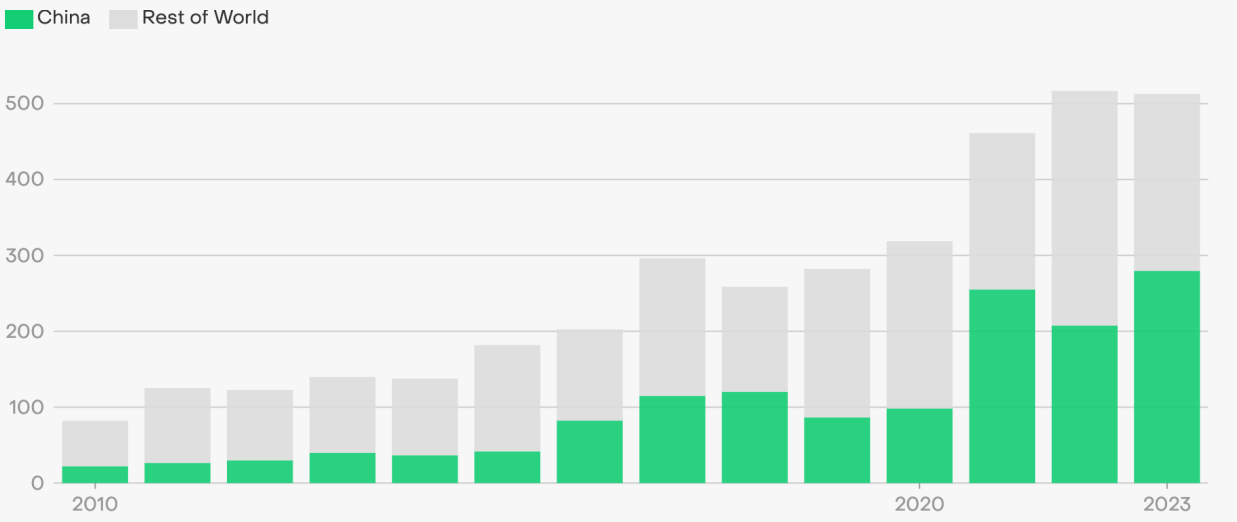
What has been achieved?

China is the global leader in wind and solar deployment. In 2023, more than half of global additions in wind and solar generation came from China. China's wind and solar share has grown from just 3.9% in 2015 to 15.6% in 2023. This is especially remarkable given the size of China's electricity system. Wind and solar are now generating 1,470 TWh of electricity, 37% of the total global wind and solar generation and more than the entire electricity demand of Japan or 75% of India's electricity demand in 2023.

The speed of the transition has accelerated in recent years with wind and solar generation doubling in just three years from 2020 to 2023. The additions of wind and solar since 2015 have helped to meet strong growth in electricity demand. This reduced growth in fossil generation and therefore avoided emissions of more than 4 gigatonnes over that period. This is equivalent to the annual power sector emissions of the US, India and the EU combined.

More than half of the global additions in wind and solar generation came from China in 2023

Annual additions of electricity generation from wind and solar (TWh)



Source: Annual electricity data, Ember

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What enabled it?

- Clean energy has received strategic prioritisation at the highest level, specifically of the so-called "new three" industries of solar power, EVs and batteries, leading to a huge surge in clean energy investments. This was driven not only by climate and pollution concerns, but also by a desire to reduce China's energy import dependency and build future export markets. In 2023, clean energy was already the top driver of China's economic growth.

- China introduced targeted policies to incentivise wind and solar. **Feed-in tariffs** and subsidies through **tax incentives** have resulted in higher investment and faster adoption.

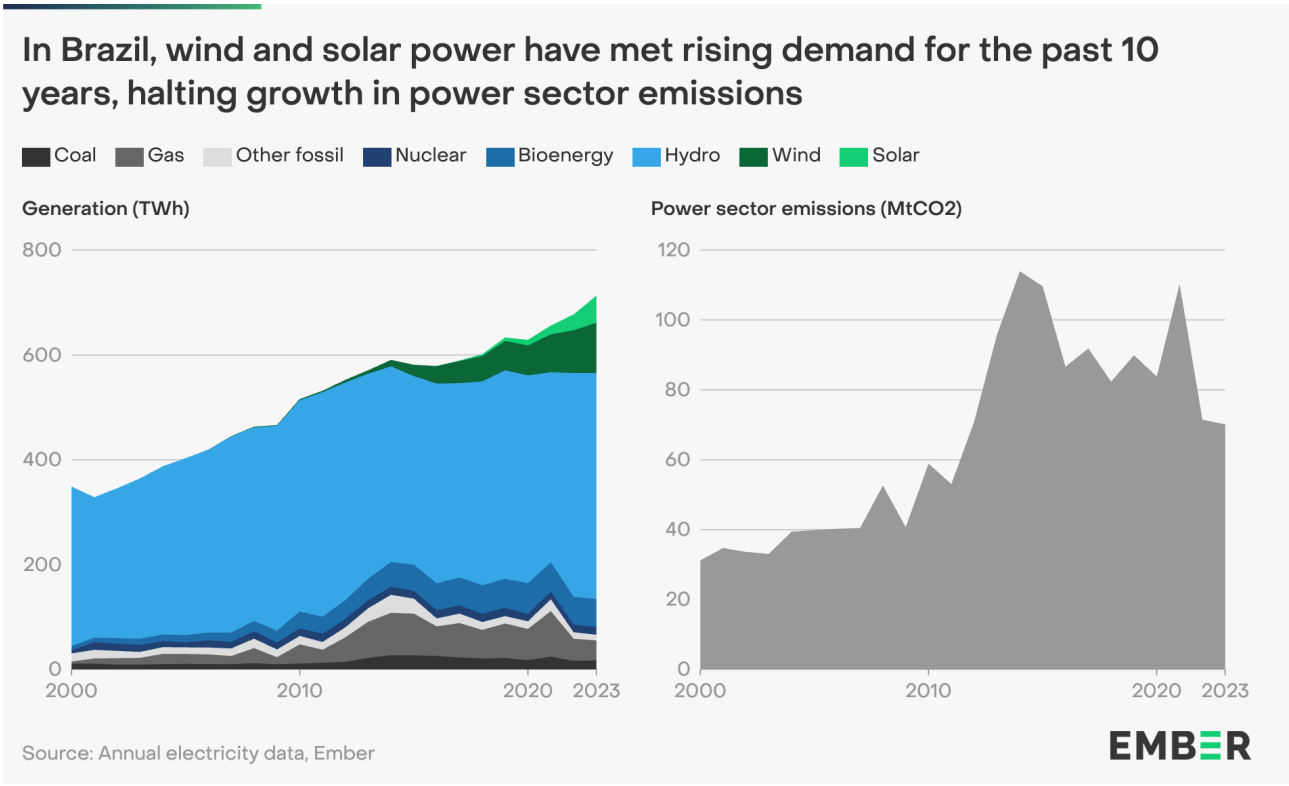
- The build-out of **grid infrastructure**, such as **long distance transmission** lines, is particularly important to reduce curtailment and make use of the abundant wind and solar resources in China's inland. Over the past decade, the country has constructed more than one-third of the global expansion of transmission grids. In combination with market reforms to prioritise offtake from wind and solar producers, China has managed to reduce the curtailment of wind and solar power in recent years despite connecting more installations to the grid than ever.

- Targets for renewable deployment have been successful at driving fast installations at scale. While China has often overachieved targets at a national level, with the country on track to achieve its 2030 deployment goals for wind and solar in 2025, **local targets** have been much more ambitious. Programs such as "whole county PV", which required solar PV to be installed on a certain percentage of rooftops, have contributed to the rapid build-up of rooftop solar throughout 2022 and 2023.

Brazil

What has been achieved?

Wind and solar reached 21% of Brazil's electricity generation in 2023, up from just 3.7% in 2015. It is a global leader in wind and solar, recording the second largest additions of any country in 2023, up from being the fourth largest in 2022 and has the second cleanest power sector in the G20. The country has avoided a major increase in its emissions, despite hydro generation not growing, thanks to wind and solar meeting all new demand in the last ten years.



What enabled it?

- Brazil became an early adopter of wind and solar in the region. After the 2001 energy crisis that saw droughts heavily restrict availability of hydropower, the country introduced the "Alternative Energy Sources Incentive Program" (PROINFA) to promote other renewable sources such as wind and solar. This included **auctions for wind and solar projects** starting in the mid-2000s that enabled fixed price contracts and spurred investment and growth in the renewables sector. This was aided by financial support for private companies through the Brazilian Development Bank (BNDES).

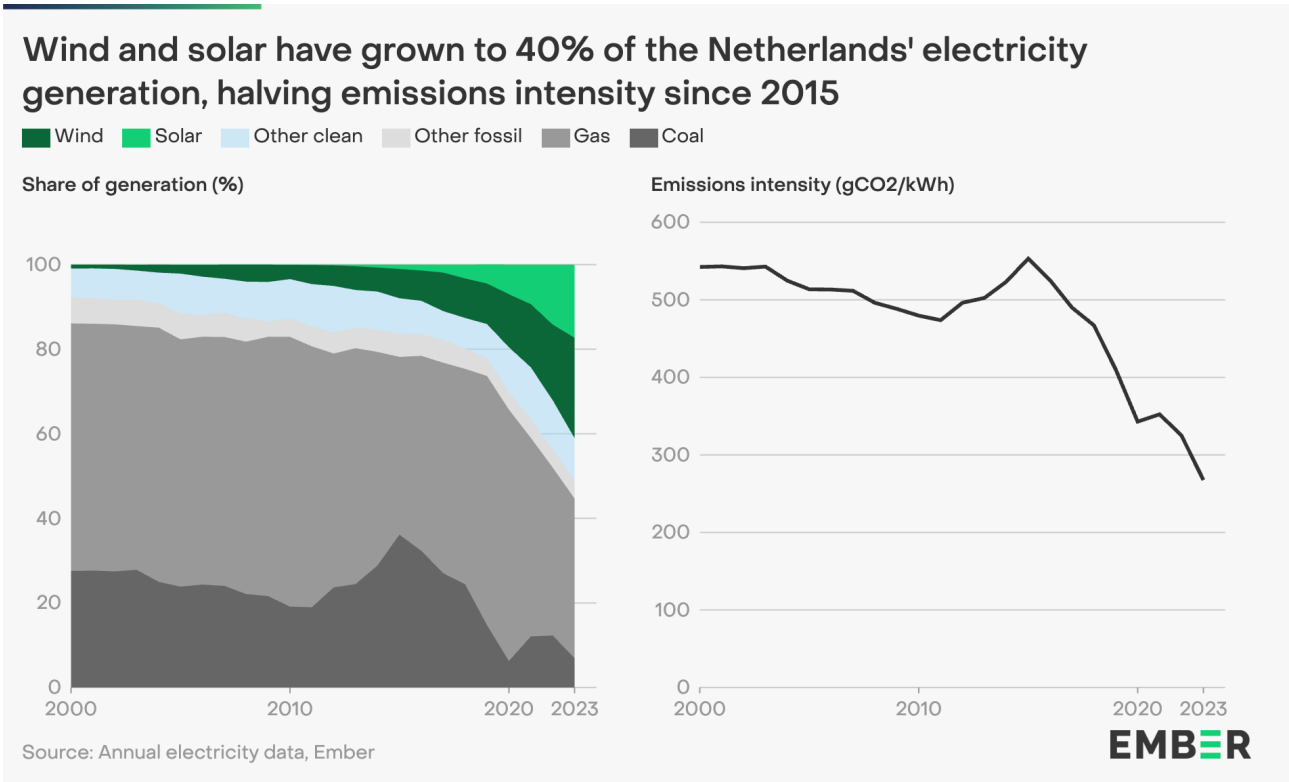
- Brazil is **using natural resources effectively**. The country has great wind as well as solar potential due to its latitude. It has further plans to develop more offshore wind, predominantly in the northeast of the country where conditions are most suited to development. Additionally, large hydropower plants and reservoirs provide the flexibility needed to incorporate variable renewables into the grid.

- The country's National Electricity Agency (ANEEL) introduced and subsequently expanded the size of installations that qualify for **net metering**. This is a tremendous driver of adoption of distributed generation, with solar PV making up the vast majority of such installations.

The Netherlands

What has been achieved?

The Netherlands is one of the fastest adopters of wind and solar in the world. Wind and solar generation rose from 8% in 2015 to 41% in 2023. This has reduced the country's reliance on fossil fuels from 84% in 2015 to less than half (49%) of generation. As a result, the emissions intensity of power generation has halved (-48%) and emissions have declined 46% since 2015. Solar additions have been rising especially fast in recent years. Despite its high latitude, the Netherlands now has the second highest per capita solar generation in the world, behind Australia.



What enabled it?

- The government announced in 2017 that it would phase out coal by 2030 to reach its climate targets. In 2019, the Dutch government agreed **legally binding targets** to reduce CO2 emissions by 2030, which necessitated a phase down in gas generation as well. The decision included targets for onshore and offshore wind, as well as solar energy. These targets set top-down ambition, ensuring policymakers introduce further actions to enable faster renewables growth.

- Long-running **financial incentives** through its Sustainable Energy Production and Climate Transition Incentive Scheme (SDE, SDE+ and SDE++) reward producers for the CO2 reduction achieved by wind and solar and create a **stable environment for investment** into renewables.

- To incentivise the adoption of rooftop solar, the Netherlands introduced a **net metering scheme** in 2004. Combined with high energy prices and the reduction in costs for solar PV installations, this policy has made rooftop solar an attractive investment for home owners. The Dutch government recently decided to continue its current net metering scheme until at least 2025.

China, Brazil and the Netherlands have seen remarkable growth in wind and solar that has transformed their electricity systems at a rapid pace. Signalling ambition can create an environment in which wind and solar can thrive, enabling trust and confidence among investors. Choosing the right set of incentive mechanisms to drive the demand for wind and solar systems as well as the regulatory solutions to overcome technical barriers and facilitate the integration of wind and solar into the mix is more important than a country's economic or geographic starting position.

Of course, even countries that have been successful in their transition so far are still facing challenges. For example, in the Netherlands new wind and solar installations are being held back by grid congestion issues that could have been avoided with better long-term planning. Similarly, policies like net metering offer great incentives for residential solar adoption, but ensuring that additional grid costs are not shifted onto lower income households is an important consideration to achieve a just transition. Additionally, the impacts of wind and solar deployment on local communities have underlined the need to ensure adequate safeguards are in place.

Crucially, China, the Netherlands and Brazil have overcome barriers to the transition in the past. The current political, economic and engineering challenges are also solvable. We have all the tools we need to get transitions off the ground where they have just started, facilitate acceleration where it is most needed and push progress further in countries leading the global transition.

Data on the global electricity sector in 2023

Data on the global electricity sector in 2023, with an overview of changes and trends over the last two decades.

Chapter contents

3.1 Electricity Generation

Key highlights

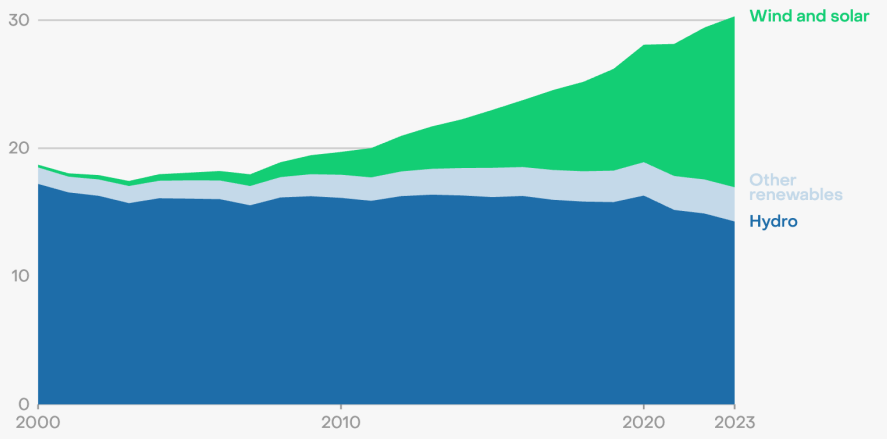
01 Renewables reached a record 30% of global power generation in 2023

02 Clean generation made up almost 40% of generation in 2023

03 Renewables increased from 19% in 2000 to 30% in 2023, driven by rapid growth in solar and wind

Global growth in wind and solar power pushed renewables to 30% of the global electricity mix in 2023

Share of global electricity generation from clean sources (%)



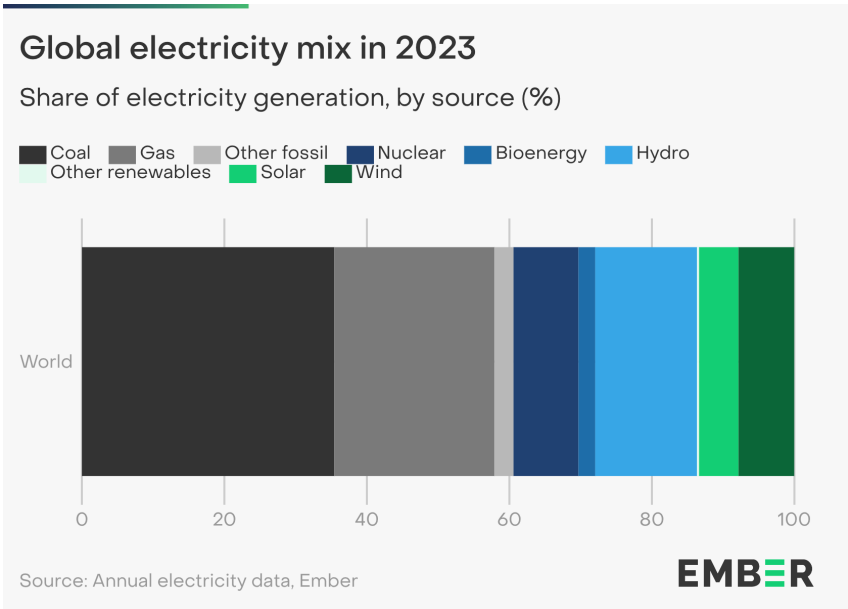
Source: Annual electricity data, Ember
'Other renewables' includes bioenergy, geothermal, wave and tide

EMBER

Generation: Current status

Renewables reached 30% of global power generation in 2023, but fossil fuels still dominated

In 2023, fossil sources such as coal and gas produced 61% of global electricity. Coal was the single largest fuel, making up 35% (10,434 TWh) of global generation. Gas produced 23% (6,634 TWh) and other fossil generation made up 2.7% (786 TWh).



In 2023, renewables reached 30% of global electricity generation for the first time. Hydro remained the largest low-carbon source of electricity at 14% (4,210 TWh). With 9.1% coming from nuclear power (2,686 TWh), clean generation made up 39% of the global electricity mix. Wind produced 7.8% (2,304 TWh) and solar produced 5.5% (1,631 TWh). Together, solar and wind generated 13.4% (3,935 TWh). Bioenergy produced a reported 2.4% (697 TWh), but actual generation is likely to be higher due to its use in off-grid generation. Lastly, other renewables generated 0.3% (90 TWh). This was mostly geothermal generation, with tidal and wave energy providing only a small portion.

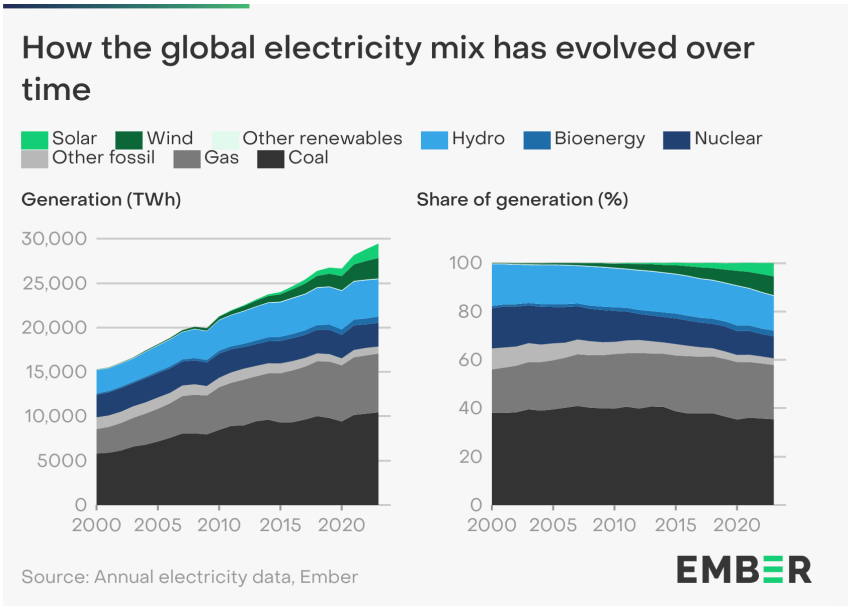
Generation: Long-term trend

Wind and solar are gaining a growing share of the global electricity mix, but fossil fuel generation is increasing

The share of fossil generation peaked at 68% in 2007 and has since declined to 61% due to fossil fuels growing at a slower rate than global electricity demand.

While the share of fossil sources in the global electricity mix is declining, fossil generation is still rising in absolute terms, with both coal and gas reaching record levels in 2023. Coal generation nearly doubled from 5,809 TWh in 2000 to 10,434 TWh in 2023. Gas generation more than doubled from 2,745 TWh in 2000 to 6,634 TWh in 2023. Other fossil fuel generation declined from 1,324 TWh in 2000 to 786TWh in 2023, driven by a fall in oil generation.

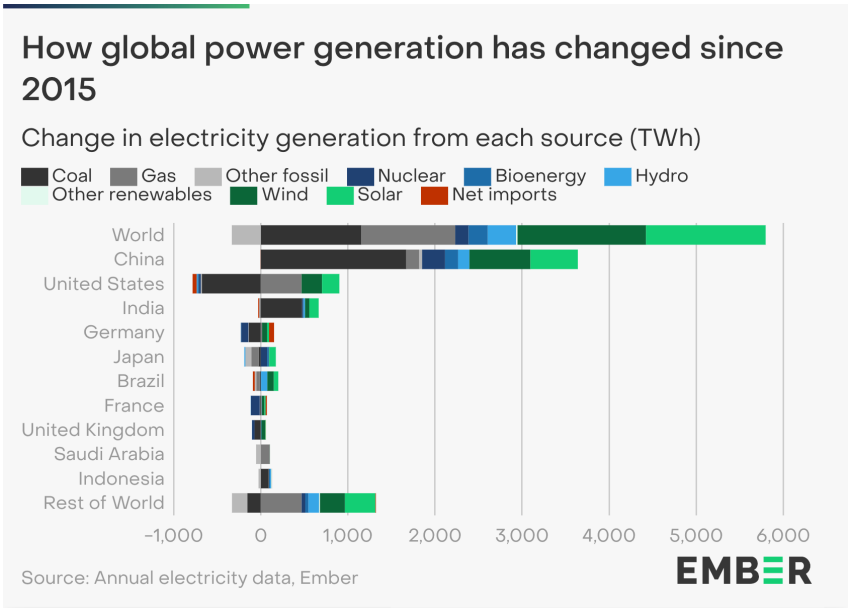
Renewables increased from 19% in 2000 to 30% in 2023, driven by rapid growth in wind and solar, which have grown substantially over the last two decades. In 2023, wind and solar made up 13.4% of global generation, rising from only 0.2% in 2000. Most of this growth happened in recent years. Wind and solar grew more in the five years since 2018 (+2,092 TWh) than in the 17 years before that (+1,811 TWh).



Hydro generation grew 60% between 2000 and 2023, but its share in the electricity mix declined from 17% to 14% as it failed to keep pace with rising demand. In fact, with a share of 16%, non-hydro renewables surpassed hydro generation in 2023 for the first time.

Nuclear generation has mostly remained stable, with the reduction in generation in Europe and Japan largely offset by growth in China. Consequently, with electricity demand nearly doubling over the last two decades, the share of nuclear generation fell from 16.6% in 2000 to 9.1% in 2023.

Since 2015, almost all sources of electricity have seen an increase. The largest gains came from wind (+1,475 TWh, +178%) and solar (+1,375 TWh, +537%) with solar generation in 2023 growing to more than six times 2015 levels. Coal (+1,153 TWh, +12%) and gas (+1,080 TWh, +19%) grew slightly less. There were smaller increases in bioenergy (+220 TWh, +46%), hydro (+326 TWh, +8.4%) and nuclear (+153 TWh, +6%). Generation from other fossil fuels, such as oil, fell by 333TWh (-30%).



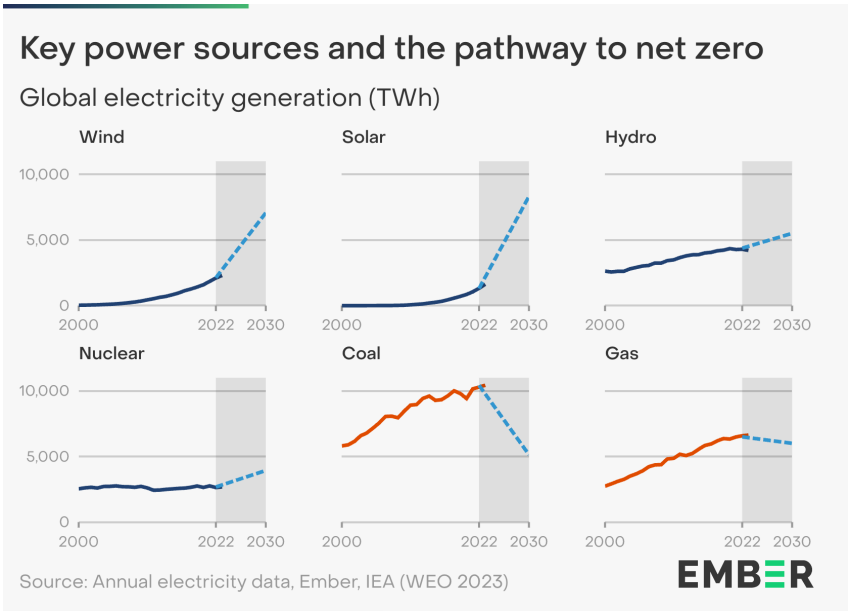
China saw the largest changes of any country for coal, nuclear, bioenergy, hydro, wind and solar. China's growth in coal generation (+1,670 TWh) since 2015 amounted to more than the overall global increase, as coal generation fell significantly in the US and other countries in that period. However, China also contributed nearly half (47%, 700TWh) of the global growth in wind and 40% (545 TWh) of the increase in solar generation from 2015 to 2023.

The US is the main driver of gas growth globally and the only major economy displaying a shift from coal generation to gas. Since 2015, gas generation in the US rose 469 TWh, accounting for 43% of the global increase over that period. In comparison, China is planning a transition from coal straight to clean energy without a transition via gas.

Generation: Progress towards net zero

Continued rapid growth in solar and wind is key to delivering emissions cuts

The global electricity sector must be decarbonised for the world to keep global heating below 1.5C. Strong growth in wind and solar in recent years offers a glimpse of the future clean electricity system, but continued – if slowing – growth in fossil fuels is still holding back progress for a pathway aligned with 1.5C. At COP28, the world agreed to a global goal to triple renewable electricity capacity by 2030, which would almost halve power sector emissions.



To align with the IEA Net Zero Emissions scenario, wind must triple between 2022 to 2030 (+16% per year). Solar needs to grow more than five times its current generation (+26% a year). In 2023, solar grew at 23% and wind grew at 10%.

Growth in hydro generation needs to return and even surpass growth seen over the last two decades, but recent years have seen output from hydro plants stagnate. Nuclear generation has remained unchanged on a global level for the last two decades, but would likely need to see a significant increase of 47% over 2023 levels. In 2023, nuclear generation increased by just 1.8% and hydro generation fell by 2%.

Under the IEA's scenario, coal and gas generation both need to fall, with coal generation responsible for most of the required emissions reductions. Coal generation would halve from 2023 to 2030 and be overtaken by wind, solar and hydro generation.

Gas generation would need to see more moderate reductions from 6,634 TWh in 2023 to 6,007 TWh in 2030. In 2023, both coal and gas generation increased.

3.2 Power Demand

Key highlights

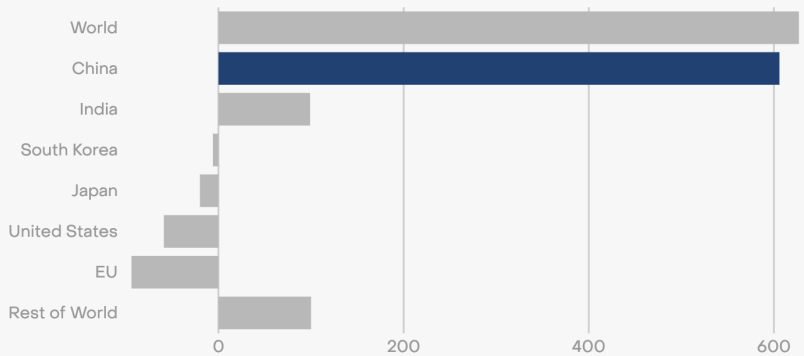
01 Global electricity demand hit a record high in 2023

02 Demand fell in mature high-income economies including the EU, US, Japan and South Korea, but rose in China and India

03 Global electricity demand almost doubled from 2000 to 2023 and will continue to grow

China was the main driver of global electricity demand growth, while demand fell in high-income economies

Change to electricity demand in 2023 (TWh)



Source: Annual electricity data, Ember

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Demand: Current status

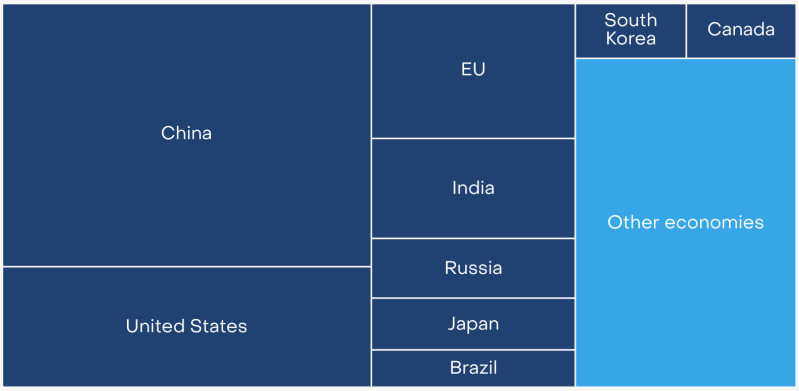
Global electricity demand hit a record high in 2023

In 2023, global electricity demand reached a new record high of 29,471 TWh, rising 627 TWh (+2.2%) compared to 2022. However, the annual growth was below average (this is explored further in Chapter 2.3).

More than half (52%) of the world's electricity demand in 2023 was in Asia, which is still relatively low given the region has 55% of the world's population. China, the country with the highest demand at 9,441 TWh, made up 62% of Asia's and 32% of global electricity demand.

A breakdown of global electricity demand in 2023

Share of global electricity demand (%)



Source: Annual electricity data, Ember
Named economies have more than 2% of global electricity demand

EMBER

The United States had the second highest electricity demand at 14.5% of global demand (4,270 TWh).

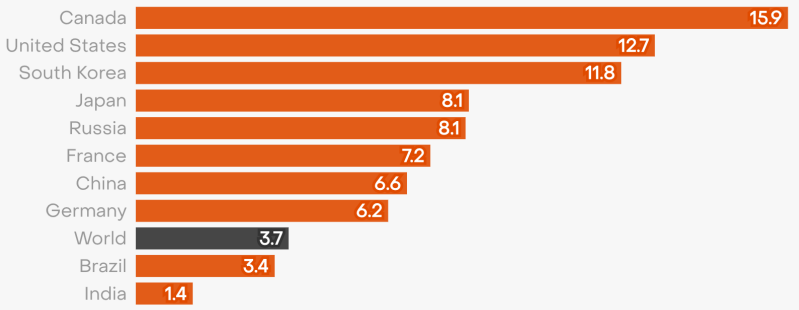
African countries accounted for only 3% of global electricity demand, despite comprising 18% of the world's population.

Global per capita demand in 2023 was 3.7 MWh. Countries with a similar per capita demand include Argentina or South Africa. As a result of improved living standards, per capita demand has been steadily rising over the last two decades and was up nearly 50% over 2000 (2.5 MWh).

Among the ten largest electricity consumers, Canada and the US have the highest per capita demand. Canada's per capita demand of 15.9 MWh

Demand per capita of top electricity consumers in 2023

MWh



Source: Annual electricity data, Ember
Graphic shows the ten countries with the highest electricity demand

EMBER

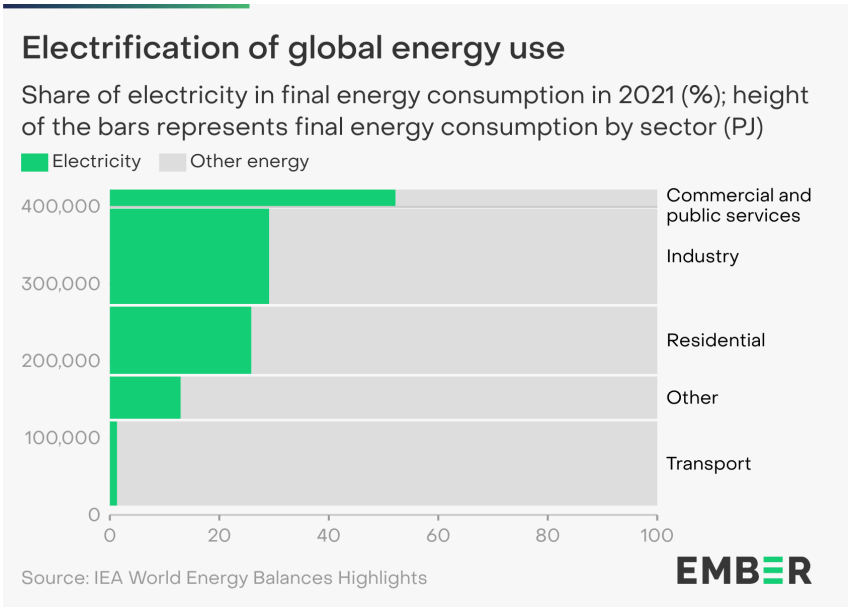
in 2023 was more than four times the world average. Per capita demand in the US and Canada was also about twice as high as that of the largest industrial nations in Western Europe, with France (7.2 MWh) and Germany (6.2 MWh) showing significantly lower values.

China's per capita demand has grown by more than six times since 2000 (1.1 MWh) to reach 6.6 MWh in 2023, surpassing Germany for the first time. In 2012, China had only half the per capita demand of Germany.

Despite substantial electricity demand growth, India's per capita demand of 1.4 MWh remained at less than half the world average.

As the global power supply becomes cleaner, electrification will be the key lever in decarbonisation across industries. As of 2021 (the latest year with data available), 21% of final energy consumption globally came from electricity. This number is set to increase substantially as electrified technologies are introduced.

Key sectors that are expected to see increased electrification include transport, residential energy use (for example, heating) and industry.



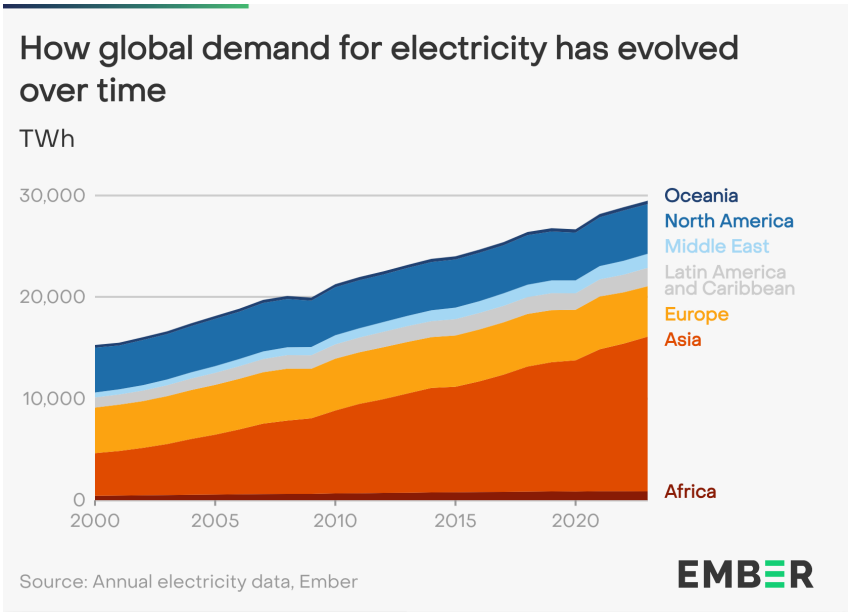
Commercial and public services currently have the highest share of final energy consumption provided by electricity at 52%. Conversely, only 1.3% of the energy consumption in the transport sector comes from electricity. This is expected to grow rapidly as battery electric vehicles gain market share. Similarly the faster adoption of heat pumps is set to increase the electrification rate of the residential sector from 26% in 2021.

Demand: Long-term trend

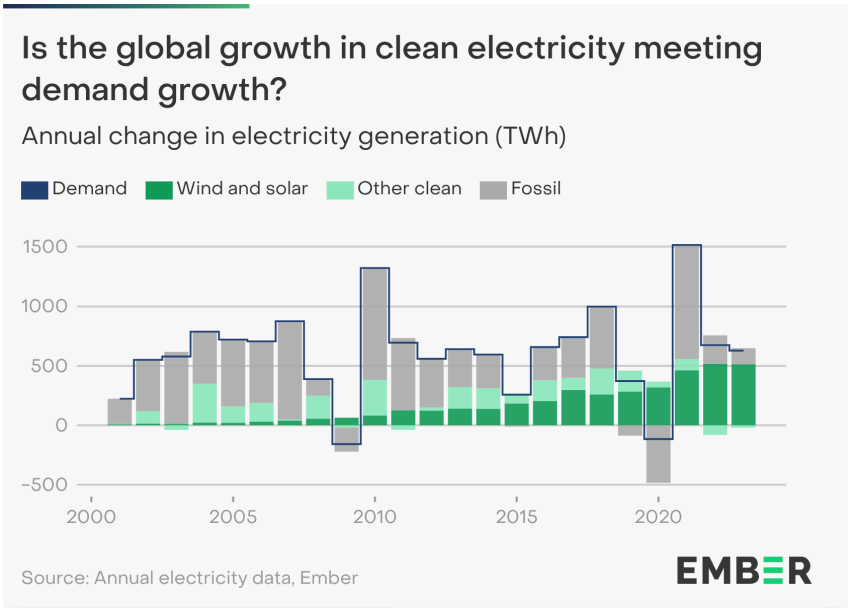
Global electricity demand almost doubled from 2000 to 2023 and will continue to grow

Global electricity demand has nearly doubled over the last two decades, from 15,277 TWh in 2000 to 29,471 TWh in 2023.

The growth in electricity demand was largely driven by economic growth in Asia, where demand more than tripled from just 4,199 TWh in 2000 to 15,228 TWh in 2023. To put this into perspective, Asia's electricity demand in 2023 was almost as high as the total global electricity demand in 2000.



For emissions to fall, clean electricity growth needs to meet and exceed new electricity demand. This has happened only twice since the turn of the century. In 2015 and 2019, clean electricity growth from wind, solar and other clean sources exceeded electricity demand rises, leading to a small reduction in fossil generation. Consequently, 2015 was the only year with falling fossil generation, excluding the demand falls caused by the financial crisis in 2009 and the Covid-19 pandemic lockdowns in 2020.



In 2022 and 2023, clean electricity capacity additions meant generation increases came close to meeting electricity demand growth, but poor nuclear output in 2022 and low hydro generation in 2023 kept increases below demand growth, resulting in small increases in fossil generation.

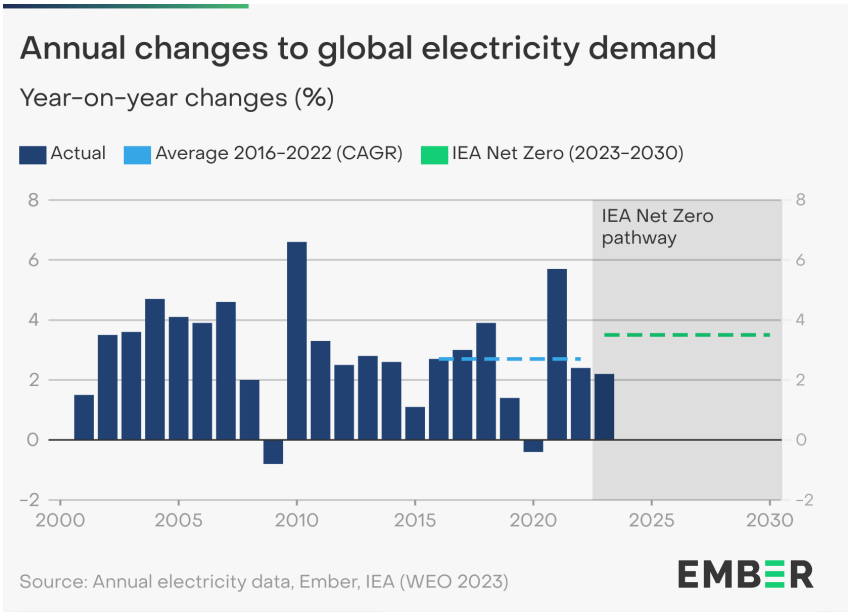
As electrification drives an increase in electricity demand over the coming years (as explored in Chapter 2.3), the rapid addition of clean generation capacity becomes even more crucial to meeting new demand while decarbonising existing power generation.

Demand: Progress towards net zero

Demand growth key to decarbonisation pathways, as clean electrification unlocks economy-wide emissions cuts

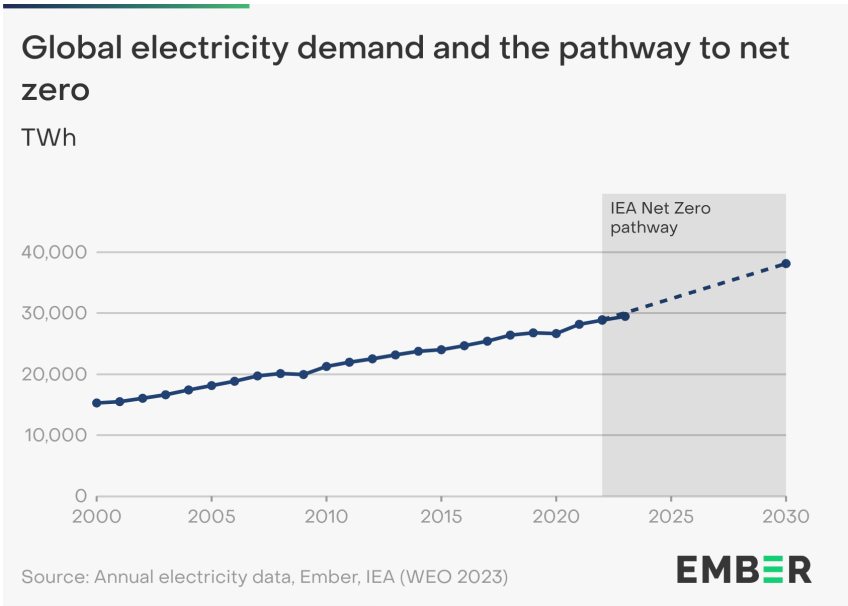
Growth in electricity demand is a central part of any pathway to net zero, as clean electrification helps reduce emissions across sectors like transport, heating and industry.

In the IEA Net Zero Emissions scenario, electricity demand grows by 3.5% annually between 2023 and 2030, a rise from the average annual growth of 2.7% between 2016-2022. In 2023, electricity demand grew 2.2% (+627 TWh) compared to the year before. Electrification increases electricity demand, while energy efficiency also helps to suppress it.



Electrification is already driving up demand (see Chapter 2.3) and with growing demand from data centres, air conditioners, and industry, a strong focus on efficiency is critical for meeting climate targets.

The power sector, the fastest-growing source of final energy demand, is set to grow substantially, driven by electrification as the world tackles the climate crisis, along with a growing global population and improved living standards. According to the IEA NZE scenario, electricity's share of final energy consumption would increase from the current 21% to 27% by 2030, enabling the electrification of transport and industry.



It is clear that higher ambition scenarios that rebuild the energy system around clean electricity will require far higher electricity demand than the current trajectory. In the IEA NZE scenario, demand is expected to grow to 38,127 TWh by 2030, up from 29,471 TWh in 2023.

3.3 Power Sector Emissions

Key highlights

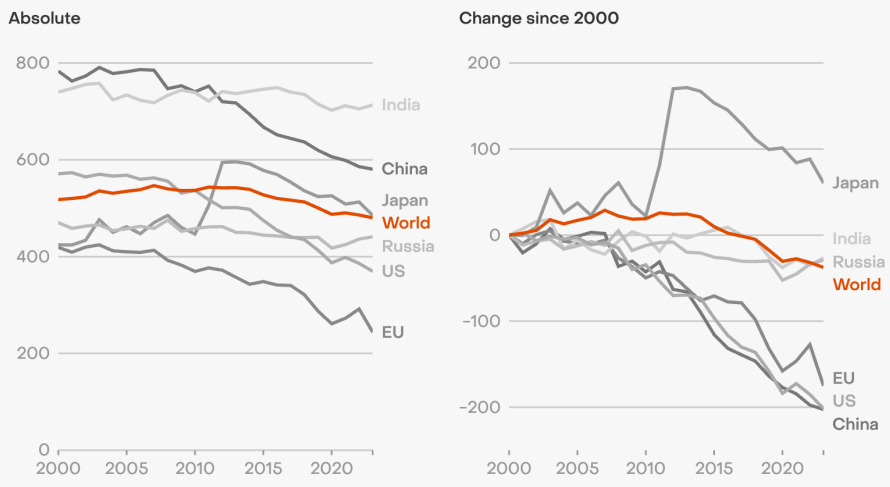
01 Power sector emissions reached a new record high in 2023, as fossil generation increased to meet rising demand

02 Carbon intensity reached a record low, as the share of clean sources increased

03 Power sector emissions have almost doubled since 2000, but growth has slowed in recent years

Electricity is getting cleaner around the world

Carbon intensity of electricity generation (gCO2/kWh)



Source: Annual electricity data, Ember

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Emissions: Current status

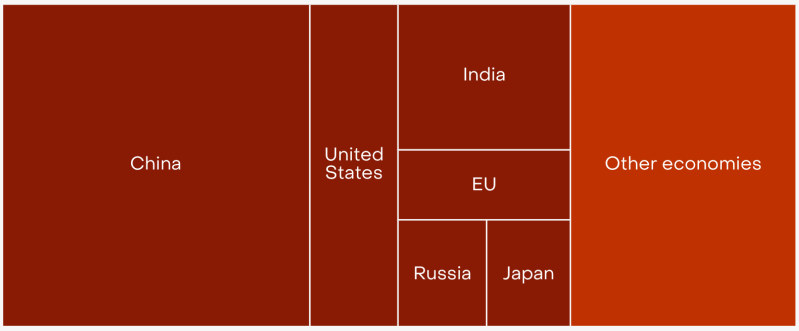
Power sector emissions reached a new record high in 2023, but carbon intensity is declining

In 2023, global power sector emissions rose to 14,153 million tonnes of CO2, an increase of 1% (+135 MtCO2) over 2022.

Asia made up 63% of global power sector emissions at 8,966 MtCO2. China had the highest global power sector emissions with 5,491 MtCO2, representing 39% of global power sector emissions. 95% of China's power sector emissions are the result of burning coal.

A breakdown of global power sector emissions in 2023

Share of global power sector emissions (%)



Source: Annual electricity data, Ember
Named economies have more than 2% of global power sector emissions

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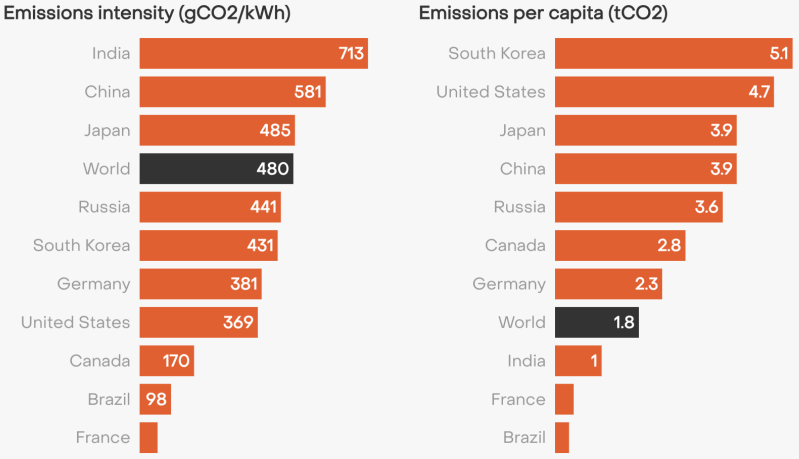
The US was the second largest emitter in 2023 with 1,570 MtCO2 (11% of global power sector emissions), followed by India with 1,404 MtCO2 (9.9%).

Economies that individually had 2% or less of global power sector emissions still made up 28% of global power sector emissions.

In 2023, global emissions intensity dropped to its lowest value in at least two decades. At 480 gCO2/kWh, the average kWh of electricity generated in 2023 is cleaner than at any point since at least 2000.

Canada, Brazil and France had the lowest carbon intensity among the top ten countries with the highest demand. All three countries generated a majority of their electricity from clean sources. Canada's electricity generation in 2023 was 58% hydro power and

Emissions of top electricity consumers in 2023



Source: Annual electricity data, Ember
Graphic shows the ten countries with the highest electricity demand

EMBER

14% nuclear. Brazil had a 60% share of generation from hydro. Additionally, 21% of Brazil's generation came from wind and solar. Historically, France's generation has been dominated by nuclear power which still made up 65% in 2023, while wind and solar contributed a further 14%.

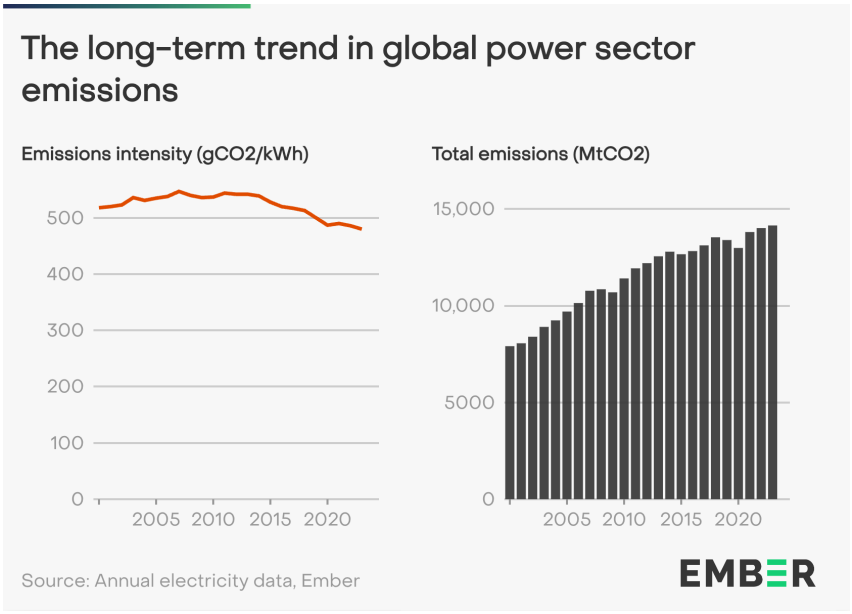
India (713 gCO2/kWh) and China (581 gCO2/kWh) were the only two countries among the top ten global electricity producers with an emissions intensity higher than the global average in 2023. This can be attributed to their substantial coal use for electricity generation – 75% of India's and 60% of China's electricity generation came from coal in 2023.

However, both China and India have lower per capita emissions than other major emitters. The top per capita emitters among the top electricity consumers are South Korea and the US. Indeed, India's per capita power sector emissions are 1.8 times lower than the global average.

Emissions: Long-term trend

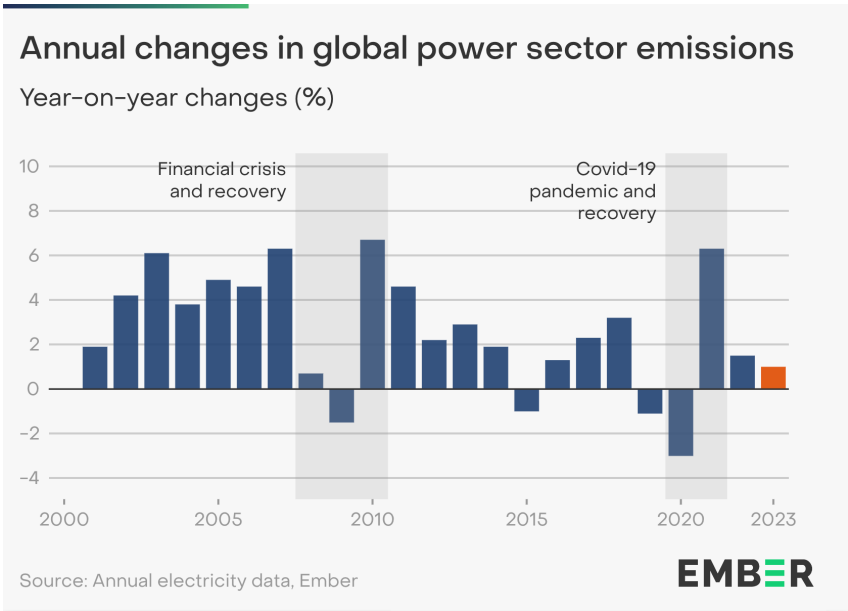
Power sector emissions have almost doubled since 2000, but growth has slowed in recent years

Since 2000, absolute power sector emissions have almost doubled, rising from 7,911 MtCO2 in 2000 to 14,153 MtCO2 in 2023. This equates to an average annual increase of 2.6%. Rapid economic growth across many regions has driven this increase, as global electricity demand has risen while the world maintained a significant dependence on fossil fuels. However, growth has slowed in recent years with annual increases of 1.5% in 2022 and 1% in 2023. This followed a rapid increase in 2021 when economic recovery from the Covid-19 pandemic saw emissions increase 6.3%.



Emissions intensity has declined significantly from its peak in 2007 at 547 gCO2/kWh. In 2023, emissions intensity of global electricity production was 12% lower, at 480 gCO2/kWh. With the exception of 2013 and 2021, emissions intensity has fallen every year since 2011 due to clean electricity (mainly in the form of wind and solar) growing faster than fossil sources of electricity production.

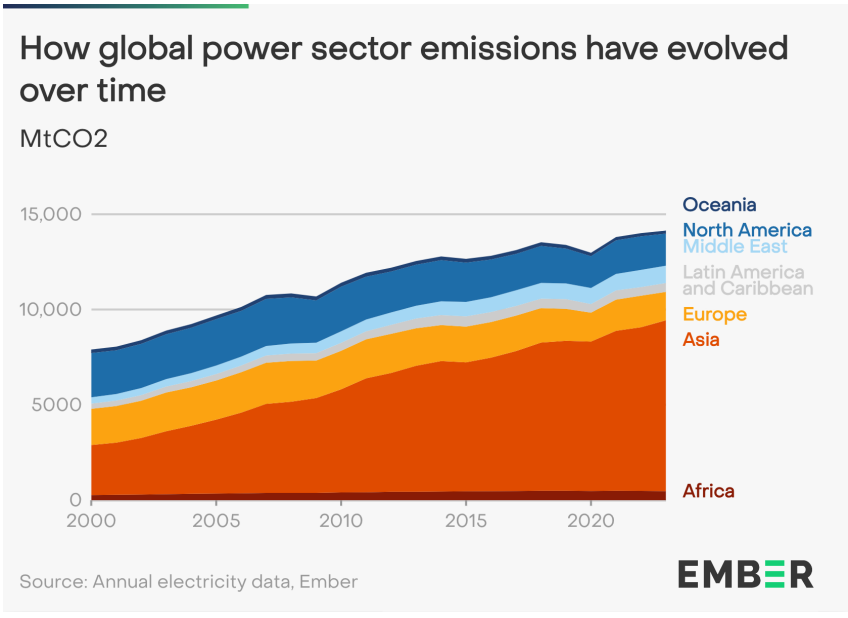
Over the last two decades, only four years have seen falls in power sector emissions. A drop of 1.5% in 2009 came amidst the global financial crisis. In 2015, reduced coal generation in China led to a temporary global emissions fall of 1%. In 2019, low global demand growth alongside coal to gas switching in the US enabled emissions to fall 1.1%. In 2020, the impact of the Covid-19 pandemic led to a record emissions fall of 3.1%.



The last decade has seen significant growth in emissions compared to the 2000s. Between 2003 and 2012, emissions rose by an average of 3.8% annually. Between 2013 and 2022, this growth rate slowed to 1.4%. The 1% increase in 2023 is further below this average.

2023 is likely to have been the peak of power sector emissions (see Chapter 2.1), with a new era of falling emissions beginning from 2024 onwards.

Emissions have not been rising across all regions. Power sector emissions in the OECD – including both the US and EU – peaked in 2007 and have fallen 28% since then. Emissions in Latin America reached a peak in 2015.



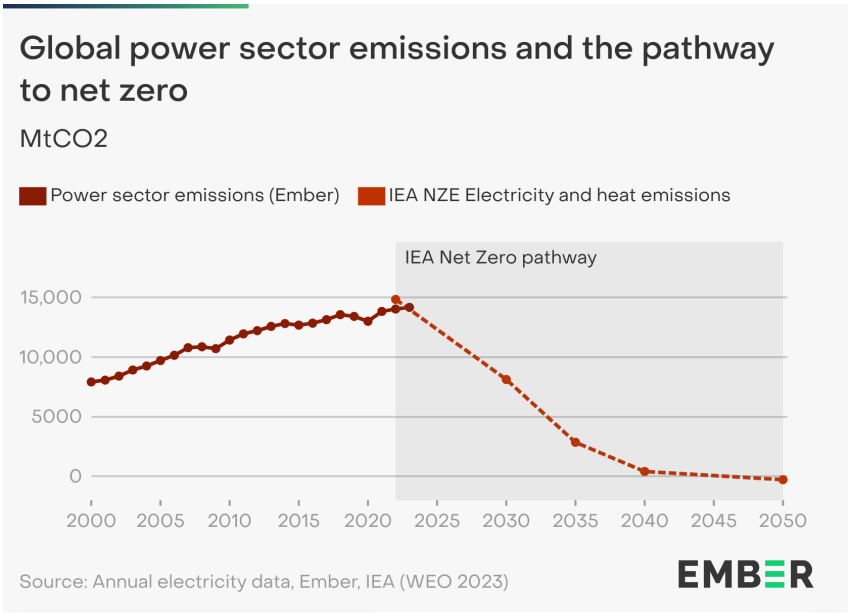
In the last two decades, Asia has seen the largest rise in power sector emissions mainly as a result of increased coal use for electricity generation as the region's emerging economies grew rapidly. Power sector emissions in Asia more than tripled from 2,623 MtCO2 in 2000 to 8,966 MtCO2 in 2023. Combined with the stagnation and falls in other major emitting regions, Asia's share of global power sector emissions rose from just 33% in 2000 to 63% in 2023. However, Asia has a large share of the global population and the bulk of global economic growth is now happening in Asia.

Despite a 75% increase in power sector emissions from African countries since 2000, they still only made up 3.4% of global emissions in 2023 – the same as Japan's share. There is an opportunity for Africa to meet rising demand with clean sources and leapfrog fossil fuels to avoid the increase in emissions previously associated with economic development.

Emissions: Progress towards net zero

Power sector emissions need to halve this decade to align with net zero

To align with the IEA Net Zero Emissions scenario, mature (OECD) economies must decarbonise their electricity generation by 2035 and the rest of the world by 2045. We are not yet seeing the declines needed for those milestones, which require emissions from the power sector to fall by more than 7.6% per year between 2023 and 2030.



In 2023, emissions increased 1% (+135 MtCO2), compared to an average annual increase in emissions of 1.5% between 2016 and 2022. OECD economies, which will decarbonise first, are already seeing declining power sector emissions, with a fall of 6.8% in 2023.

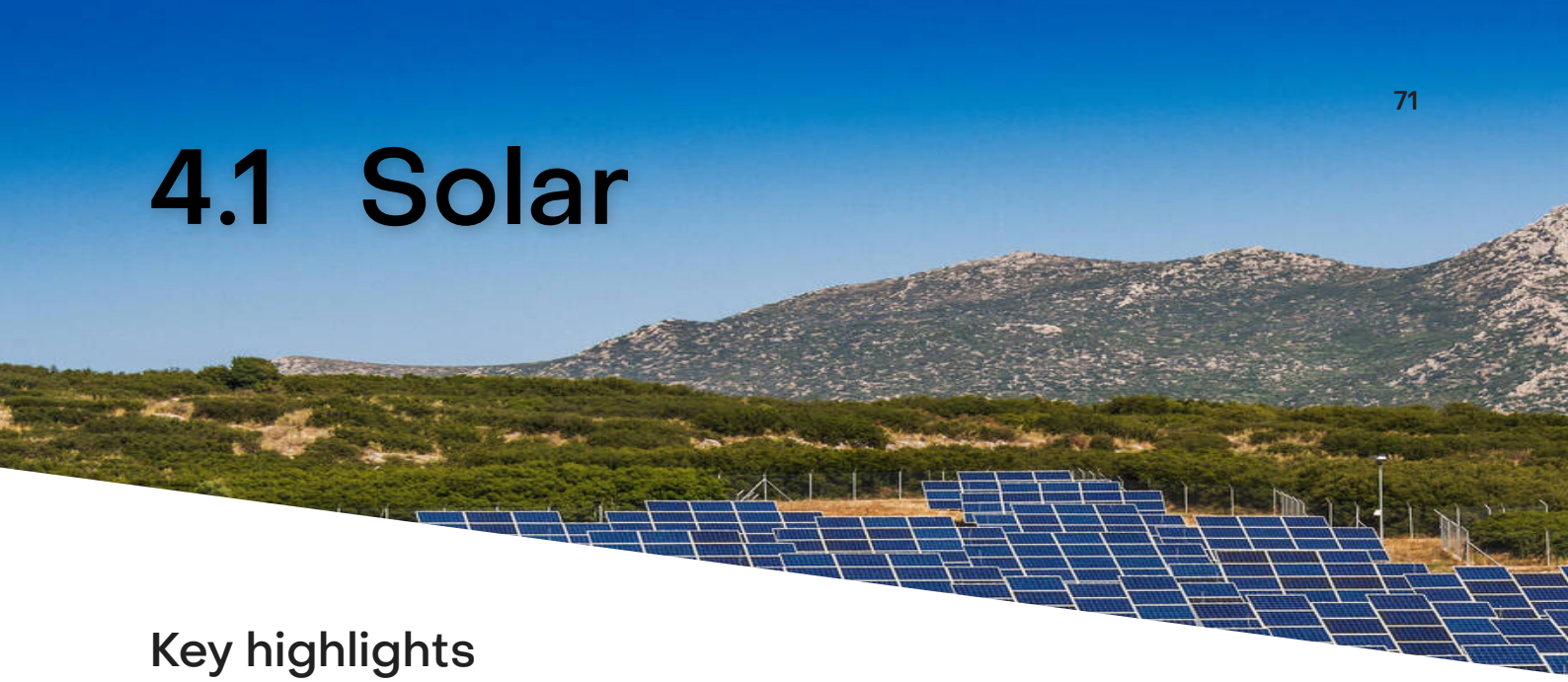
The world is closing in on falling power sector emissions, but will need to move much faster to achieve the steep declines required. If delivered, the global goal to triple renewable electricity capacity announced at COP28 has the potential to almost halve power sector emissions by 2030, according to the IEA NZE scenario. This would see solar and wind provide around 40% of global electricity generation by 2030.

Analysis of the different electricity sources in 2023

Data on global electricity generation from solar, wind, coal, gas, hydro, nuclear and bioenergy in 2023, with an overview of changes and trends over the last two decades alongside the role of each source in reaching net zero. We have ordered the sections according to the fastest growing sources of electricity.

Chapter contents

4.1 Solar



Key highlights

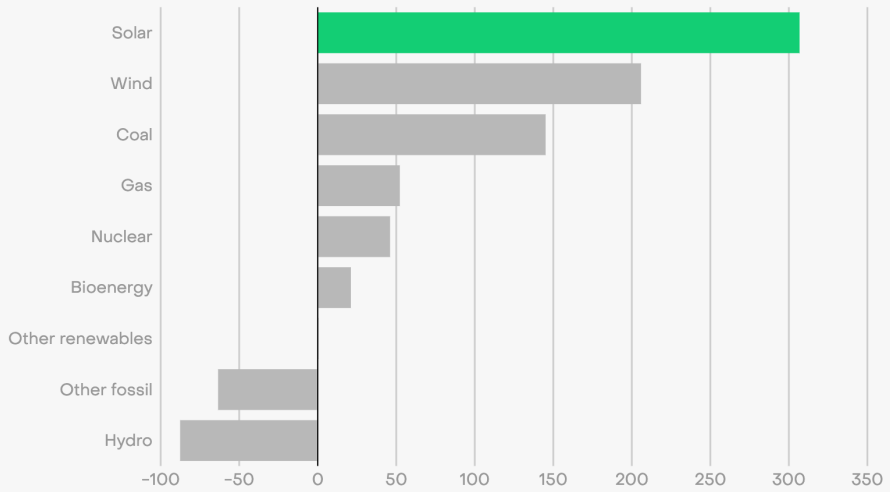
01 Solar produced a record 5.5% of global electricity in 2023

02 China made up more than half of record solar growth in 2023

03 Solar added twice as much new electricity in 2023 as coal

Solar grew more than any other source of electricity in 2023

Year-on-year change in global electricity generation (TWh)



Source: Annual electricity data, Ember

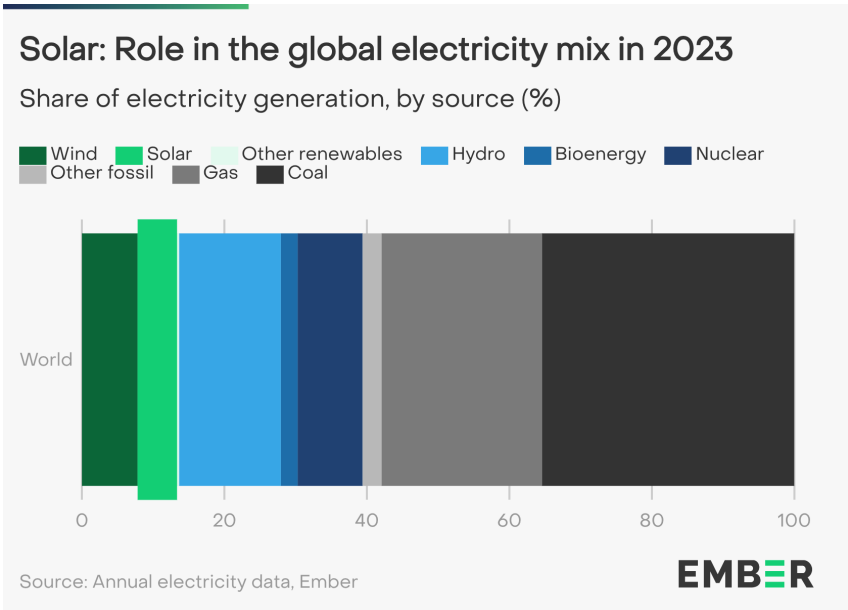
EMBER

Solar: Current status

Solar produced a record 5.5% of global electricity in 2023

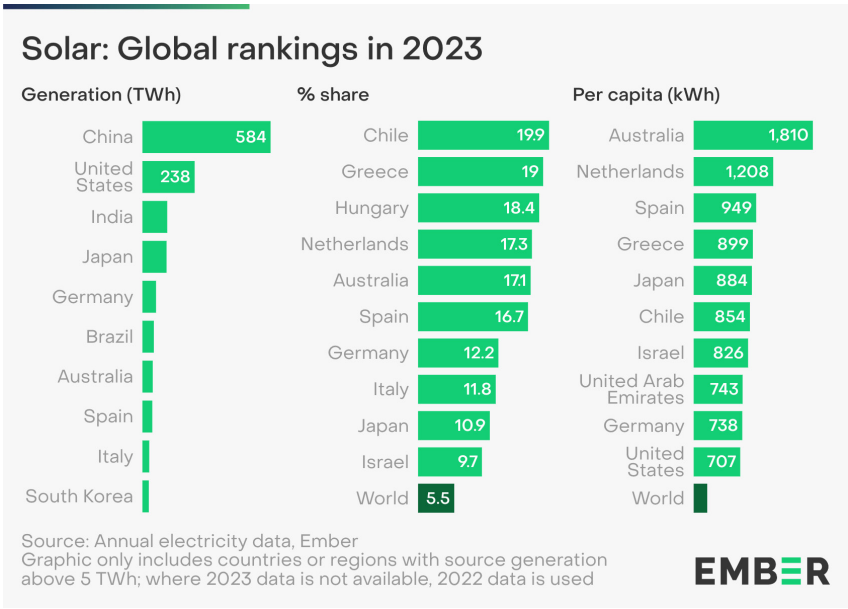
Solar power produced a record 5.5% (1,631 TWh) of global electricity in 2023. As of 2023, 33 countries generated more than a tenth of their electricity from solar.

Solar provides clean power that can be deployed quickly and locally to the demand source. New solar power produces the cheapest electricity in history, according to the IEA. As such, together with wind, solar will form the backbone of the future electricity system, providing nearly 70% of global electricity by 2050.



In 2023, China generated the most electricity from solar power (584 TWh), ahead of the United States (238 TWh). China's generation made up more than a third (36%) of global solar generation. India overtook Japan to become the third largest solar power generator in 2023 (113 TWh).

Chile continued to have the highest share of solar generation in the electricity mix, increasing to 20% in 2023, from 17% the previous year. This ranking excludes countries with less than 5 TWh of solar generation. Greece had the second highest share (19%), followed by Hungary (18%) and Netherlands (17%).

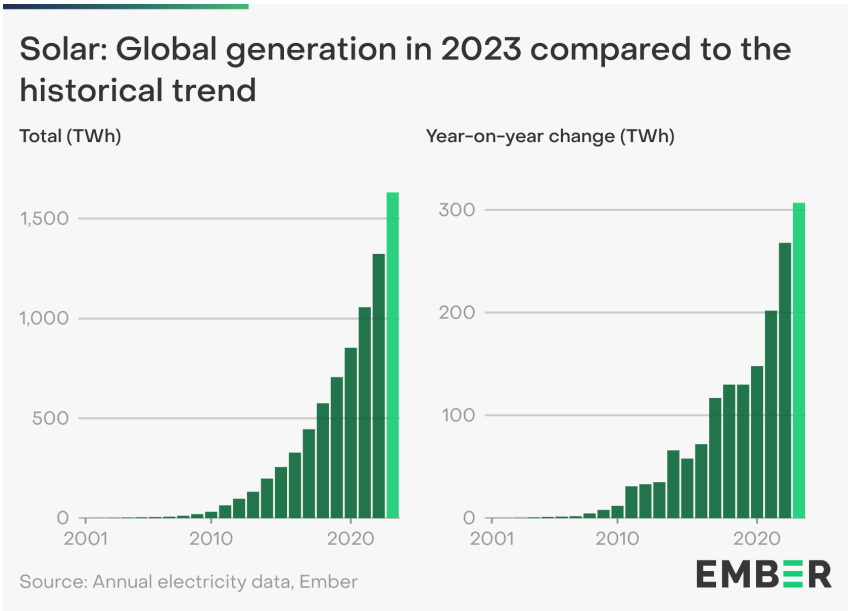


On a per capita basis, Australia produced the most electricity from solar at 1,810 kWh, while the Netherlands came in second with 1,208 kWh. Spain became the third largest solar producer on a per capita basis in 2023, after ranking fifth in 2022.

Solar: Current status

China made up more than half of record solar growth in 2023

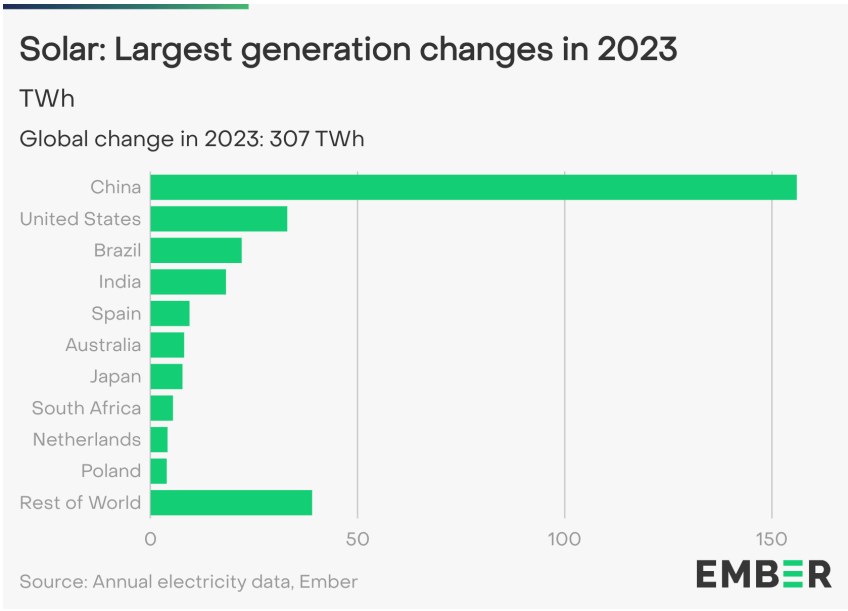
2023 saw a record absolute increase in solar generation of 307 TWh – the largest rise of any electricity source in 2023, adding more than twice as much new electricity as coal. 2023 was the eighth consecutive year of record TWh growth for global solar generation. Added total solar generation rose to a new high of 1,631 TWh. This represents a 23% rise year-on-year, only slightly lower than the 25% increase seen in 2022. The record generation increase in 2023 was the result of record solar capacity additions, particularly in China.



Solar's share of global generation in 2023 increased from 4.6% in 2022 to 5.5%.

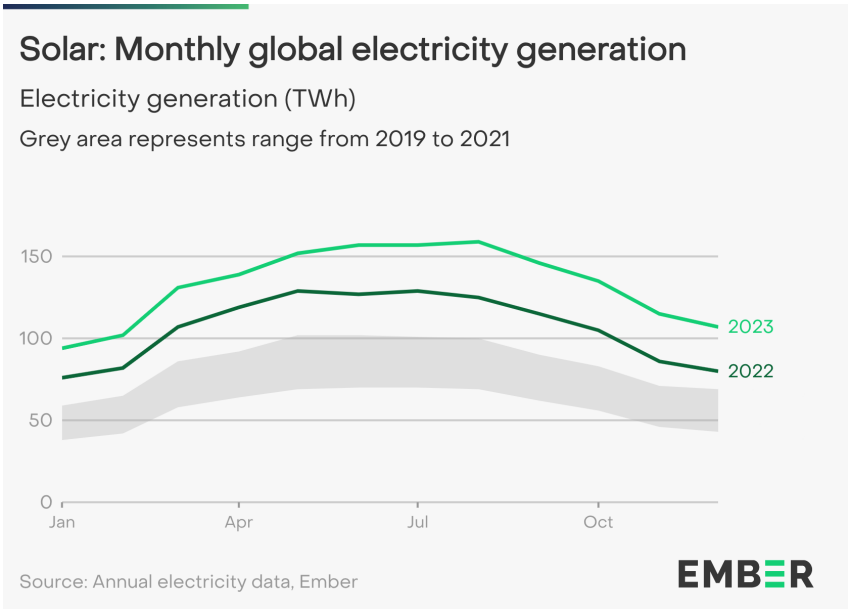
The record global increase in solar generation was in large part driven by China, which saw an increase of 156 TWh (+37%). Growth in China made up more than half (51%) of global growth in solar in 2023.

Major year-on-year increases in solar generation were also seen in the United States (+33 TWh, +16%), Brazil (+22 TWh, +72%) and India (+18 TWh, +19%). Brazil nearly doubled solar generation due to new regulation and feed-in tariffs. Together the top four solar growth countries accounted for 75% of growth in 2023.



The remaining solar growth was widespread, with countries outside the top ten contributing 13% (39 TWh) of global growth.

2023 saw substantial increases and new records in solar generation for every month of the year. The highest monthly generation occurs from May to August when solar irradiation is highest in the northern hemisphere, which is where most of the world's solar installations are located.



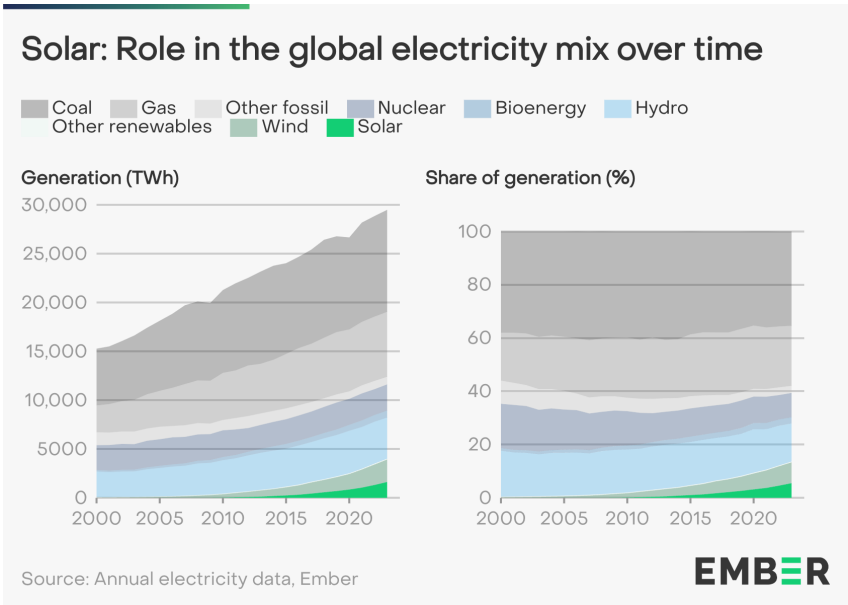
In August 2023, a new record was set for the all-time monthly high for solar generation at 159 TWh. August's record was 28% above generation in August 2022 and 23% above the previous record of 129 TWh in July 2022.

Solar generation in every month between March to October of 2023 was higher than any month in 2022.

Solar: Long-term trend

Solar generation in 2023 was more than six times higher than in 2015

Global solar generation has increased significantly over the last two decades, from just 1 TWh in 2000 to 1,631 TWh in 2023. In 2023, solar was the source with the largest year-on-year percentage growth for the 19th year running.

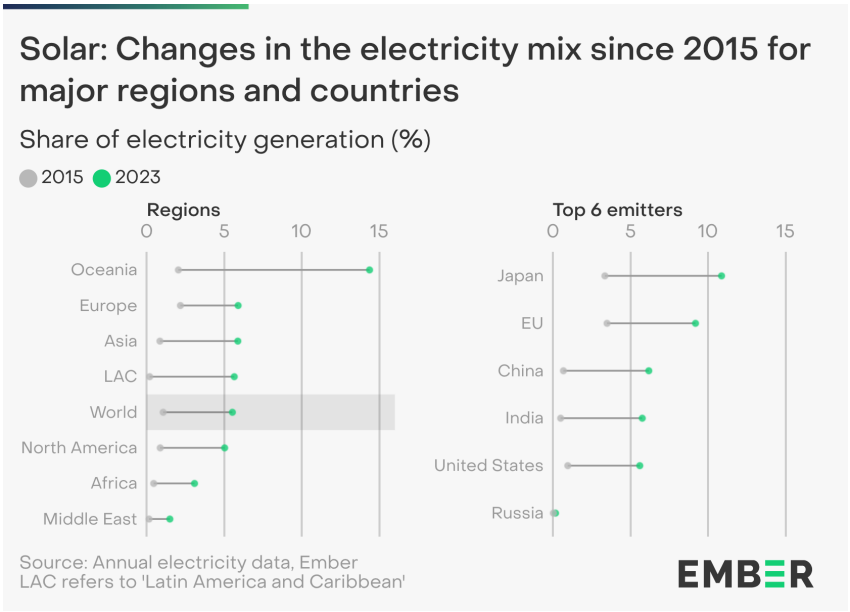


As a result, the share of solar generation has increased from just 1.1% in 2015 to 5.5% in 2023.

Most of the growth came in recent years. Solar generation in 2023 was more than six times larger than in 2015 (256 TWh). Solar still continues to accelerate and has more than doubled (+131%, +925 TWh) since 2019. Deployment of solar capacity has been rapidly increasing, in part due to costs falling by 87% from 2010 to 2020.

Many countries have seen their solar share increase. China's share in 2023 was above the world average at 6.2% (584 TWh), up from just 0.7% (39 TWh) in 2015. Over the same period, in the US the solar share increased from 1% (39 TWh) to 5.6% (238 TWh) and in Japan from 3.4% (35 TWh) to 11% (110 TWh).

Across all regions, solar generation is playing a more prominent role in the mix.



In Latin America, Brazil saw solar rise from negligible amounts in 2015 (0.01%, 0.06 TWh) to 7.3% (52 TWh) in 2023. In Chile, solar went from 1.9% (1.4 TWh) in 2015 to 20% (17 TWh) in 2023.

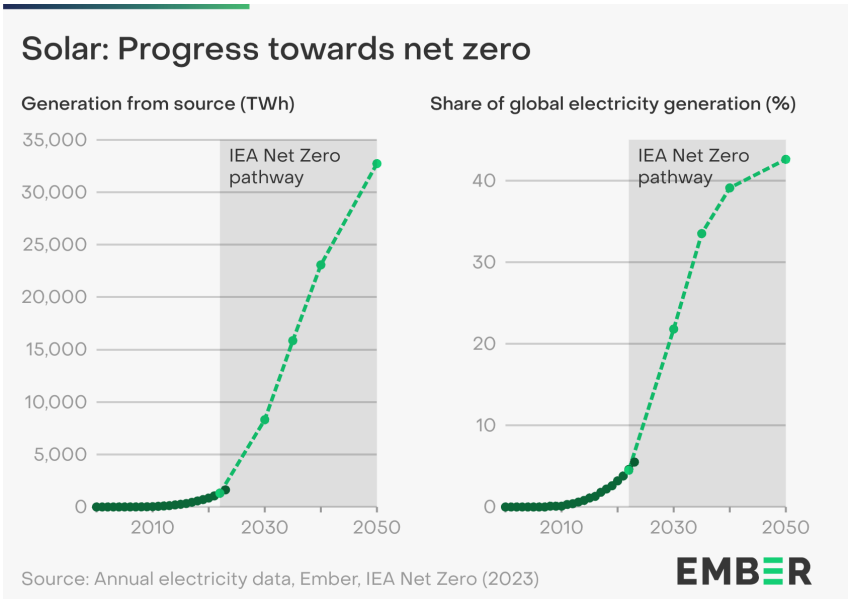
Large increases also occurred across Europe. Spain saw an increase from 5% (14 TWh) in 2015 to 17% (45 TWh) in 2023. Germany saw its share double from 6% (38 TWh) in 2015 to 12% (62 TWh) in 2023.

The Middle East and Africa are still lagging behind, but countries like South Africa (1.1% in 2015 to 6.8% in 2023) and the United Arab Emirates (0.2% in 2015 to 4.5% in 2022) have seen recent increases.

Solar: Progress towards net zero

Growth in solar generation is on track for net zero targets

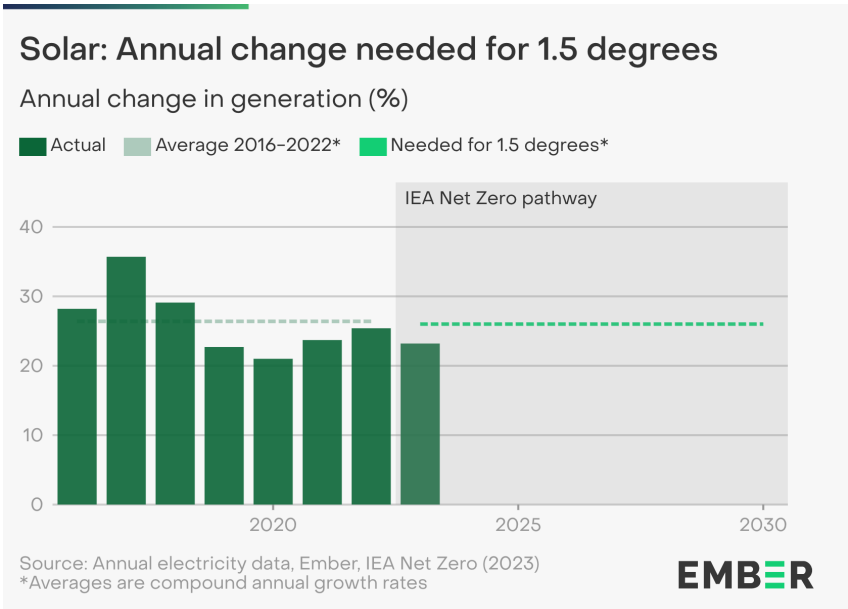
Global solar generation needs to grow by more than five times from the current 1,631 TWh in 2023 to 8,316 TWh in 2030, according to the IEA Net Zero Emissions scenario. This would take solar's share of global electricity generation from 5.5% in 2023 to 22% in 2030. Solar's trajectory in the scenario is steeper than current deployment rates, although additions have increased rapidly in the past few years.



In the IEA NZE scenario, solar continues to grow beyond 2030, making up 43% of all generation in 2050.

While solar generation will need to see a large rise across the globe, country trajectories will inevitably vary. Countries with good solar conditions like Australia, China or the US may well exceed the global average, while others will rely more on other clean sources like wind, hydro and nuclear in their power sector transition.

In 2023, solar generation rose by 23%. This was slightly below the average growth rate recorded since 2015, of 26%. However, the growth rate from 2016 to 2022 was in line with net zero targets, and as explained in Chapter 2.2 the slower growth in 2023 does not represent a structural slowdown. To align with the goal for solar generation outlined in the IEA NZE scenario, an average annual growth rate (CAGR) of 26% needs to be maintained from 2023 to 2030.



This growth rate would see larger and larger absolute increases every year. This requires additions in generation of more than 1,000 TWh per year by 2030, compared to the 314 TWh in 2023.

4.2 Wind

Key highlights

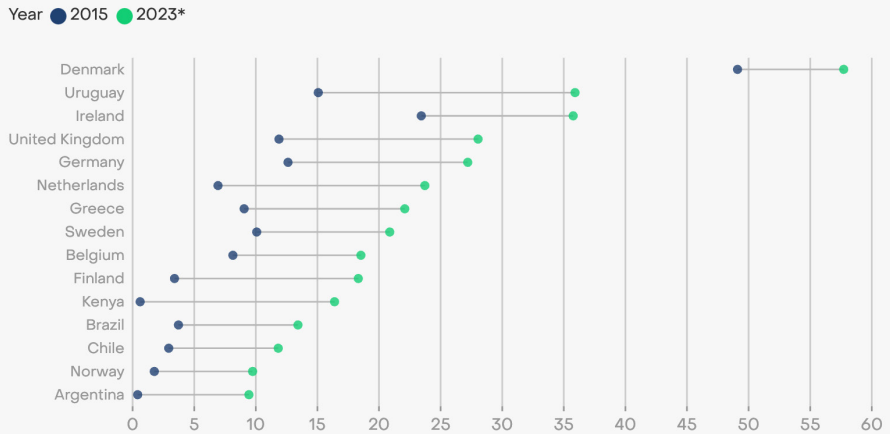
01 Global wind generation reached a new record high, adding enough electricity to power all of Poland

02 32 countries generated more than a tenth of their electricity from wind power in 2023

03 Wind generation has nearly tripled since 2015

The economies with the largest increases in wind share between 2015 and 2023

Share of electricity generation (%)



Source: Annual electricity data, Ember
*2023 or latest available year
Graphic shows top 15 increases; analysis only includes countries with at least 10 TWh of electricity demand and electricity imports of less than 50% of demand

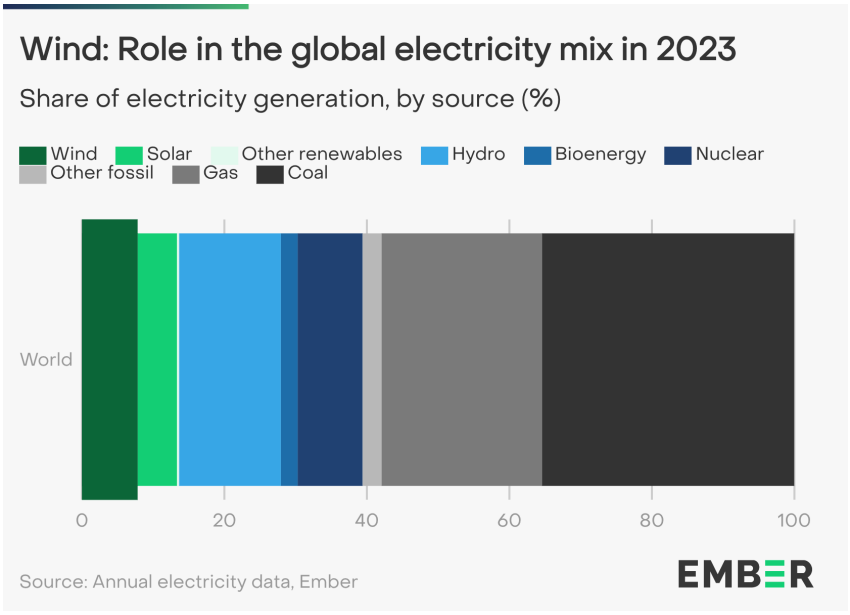
EMBER

Wind: Current status

32 countries generated more than a tenth of their electricity from wind power in 2023

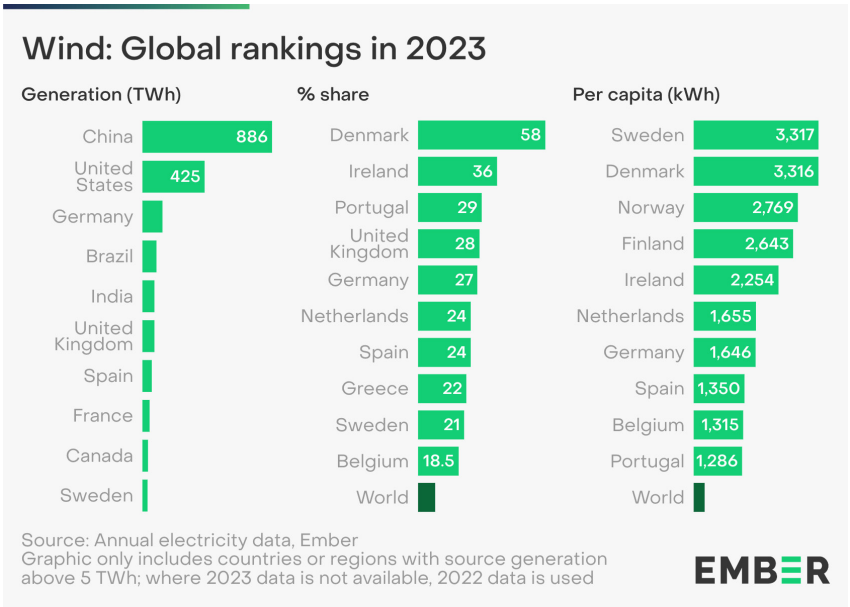
Wind produced 7.8% (2,304 TWh) of global electricity in 2023.

Wind, alongside solar, is key to reducing emissions in the electricity sector. Both sources will form the backbone of the future electricity system by providing nearly 70% of global electricity by 2050. Therefore, rapid scale-up is required this decade.



China leads the world in wind power. It generated 886 TWh from wind in 2023, more than twice that of the United States (425 TWh) and six times that of Germany (137 TWh).

32 countries generated more than a tenth of their electricity from wind power in 2023. Denmark had the highest share of wind generation in the electricity mix at 58% in 2023, up from 54% in 2022 and setting a new record high. Ireland had the second highest share at 36%.



The Scandinavian countries of Sweden (3,317 kWh), Denmark (3,316 kWh), Norway (2,769 kWh) and Finland (2,643 kWh) lead the world in wind generation per capita.

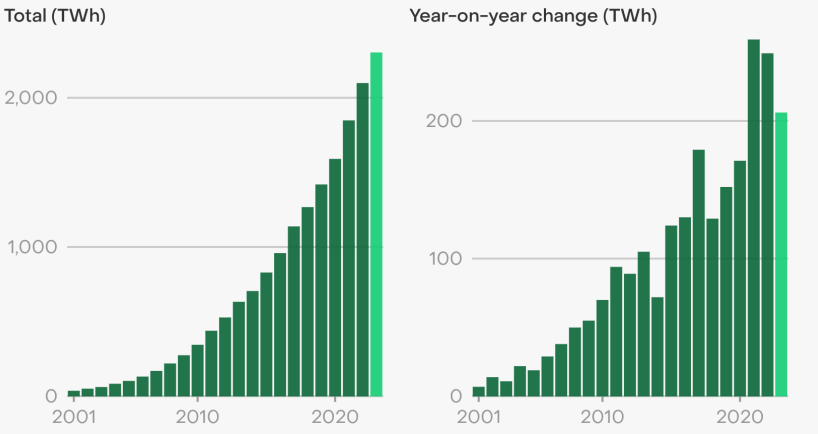
Wind: Change in 2023

Global wind generation reached a new record high, adding enough electricity to power all of Poland

Global wind generation reached a new record high of 2,304 TWh in 2023, up 206 TWh (+9.8%) compared to 2,099 TWh in 2022. As a result, wind's share in the global electricity mix increased from 7.3% in 2022 to 7.8% in 2023.

The growth in wind power in 2023 of 206 TWh was the third-largest addition after 2021 and 2022.

Wind: Global generation in 2023 compared to the historical trend



Source: Annual electricity data, Ember

EMBER

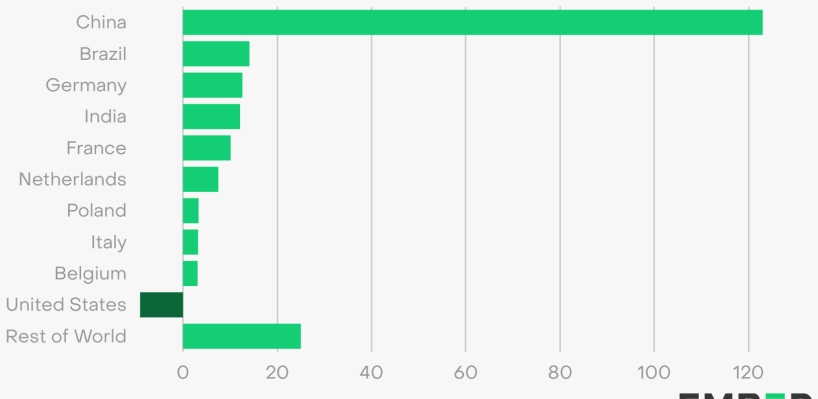
China's wind increase of 123 TWh (+16%) accounted for 60% of global wind generation additions in 2023. It was more than eight times higher than the second-highest increase recorded in Brazil of 14 TWh (+17%).

Across the EU, wind generation grew by 50 TWh (+12%) with the largest increases in Germany, France and the Netherlands.

Wind: Largest generation changes in 2023

TWh

Global change in 2023: 206 TWh



Source: Annual electricity data, Ember

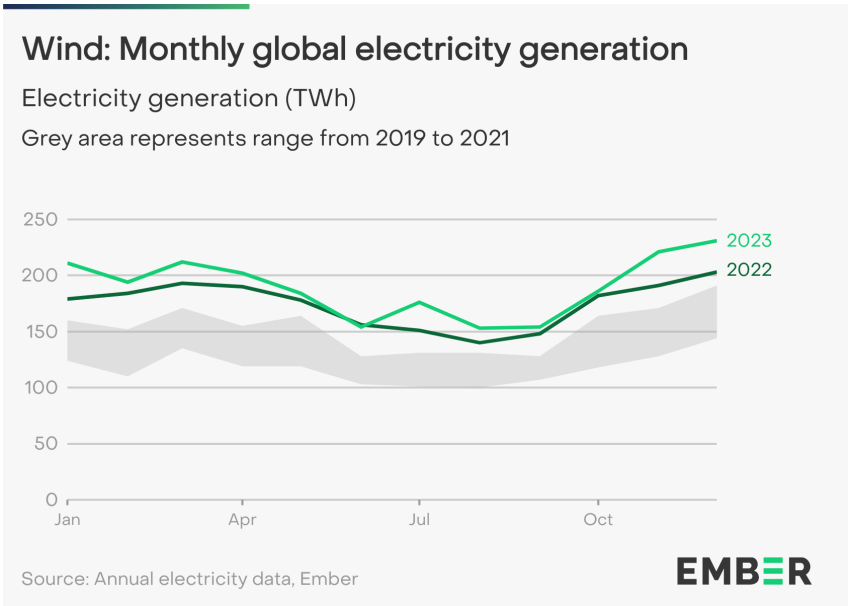
EMBER

The US saw wind generation fall 9 TWh (-2.1%) despite capacity additions, due to unfavourable wind conditions. Generation is expected to rise again in 2024.

Throughout 2023, monthly global wind generation remained mostly above 2022 values.

December 2023 set a new all-time monthly record for wind generation with 231 TWh, a 14% increase over December 2022.

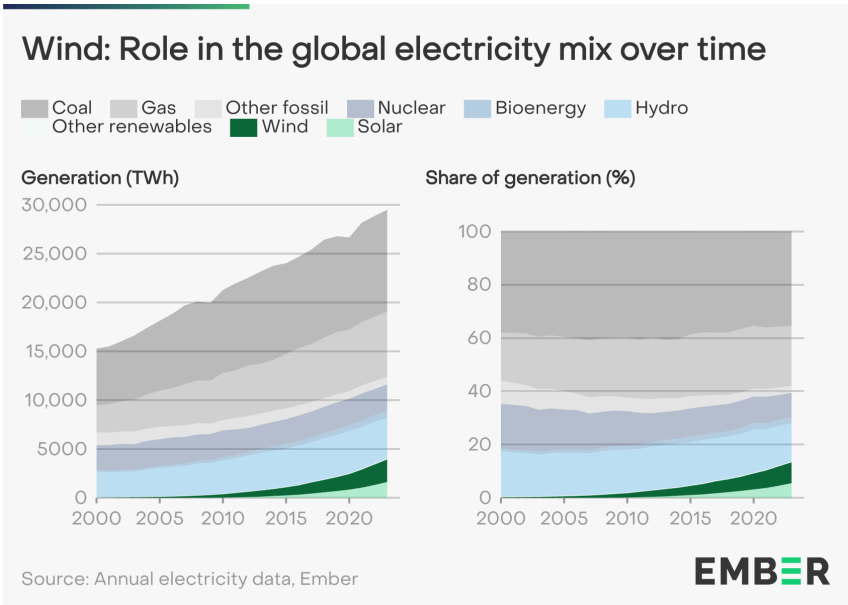
Wind generation is generally highest during the winter months in the northern hemisphere, with wind capacity currently concentrated in Europe, the US and China.



Wind: Long-term trend

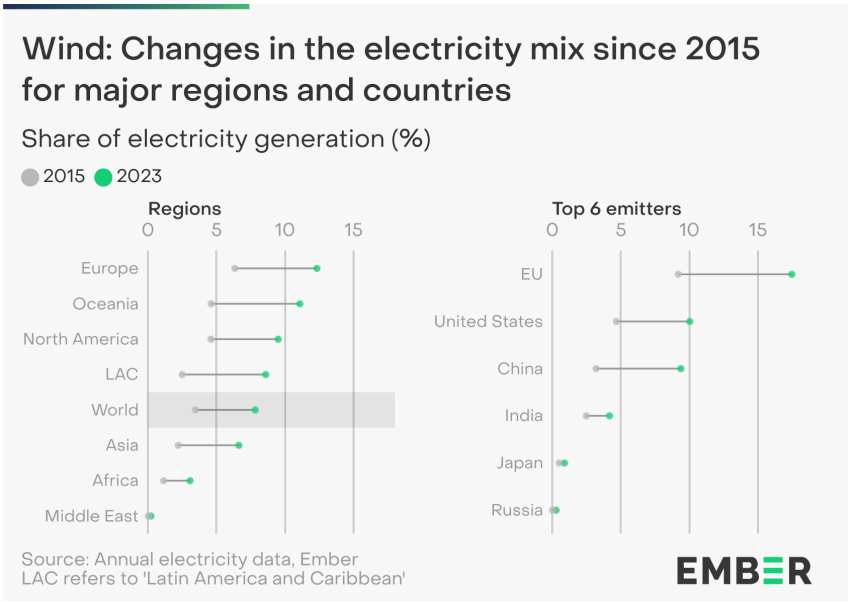
Wind generation has nearly tripled since 2015

Wind and solar are currently the only two sources growing substantially in the global electricity mix. Wind generation was just 31 TWh and 0.2% of the mix in 2000. In 2015, this had grown to 830 TWh and 3.5%. In just eight years since 2015, wind generation nearly tripled to 2,304 TWh, with its share more than doubling to 7.8% in 2023.



Europe has the highest share of wind generation. This was mainly driven by increases in the EU, where the share of wind generation reached a record high of 17% in 2023 – almost double the 9% share in 2015. Over the same period, the share in the United Kingdom increased from 12% to 28%, and in Denmark, it reached a share of 58%, up from 49% in 2015.

The Americas, Asia and Oceania also saw rapid build up of wind power in some countries. In Australia, wind generation increased from 4.7% in 2015 to 12.1% in 2023. China's share increased from 3.2% to 9.4% in the same period. Wind generation in the US increased from 4.7% in 2015 to 10% in 2023, while Brazil's share reached 13% in 2023, up from 3.7%.



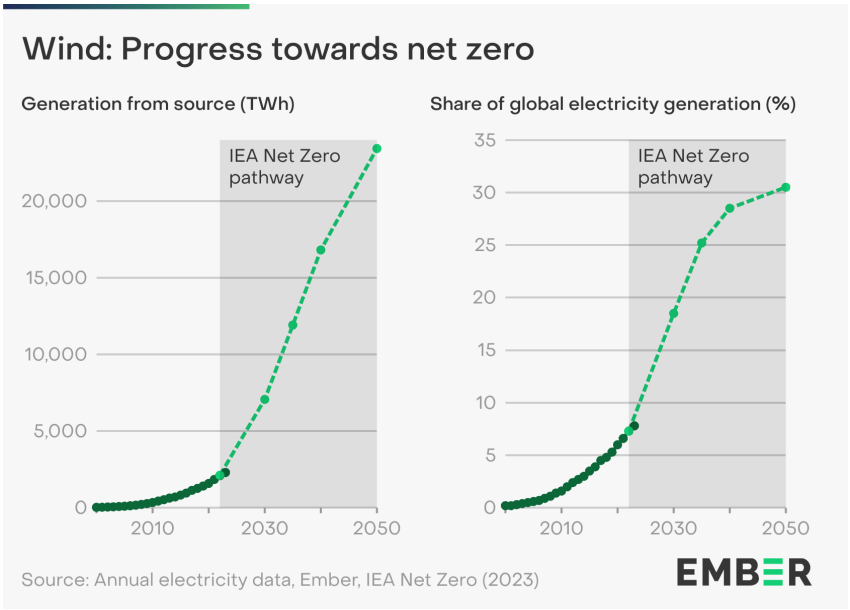
Africa and the Middle East have recently seen more wind installations, but shares still lag behind. Morocco stood out with an increase in wind generation share from 2015 to 2023 from 8.4% to 14.8%.

Wind: Progress towards net zero

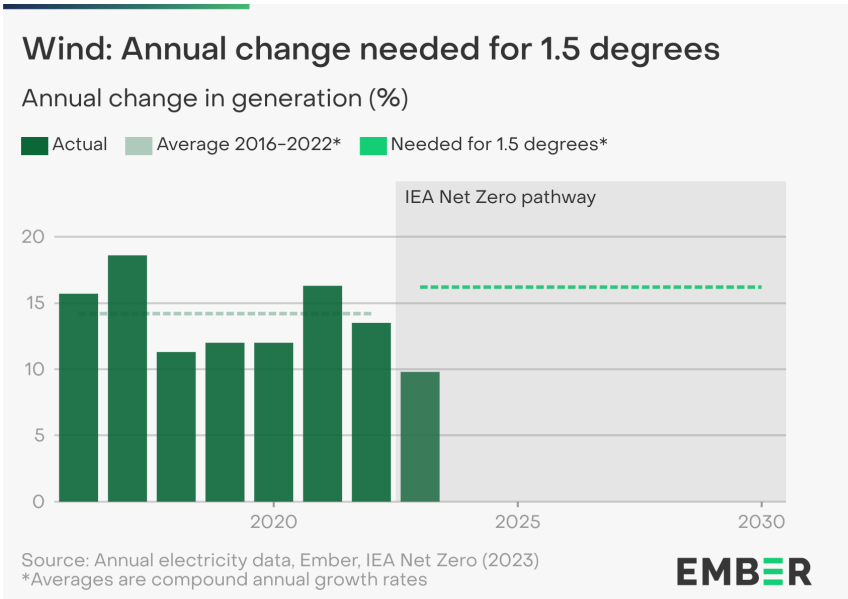
To reach net zero, wind needs to grow at twice the rate it did in 2023

According to the IEA Net Zero Emissions scenario, global wind generation needs to increase to 7,070 TWh in 2030 from today's 2,304 TWh to meet rising demand and replace fossil fuels. This would increase the share in the mix from 7.8% to 18.5%. By 2050, the IEA NZE scenario sees wind growing further to 31% of the global electricity mix.

Wind generation is not expected to rise uniformly across the world. The largest increases are expected in China, the US and Europe.



Global wind generation rose by 9.8% in 2023. This was significantly below the average annual growth of 14.2% seen between 2016 and 2022. In part this was caused by temporary weather conditions in the US. Additionally, capacity additions – while larger in absolute terms every year – are not yet growing fast enough to maintain high percentage growth rates.



To align with the IEA NZE scenario, global wind generation needs to grow at an average 16.2% every year through to 2030. This is nearly twice as fast as in 2023 and two percentage points higher than the average growth between 2015 and 2023.

4.3 Coal

Key highlights

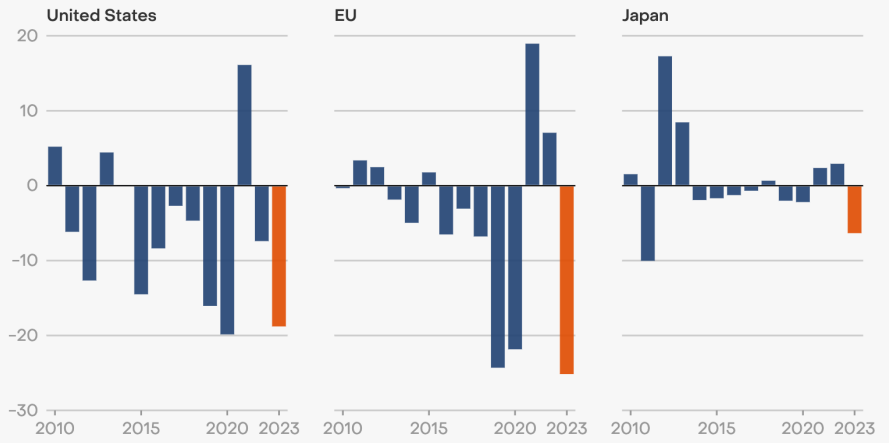
01 Coal generated 35% of global electricity in 2023, with China responsible for more than half of global generation

02 The increase in global coal generation was driven in large part by low hydro output in just four countries

03 OECD economies including the EU, US and Japan saw major falls

There were major coal falls in the US, the EU and Japan in 2023

Annual change in electricity generation from coal (%)



Source: Annual electricity data, Ember

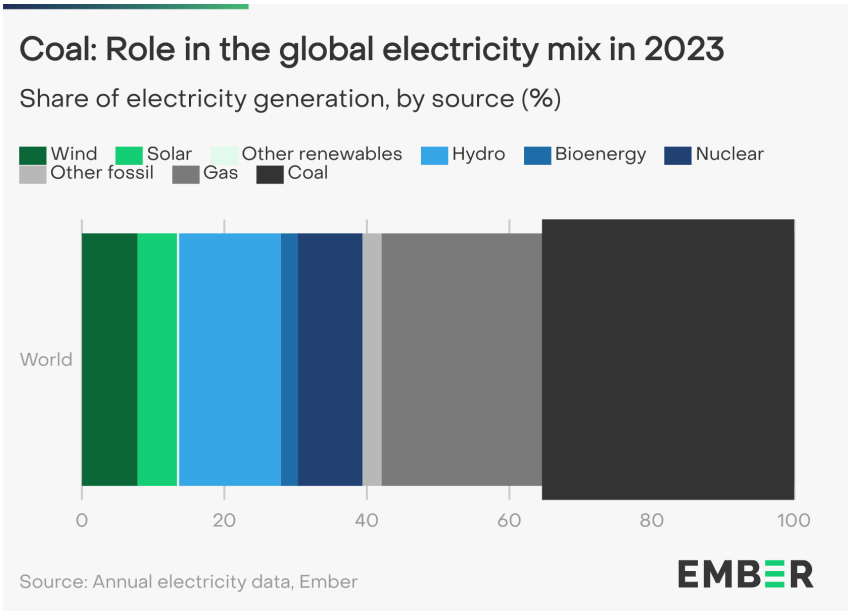
EMBER

Coal: Current status

Coal generated 35% of global electricity in 2023, with China responsible for more than half of global generation

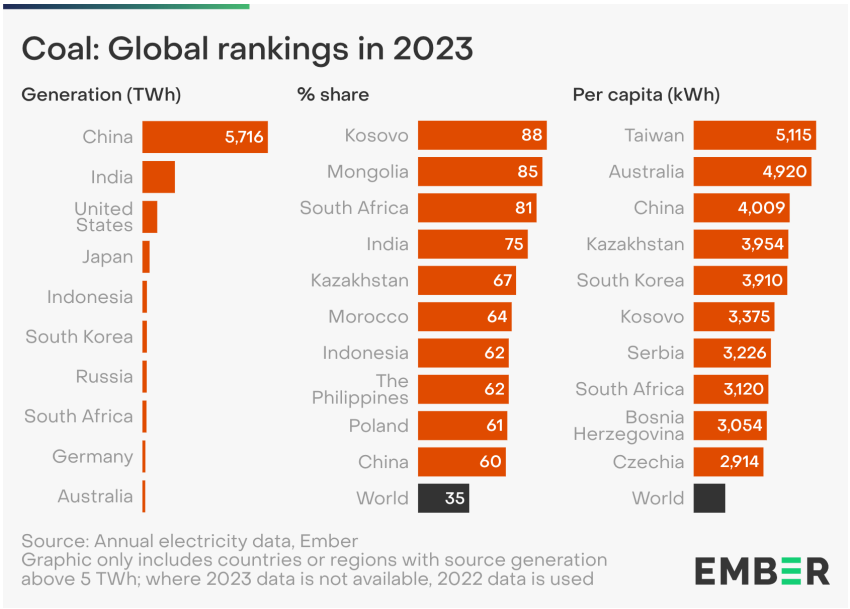
Coal generated 35% (10,434 TWh) of global electricity in 2023, remaining the largest source of electricity generation.

Coal power is the single largest contributor to emissions from the power sector, and indeed the single largest source of emissions across the entire global economy. The world must move rapidly to reduce its role in the next two decades to have a chance at limiting global warming to 1.5C. As per the IEA Net Zero Emissions scenario, unabated coal plants will have to be phased out by 2030 in mature economies and by 2045 in emerging economies.



China produced by far the most electricity from coal in 2023. Its output of 5,716 TWh represented more than half (55%) of total global coal generation in 2023. India produced the second highest amount of electricity from coal, but at 1,480 TWh this amounted to only a quarter of China's coal generation.

Just 13 countries generated more than half of their electricity from coal. Kosovo had the highest share of coal power in its electricity mix (88%). Mongolia (85%) and South Africa (81%) had the second and third highest shares respectively. China and India were also in the top ten for share of generation from coal, producing 60% and 75% of their electricity from coal.



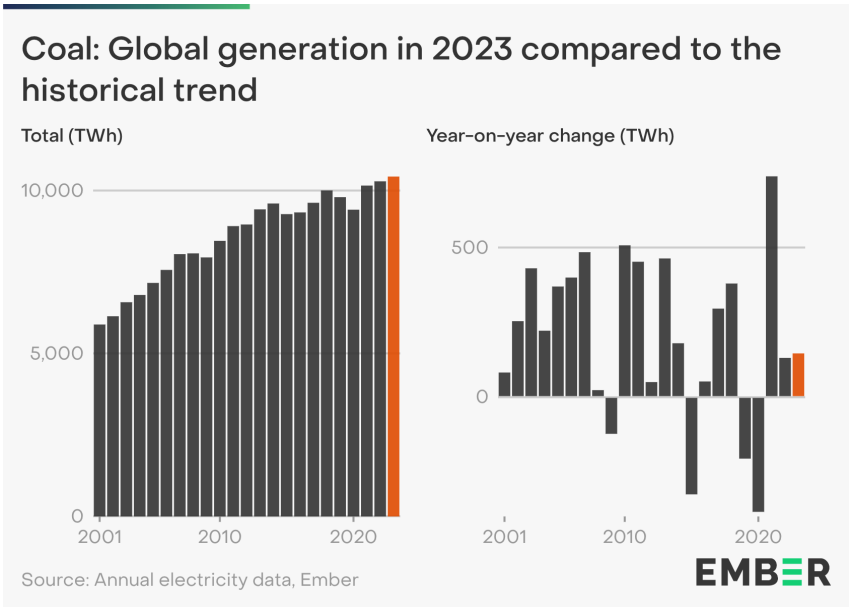
Taiwan (5,115 kWh) and Australia (4,920 kWh) had the highest coal generation per capita, more than three times the world average of 1,319 kWh.

Coal: Change in 2023

The increase in global coal generation was driven largely by low hydro output in four countries, but OECD economies including the EU, US and Japan saw major falls

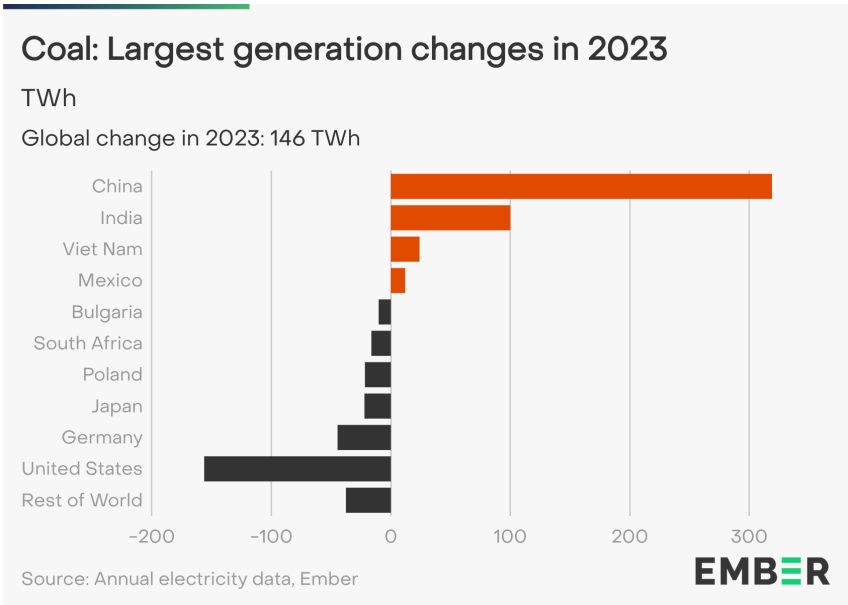
Coal generation reached another record high in 2023. Globally, 10,434 TWh of electricity was produced from coal last year.

Generation increased by 146 TWh (+1.4%) compared to 2022, slightly higher than the annual growth seen from 2021 to 2022 of 131 TWh (+1.3%). However, while total global electricity generation increased, the share of coal in the global mix has actually fallen slightly, by 0.3 percentage points, from 35.7% in 2022 to 35.4% in 2023.



Of countries with available data for 2023, 38 showed falls in coal generation and only 14 showed increases. Only four countries had increases over 10 TWh, driven in large part by drought conditions that caused low hydro output.

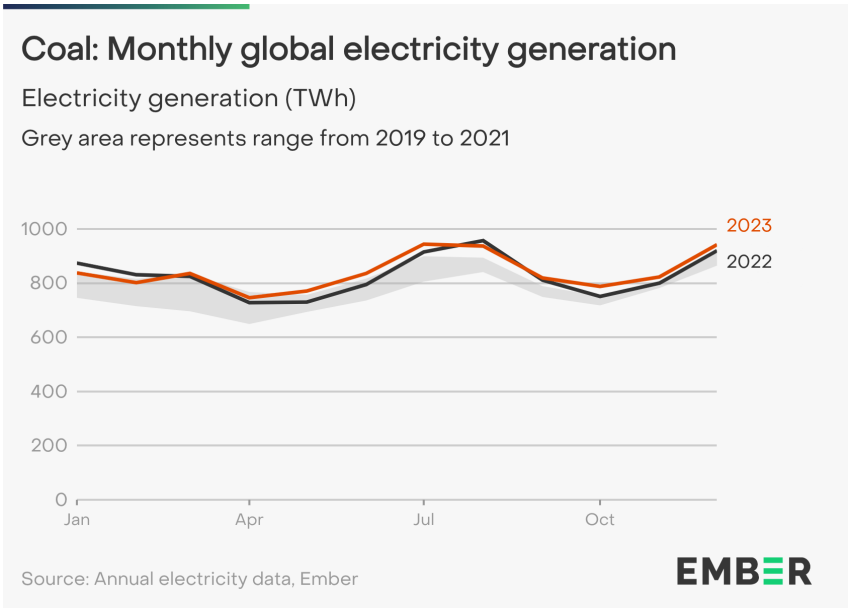
Coal generation increased most in China (+319 TWh, +5.9%) and India (+100 TWh, +7.3%). Smaller increases were recorded in Viet Nam (+24 TWh, +23% TWh) and Mexico (+12 TWh +55%).



In the US, coal generation collapsed 156 TWh (-19%). In Germany, coal fell by 45 TWh (-25%). The entire EU saw a fall of 113 TWh (-25%).

In January and February 2023, coal generation remained below 2022 values. However, as droughts in China reduced availability of hydro generation, coal generation saw larger increases from March to July.

In the second half of the year, coal generation was only slightly above 2022 as hydro generation in China returned to previous levels. With China accounting for more than half of global coal generation, changes in the country have a large-scale impact on generation worldwide.



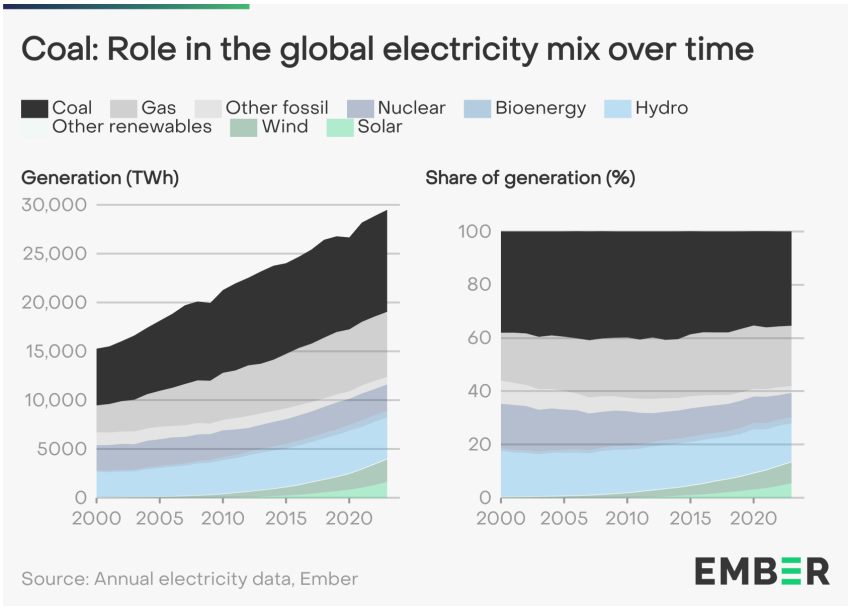
Generation tends to be high in the winter and summer months of the northern hemisphere when electricity demand peaks due to increased demand from heating and air conditioning.

Coal: Long-term trend

Coal's share in the electricity mix has declined since its peak in 2013

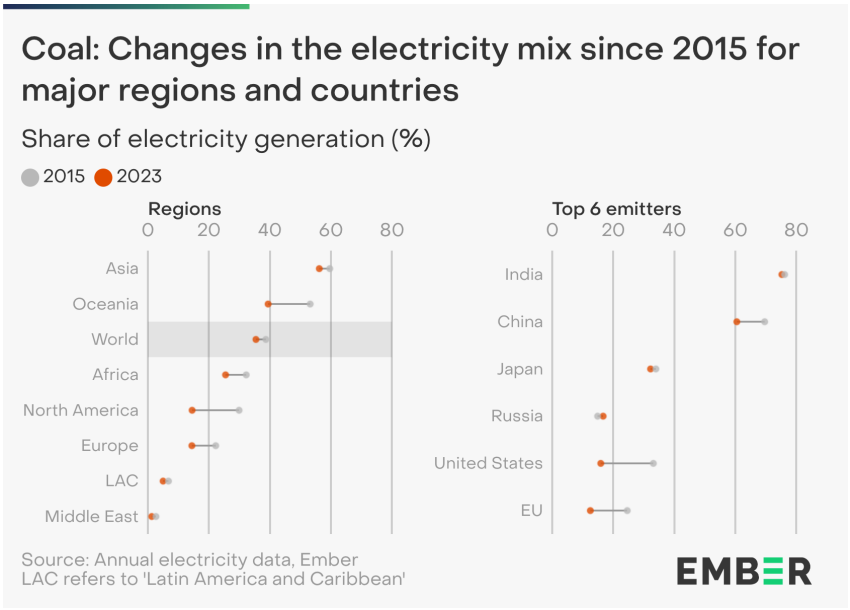
Electricity generation from coal has been consistently growing for the last two decades. Generation nearly doubled from 5,809 TWh in 2000 to 10,434 TWh in 2023.

At the same time, the share of coal in the electricity mix decreased slightly, from 38% in 2000 to 35% in 2023. Coal generation share increased globally until 2013 when it reached a peak of 41%. Even though coal generation continued to grow after 2013, growth was slower than increases in overall electricity demand, resulting in declining share. In particular, additions of solar and wind power in the last decade have resulted in coal's share of the mix declining six percentage points from its peak in 2013.



Since 2015, the share of coal generation has fallen across all regions. The largest falls came from North America, driven by growth in gas in the United States pushing coal out. As a result, coal share in the region fell from 30% in 2015 to 14% in 2023. Globally, the share of coal fell from 39% to 35% over the same period.

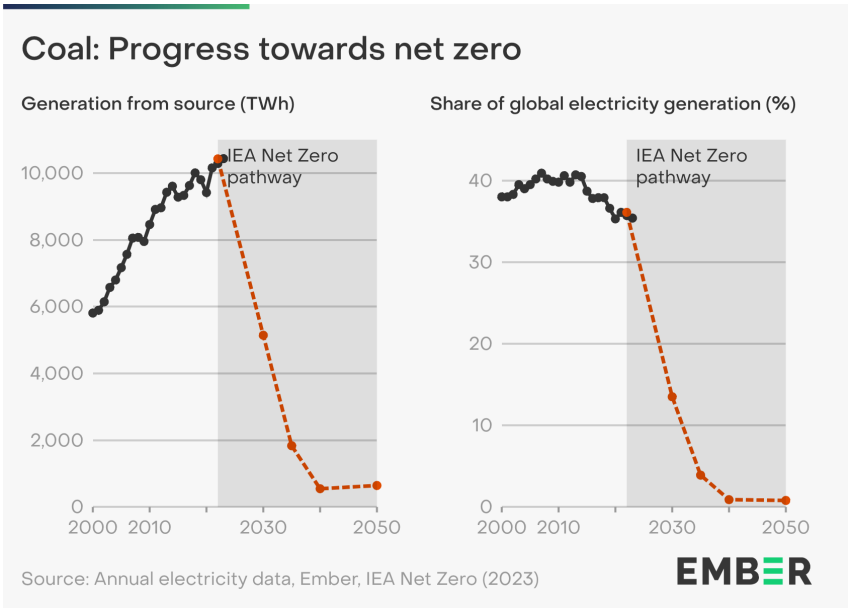
Among the top emitters, China, the US and the EU all saw large falls in coal share. In the US, the share more than halved, falling 17 percentage points from 33% to 16% of the mix.



Coal: Progress towards net zero

Net zero pathways see coal generation halve this decade, a sharp reversal of the ongoing increases

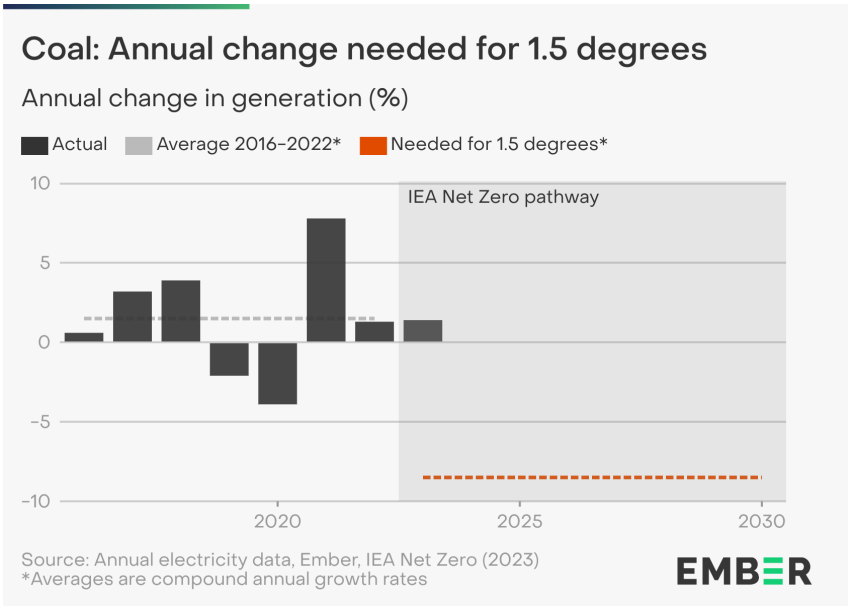
According to the IEA Net Zero Emissions scenario, coal generation needs to be almost entirely phased out by 2040. By 2030, this pathway requires a halving of coal generation, from 10,434 TWh in 2023 to 5,144 TWh. As a result, the share in the global electricity mix would fall from 35% now to just 14% by 2030.



On this pathway, countries in Europe and North America, as well as other OECD countries such as Australia, Japan and South Korea, which have a larger historical responsibility for emissions, would phase out coal by 2035. For less developed countries with large amounts of coal generation – such as China, India and Indonesia – the next step is to end growth in coal generation and begin a phasedown.

Between now and 2030, the IEA NZE scenario requires an average 8.5% annual decrease in coal generation. In 2023, generation increased by 1.4%, while the average annual growth recorded since the Paris Agreement in 2015 was 1.5%.

However, there are encouraging signs in the OECD. From 2016 to 2022, coal declined by an average of 5% annually across OECD countries. In 2023 the decline accelerated to 13%.



4.4 Gas

Key highlights

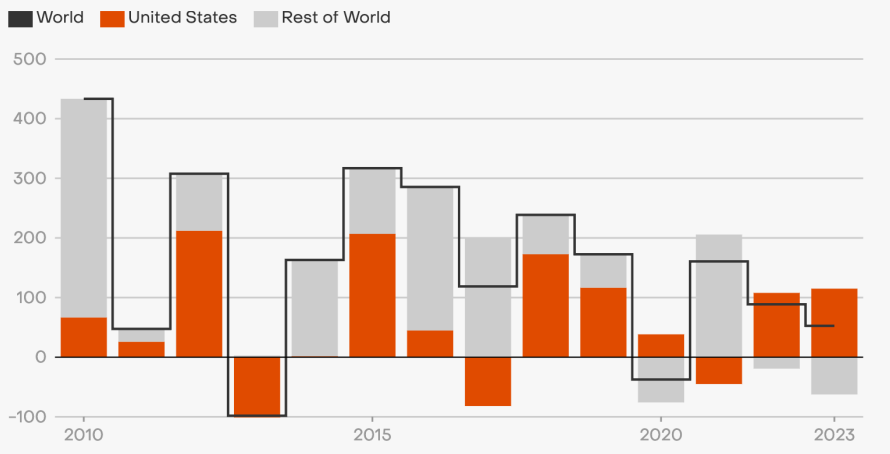
01 The US was responsible for a quarter of global gas generation in 2023, more than three times the second largest generator, Russia

02 US gas growth prevented a global fall in gas generation in 2023

03 The world's three highest power sector emitters per capita are all highly dependent on gas: Bahrain, Qatar and Kuwait

Without the US, global gas generation would have fallen in the last two years

Year-on-year change in electricity generation from gas (TWh)



Source: Annual electricity data, Ember

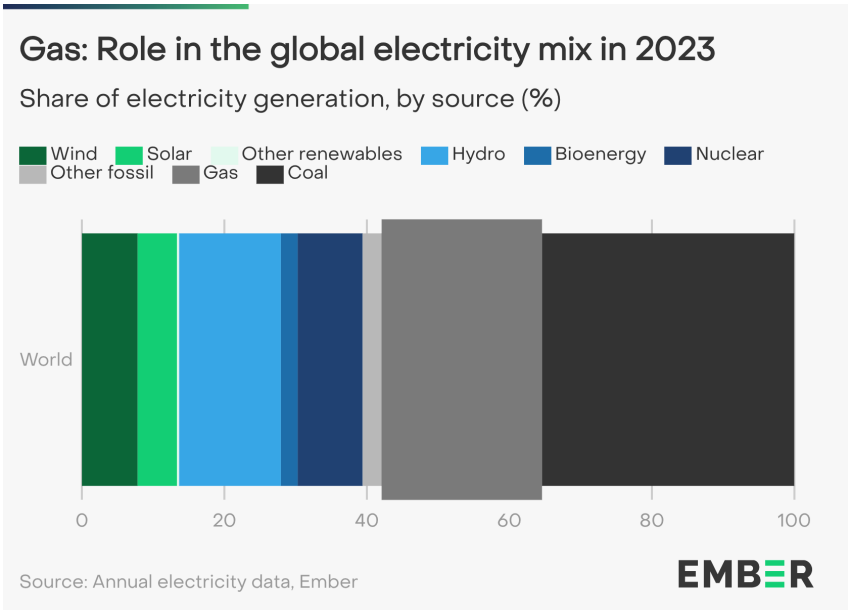
EMBER

Gas: Current status

The US was responsible for a quarter of global gas generation in 2023, more than three times the second largest generator, Russia

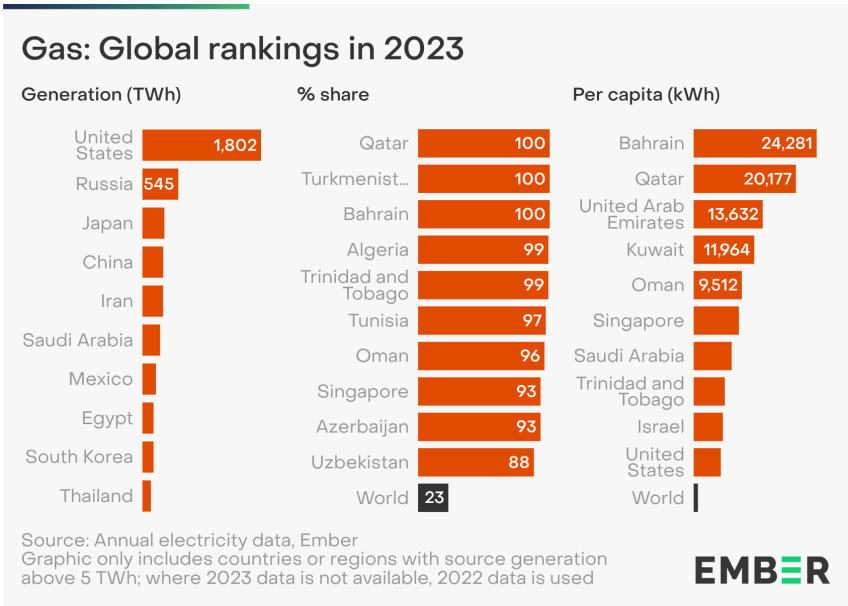
Fossil gas produced 23% (6,634 TWh) of global electricity in 2023, the second-largest source worldwide.

After coal, gas is the second-largest contributor to emissions from the power sector. Although it will play a role in the medium term, helping with power system flexibility to accommodate larger shares of wind and solar, the use of unabated gas will be limited as countries move to clean power systems.



The US had the highest electricity generation from gas in 2023 with 1,802 TWh (42% of the mix). This was more than three times the second-highest, Russia, at 545 TWh (46% of the mix). US gas generation accounted for more than a quarter (27%) of the global total.

Turkmenistan, Bahrain and Qatar all produced nearly 100% of their electricity from gas. Globally, 15 countries had a gas share of over 80%.



Countries in the Middle East with high electricity demand and a generation mix dominated by gas had the highest per capita gas generation worldwide. Bahrain reached 24,281 kWh per capita – ahead of Qatar (20,177 kWh) and the UAE (13,632 kWh).

The world's three highest per capita power sector emitters are all highly dependent on gas: Bahrain, Qatar and Kuwait.

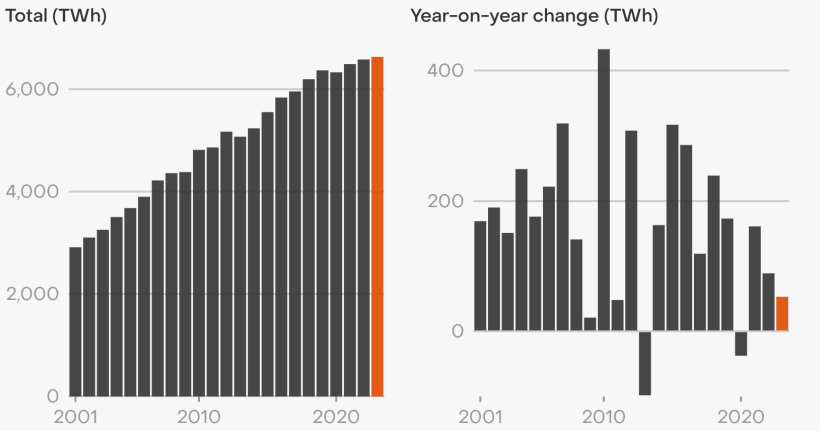
Gas: Change in 2023

US gas growth prevented a global fall in gas generation in 2023

Gas generation reached a new record high of 6,634 TWh in 2023. Gas generation was up 53 TWh (+0.8%) from 6,582 TWh in 2022.

Despite the record total gas generation, the increase of 53 TWh is one of the lowest increases recorded since the turn of the century. While generation increased, the gas share fell slightly by 0.3 percentage points, from 22.8% in 2022 to 22.5% in 2023 due to overall electricity demand rising at a faster rate.

Gas: Global generation in 2023 compared to the historical trend



Source: Annual electricity data, Ember

EMBER

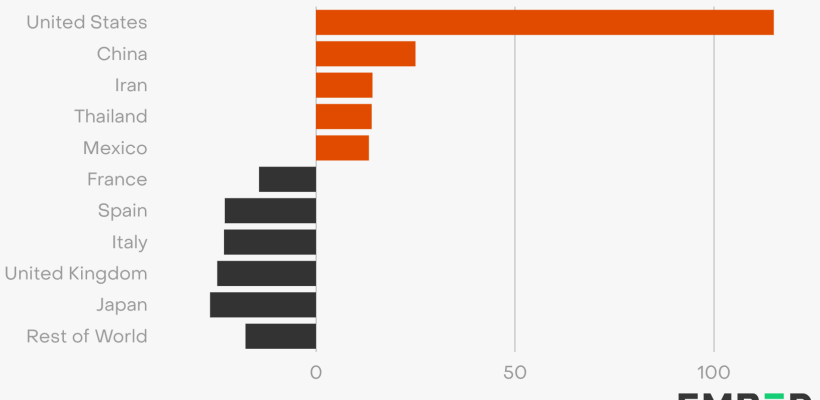
Growth in gas generation in 2023 was largely driven by the US, which saw an increase of 115 TWh – more than double the global growth and more than four times the increase in China of 25 TWh. Iran recorded the third-largest increase in gas generation in 2023 (+14 TWh).

In other large economies, gas generation is falling. In 2023, Japan saw the largest fall with 27 TWh, followed by the UK (-24 TWh) both in part due to high gas prices and a fall in electricity demand. Italy (-23 TWh), Spain (-23 TWh) and France (-14 TWh) also recorded significant falls.

Gas: Largest generation changes in 2023

TWh

Global change in 2023: 53 TWh

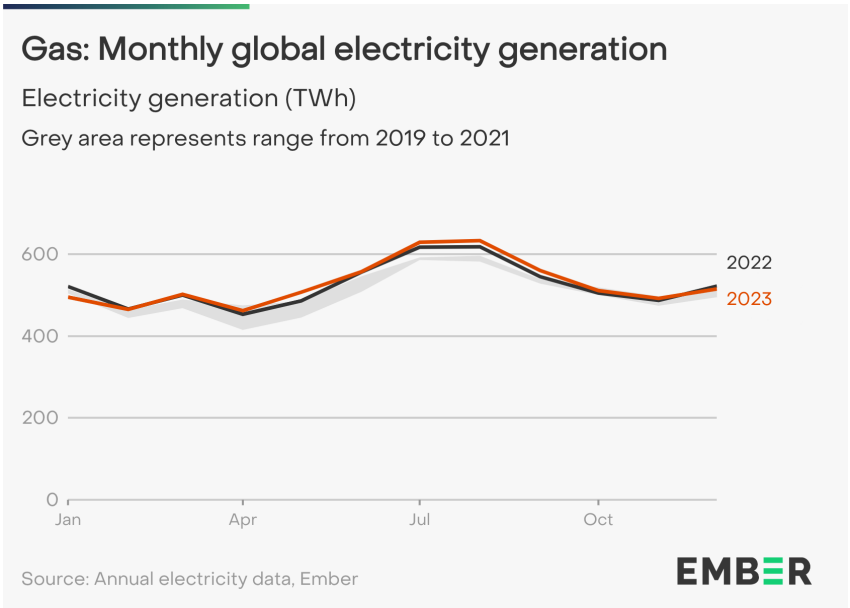


Source: Annual electricity data, Ember

EMBER

Monthly global gas generation across 2023 remained largely similar to 2022. There were minimal monthly fluctuations.

July and August recorded two consecutive new all-time highs for gas generation in a single month, with 629 TWh and 633 TWh respectively, beating the previous record set in August 2022 of 618 TWh.

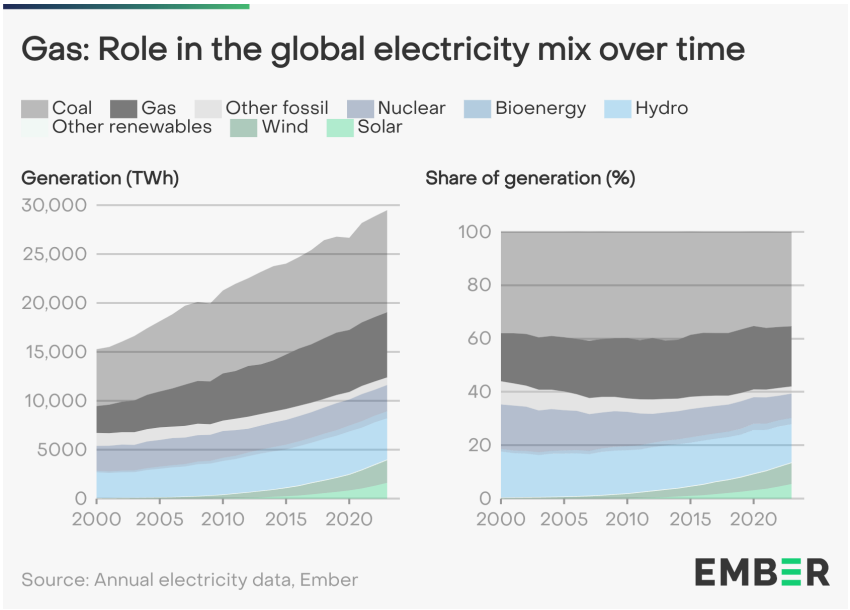


Gas: Long-term trend

Gas generation has doubled since 2000, but growth is slowing

Global gas generation has grown substantially over the last two decades. It more than doubled, rising from 2,745 TWh in 2000 to 6,634 TWh in 2023.

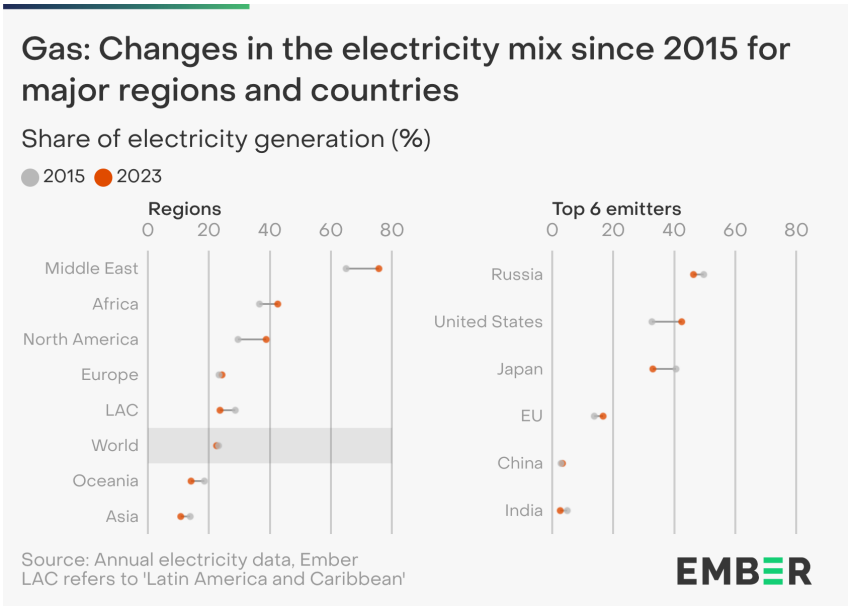
However, growth has been slowing recently. In the four years from 2015 to 2019, gas generation increased 816 TWh. In the four years since, generation only increased a third of that (+265 TWh) signalling a slowdown in global gas growth.



The share of gas generation in the global electricity mix increased four percentage points, from 18% in 2000 to 23% in 2023. Gas share peaked in 2019 at 24%.

The share of gas generation increased in the Middle East and Africa from 2015 to 2023, but it has stagnated in Europe and fallen in Latin America, Oceania and Asia.

In the US, the gas share increased from 33% in 2015 to 42% in 2023 as the country saw a significant shift from coal to gas generation. From 2015 to 2023, the growth in gas generation in the US contributed 43% of the total global increase.



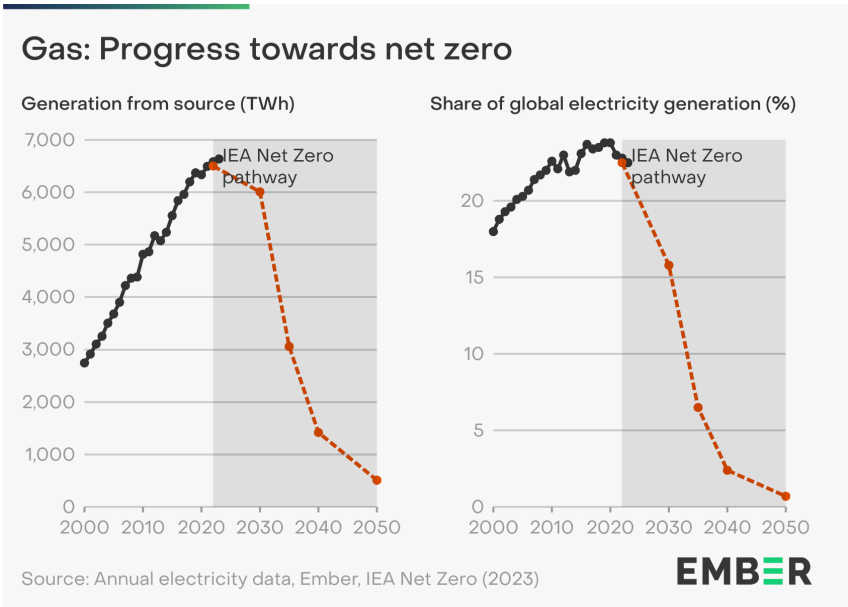
Gas plays only a small role in generation in China and India. Unlike the US, China and India are not planning a transition from coal to gas generation and are instead focusing on the deployment of renewables.

Gas: Progress towards net zero

Gas growth is slowing, but should be falling

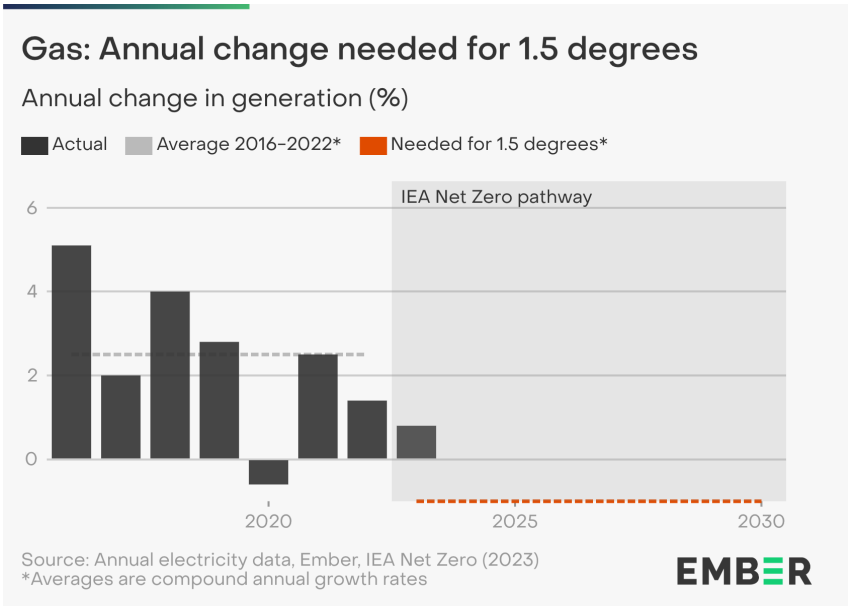
According to the IEA Net Zero Emissions scenario, gas generation needs to see moderate falls until 2030, dropping to 6,007 TWh from 6,634 TWh in 2023, with larger falls in the following decade to 2040. Although growth has been slowing in recent years, this would represent a reversal from current trends.

This pathway sees the share of generation from unabated and abated gas fall from 23% of global electricity generation in 2023 to 16% in 2030 and then further to just 2.4% in 2040.



The reduction in gas generation by 2030 requires an average annual fall of 1%. From 2016 to 2022, gas generation increased by an average 2.5% per year.

The increase in 2023 of 0.8%, while below the recent average, still represents a trend in the wrong direction. However, the global energy crisis and high gas prices over the last two years have led to significant falls in gas generation in Europe and some Asian countries, highlighting that a rapid change in trend is possible.



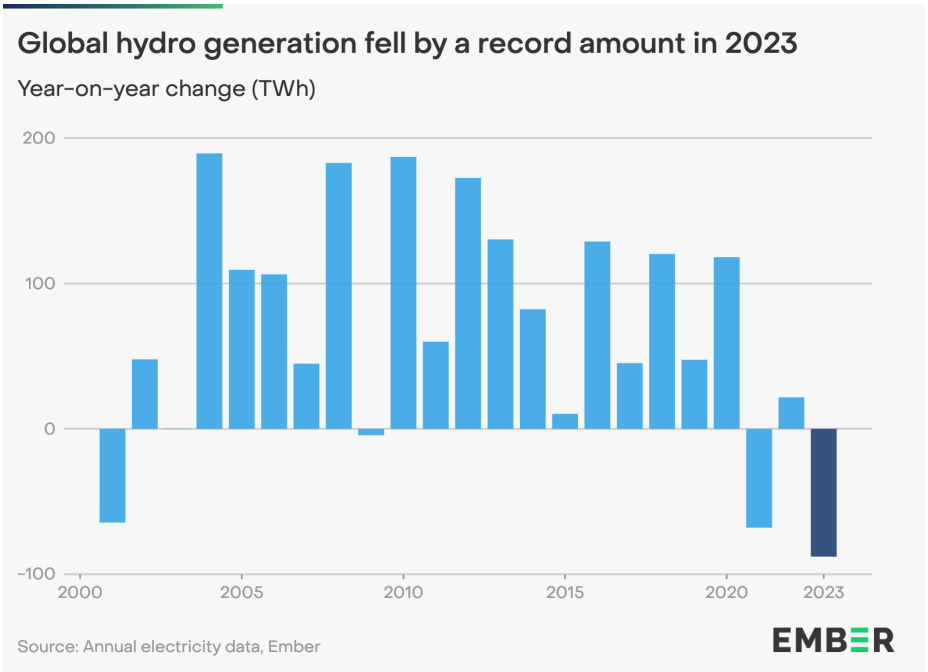
4.5 Hydro

Key highlights

01 Hydro remains the largest source of clean power globally

02 Global hydropower generation fell by a record amount in 2023 to a five-year low, as droughts affected output in the first half of the year

03 Hydro generation has flattened since 2019, with less clean electricity added to the mix at a crucial moment in the transition

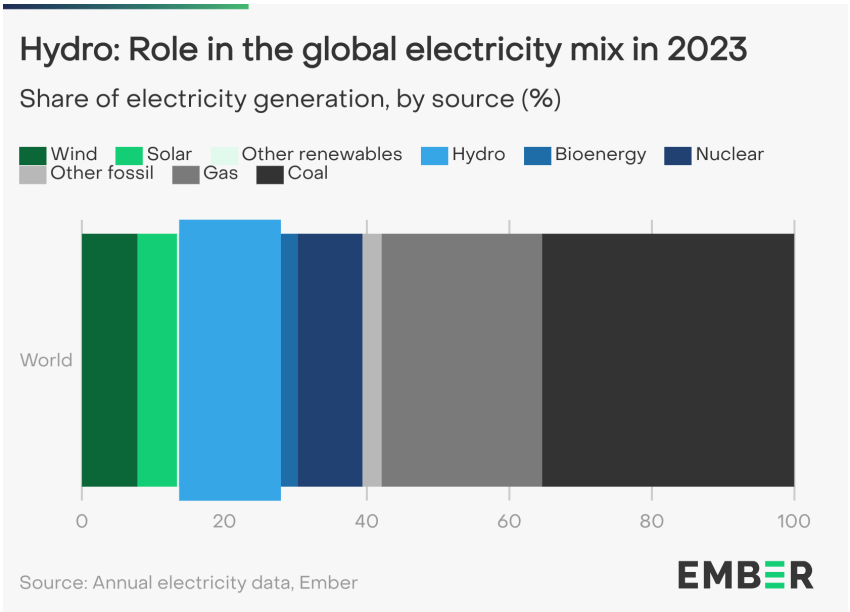


Hydro: Current status

Hydro remains the largest source of clean power globally

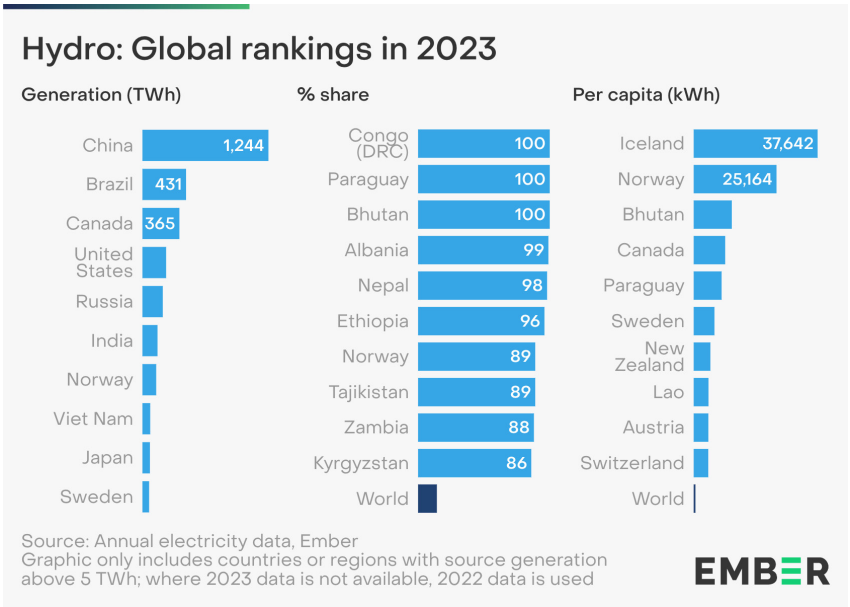
Hydro power produced 14% (4,210 TWh) of global electricity in 2023.

Hydro power has an important role in the current energy mix. Not only is it the largest source of clean power, but it also provides flexibility to help accommodate the large influx of wind and solar. The world needs new hydro power plants, but in many regions hydro resources have already been maximised, and in others where there is potential, the projects may come at too high an ecological cost.



In 2023, China produced the most electricity from hydro power with 1,244TWh (13% of its mix), ahead of Brazil (431 TWh) and Canada (365 TWh), which both rely on hydro for about 60% of their electricity generation.

Bhutan, Paraguay and the Democratic Republic of the Congo produce 100% of their electricity from hydro. Many other countries with the right topography also rely overwhelmingly on hydro.



Iceland and Norway lead the per capita generation of hydro power with 37,642 kWh and 25,164 kWh, respectively.

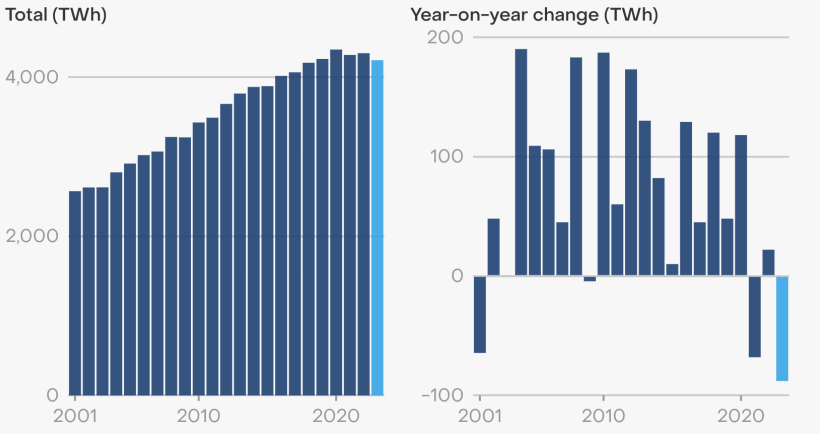
Hydro: Change in 2023

Global hydropower generation fell by a record amount in 2023 to a five-year low, as droughts affected output in the first half of the year

Despite continued additions of new hydro capacity, generation growth has stagnated since 2019. At 4,210 TWh, generation in 2023 was lower than in 2019 (4,226 TWh) and significantly below the level in 2020 (4,344 TWh).

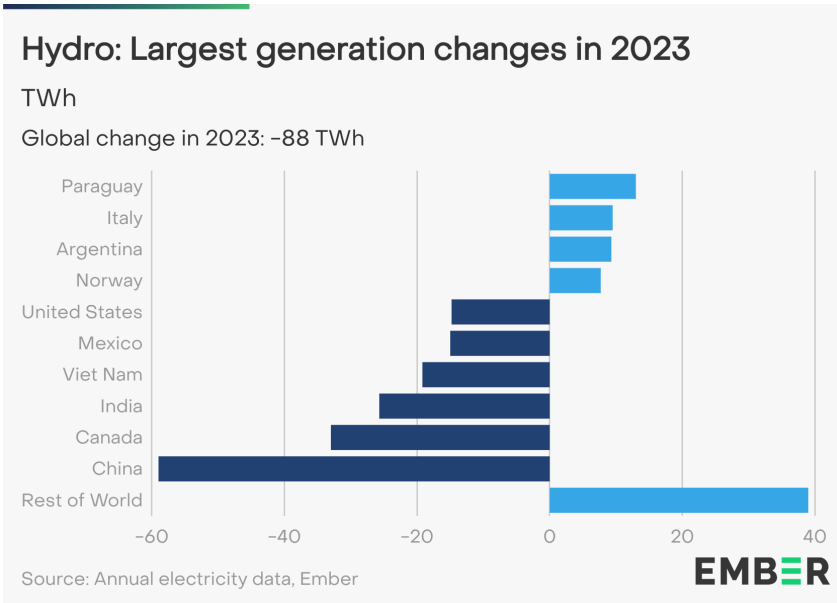
2023 saw a record fall in hydro generation (−88 TWh, −2.0%). Crucially, the fall in 2023 came after a similarly large fall in 2021 and only a moderate recovery in 2022. This led to a fall in hydro share in the global electricity mix, from 15% in 2022 to 14% in 2023.

Hydro: Global generation in 2023 compared to the historical trend



The largest increases in hydro generation in 2023 occurred in Paraguay (+13.0 TWh, +30%), Italy (+9.5 TWh, +34%), Argentina (+9.3 TWh, +39%) and Norway (+7.7 TWh, +6%). These countries all recorded a rebound in output as a result of experiencing poor hydro conditions in 2022, rather than increases due to added capacity.

Hydro: Largest generation changes in 2023

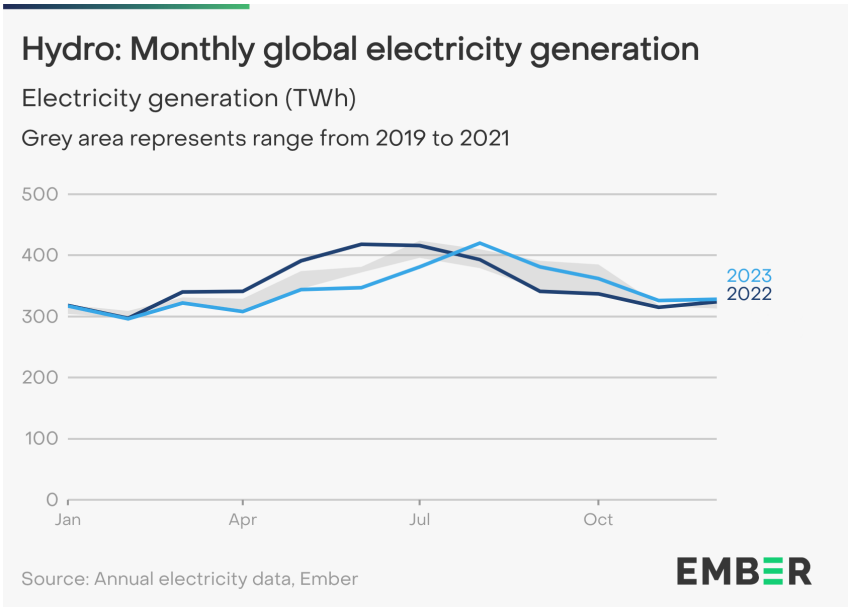


The global fall in hydro generation in 2023 was predominantly driven by China, where hydro fell by 59 TWh, making up 67% of the global fall. This resulted in a larger increase in coal generation.

Canada, India, Viet Nam, Mexico and the United States also saw significant falls due to poor conditions. Despite the rest of the world recording increases in 2023, the falls in China and other countries were large enough to cause a significant global hydro deficit of 88 TWh compared to 2022.

Global hydro generation underperformed particularly in the first half of 2023. This was especially noticeable in May and June, when droughts in China had the largest impact. Generation remained below 2022 levels until August and even fell below generation levels seen in 2019–2021 for much of the first half of the year.

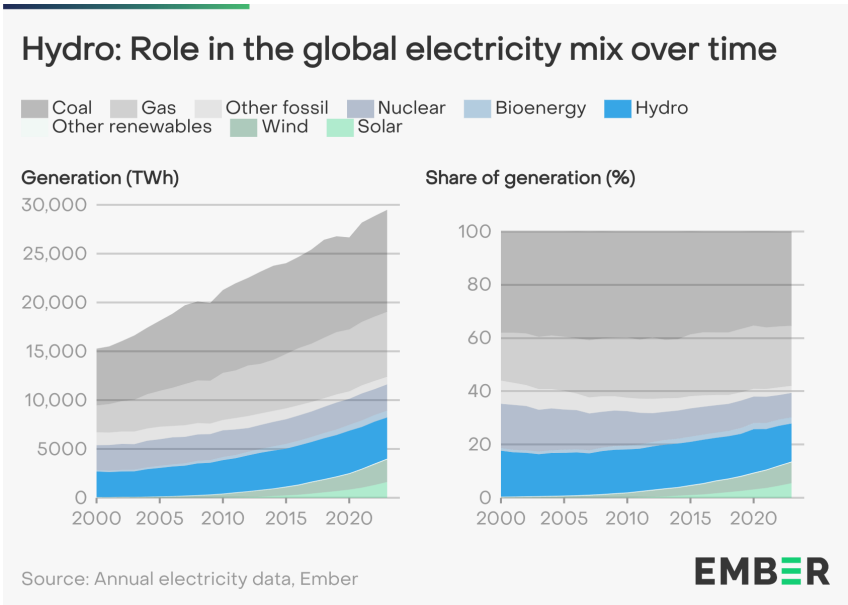
Generation recovered partially in the second half of the year, with three months recording five-year highs.



Hydro: Long-term trend

Hydro generation has flattened since 2019, adding less clean electricity to the mix at a crucial moment in the transition

Hydro's role in the electricity mix has become smaller over the last two decades. While generation increased from 2,629 TWh in 2000 to 4,210 TWh in 2023, the share in the mix fell from 17% to 14% due to total global demand nearly doubling over the same timeframe.



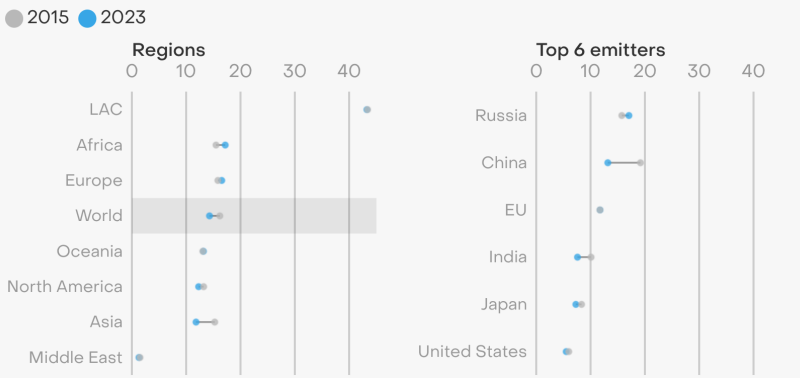
Over the last two decades, hydro capacity continued to increase, leading to consistent growth in hydro generation until 2020. As the last few years have shown, however, poor hydro conditions in Latin America, China, the US and Europe have caused a plateau and even small decreases in generation.

Although individual events like droughts may be temporary, hydro generation has remained effectively flat since 2019, meaning that less clean electricity has been added to the mix at a critical point in the energy transition.

Hydro generation has remained stable in the electricity mixes of most countries and regions since 2015, with relatively few undergoing structural shifts in their hydro generation.

Hydro generation tends to fluctuate significantly from year to year. Therefore, small decreases in some European countries, such as Norway's change from 96% in 2015 to 89% in 2023, do not necessarily represent a structural decline in hydro generation.

Hydro: Changes in the electricity mix since 2015 for major regions and countries



Source: Annual electricity data, Ember
LAC refers to 'Latin America and Caribbean'

EMBER

Shares of hydro generation are highest in the Americas, Asia and Europe. Only a few countries in Africa rely on hydro for significant parts of their electricity mixes. In Nigeria, the share of hydro increased from 19% in 2015 to 20% in 2023. The average generation share of hydro in the Middle East was just 1.3% in 2023, slightly down from 1.5% in 2015.

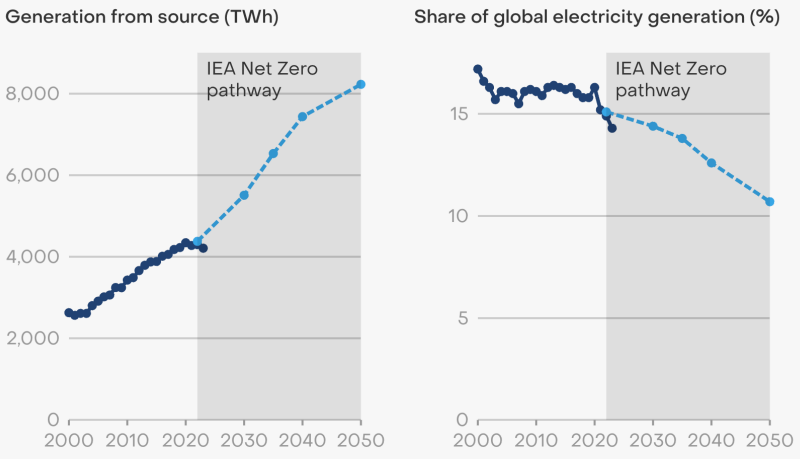
Hydro power: Progress towards net zero

Hydro generation needs to return to growth to meet net zero goals

According to the IEA Net Zero Emissions scenario, hydro generation needs to increase from the current 4,210 TWh to 5,507 TWh in 2030 and then further to 8,225 TWh in 2050. Due to the rapid growth in electricity demand, the share of hydro generation is expected to fall to 11% by 2050.

While most of the clean electricity additions are expected to come from wind and solar, other low emissions sources like hydro and nuclear are a key part of a successful electricity transition.

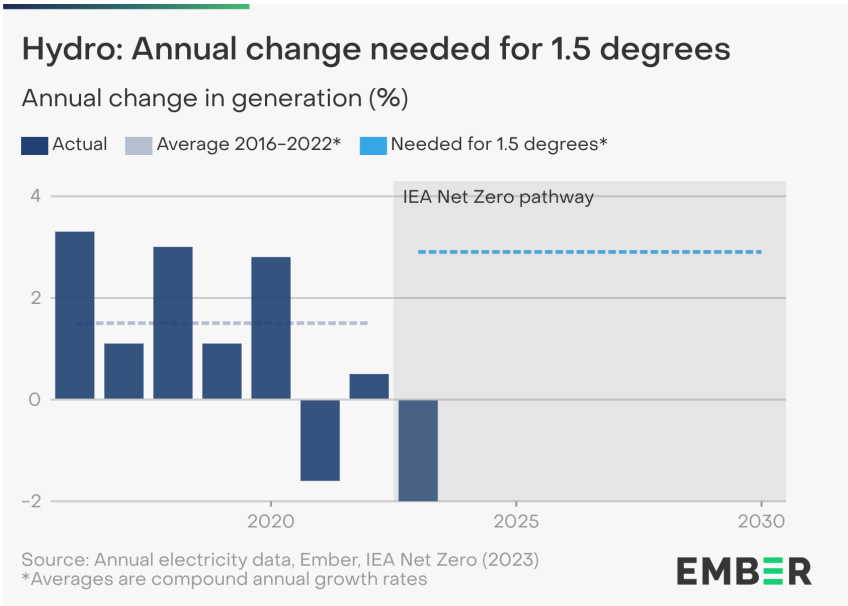
Hydro: Progress towards net zero



Source: Annual electricity data, Ember, IEA Net Zero (2023)

EMBER

In 2023, hydro generation saw its largest absolute and second-largest percentage fall in at least two decades. The 2% fall was therefore significantly out of step with the 1.5% average annual growth seen from 2016 to 2022.



For hydro generation to grow in line with the IEA NZE scenario, annual growth until 2030 needs to reach an average of 2.9% between 2023 and 2030 – double the rate achieved between 2016 and 2022. The fall in 2023 is a step in the wrong direction.

The IEA assumes hydro output from added capacity will continue at historic rates. However, the long-term global outlook on the impact of climate change on hydro output is uncertain, as the effects of climate change on hydro potential vary geographically. If hydro does not grow at the rates needed, it is possible that solar and wind may need to compensate.

4.6 Nuclear

Key highlights

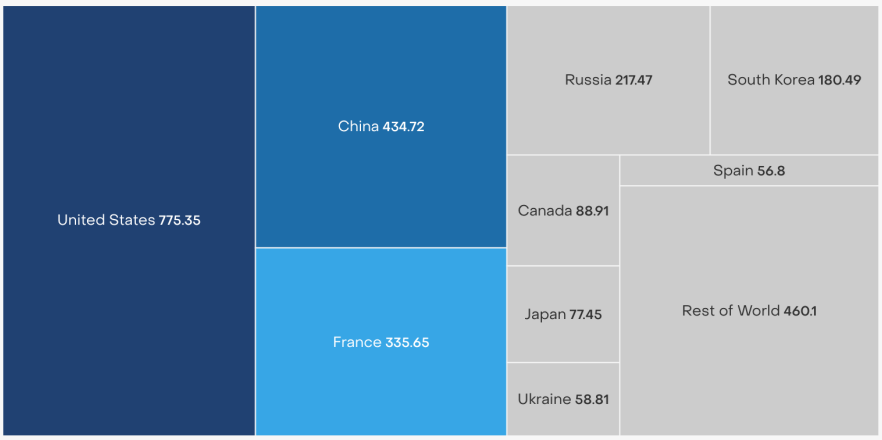
01 The US, China and France accounted for more than half of global nuclear generation in 2023

02 Nuclear generation rebounded slightly from a five-year low in 2022

03 Nuclear's share in the mix has nearly halved since 2000

The US, China and France accounted for more than half of global nuclear generation in 2023

Electricity generation (TWh)



Source: Annual electricity data, Ember
Only economies with a share of global nuclear generation of more than 2% are labelled

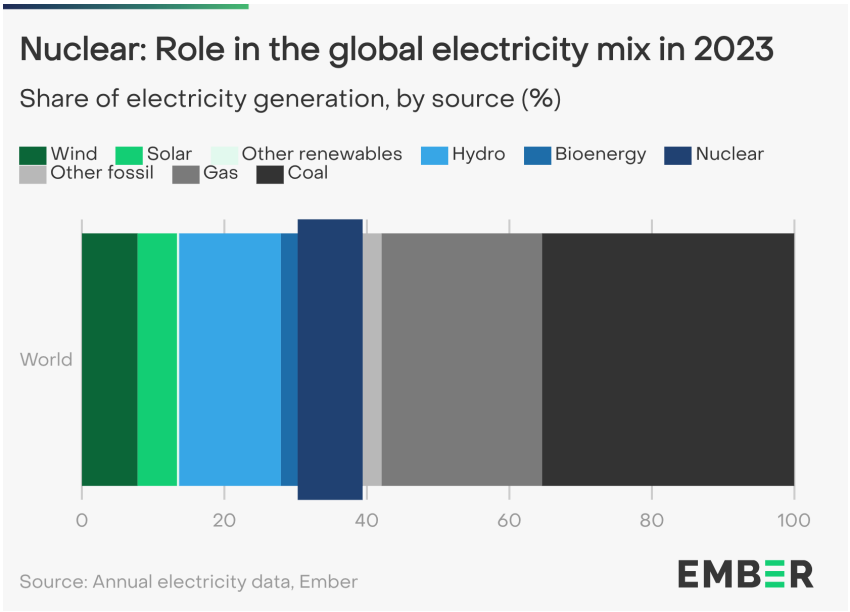
EMBER

Nuclear: Current status

The US, China and France accounted for more than half of global nuclear generation in 2023

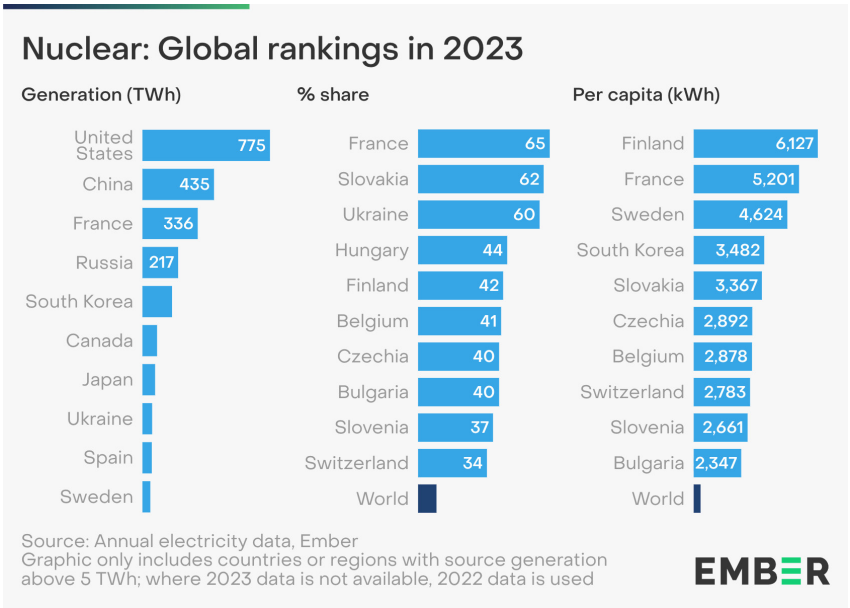
Nuclear power made up 9.1% (2,686 TWh) of the global electricity mix in 2023.

Nuclear power is an important source of low-carbon energy. Many scenarios foresee nuclear power capacity increasing significantly over the coming decades in line with growing electricity demand.



In 2023, the US was the largest producer of electricity from nuclear power with 775 TWh, ahead of China (435 TWh) and France (336 TWh). Together, these three countries account for more than half (58%) of global nuclear power generation.

The highest shares were in European countries, including France (65%), Slovakia (62%) and Hungary (44%). Based on estimated data, Ukraine generated 60% of its electricity from nuclear power in 2023.



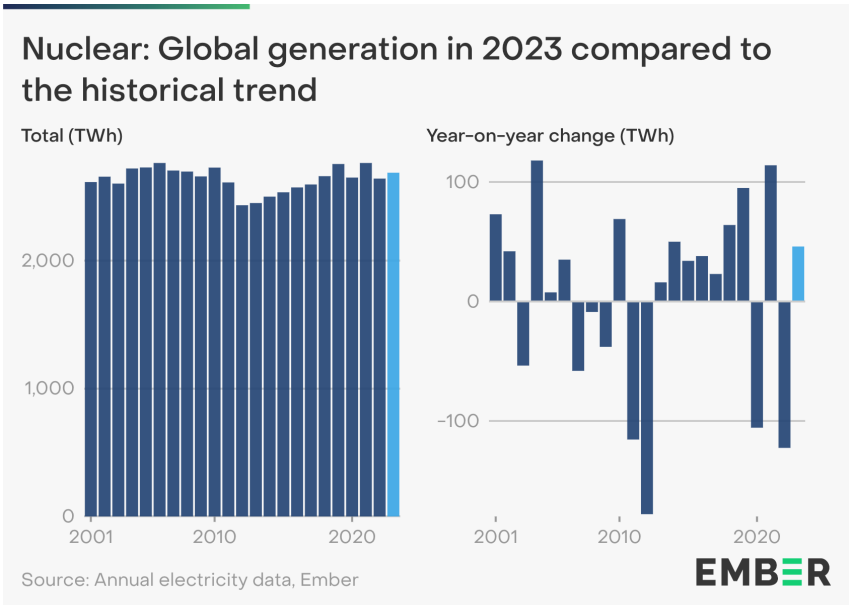
Finland (6,127 kWh) and France (5,201 kWh) have the highest per capita nuclear generation.

Nuclear: Change in 2023

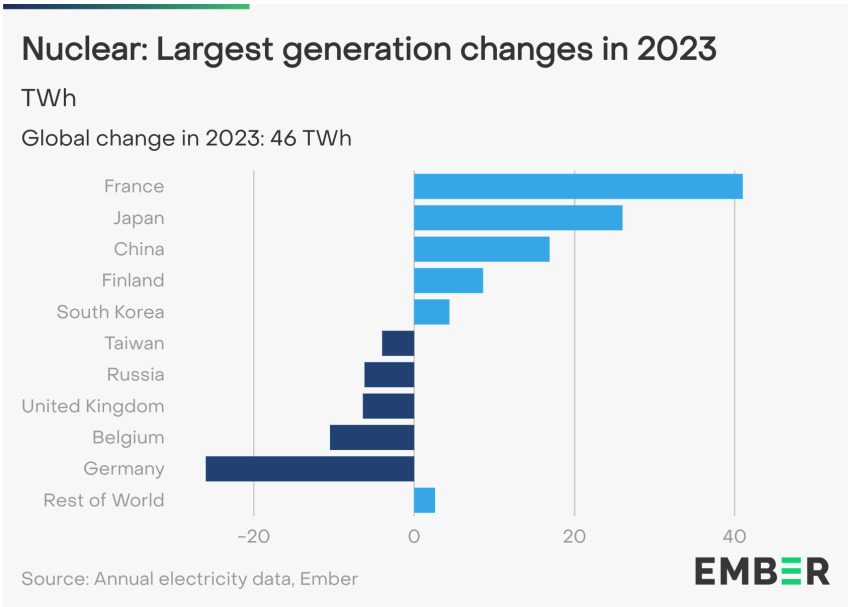
In 2023, nuclear generation rebounded slightly from a five-year low in 2022

In 2023, nuclear generation rose slightly to 2,686 TWh – up 46 TWh (+1.8%) from a five-year low in 2022. At the same time, nuclear's share in the mix remained mostly unchanged from 2022 at 9.1%.

After a period of consistent growth from 2013 onwards, the last five years have seen global nuclear generation fluctuate significantly. Retirements in some European economies, maintenance in France and Japan, as well as growth in China, have resulted in increased volatility.



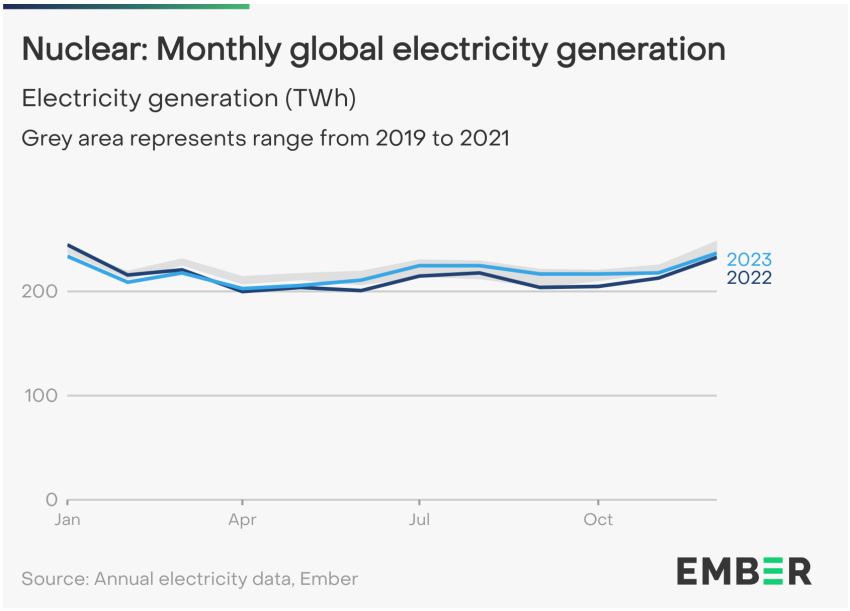
France saw the largest increase in nuclear generation in 2023 (+41 TWh) ahead of Japan (+26 TWh) and China (+17 TWh). France's additions were due to a recovery of reactor availability from the previous year. Similarly, reactors coming back online after maintenance caused the generation increase in Japan. China's increase represents new additions to the country's nuclear fleet.



The largest reductions occurred in Germany (-26 TWh), which completed its planned phaseout of nuclear power in 2023. Belgium also saw a significant reduction (-10 TWh) due to reactor retirements.

Despite starting the year below the January 2022 level, nuclear generation was higher for 2023 from April onwards.

Nuclear generation does not traditionally see large seasonal fluctuations. Maintenance is scheduled for summer months to minimise disruption during the winter when there is higher electricity demand. This explains the slightly lower summer generation values in the northern hemisphere, where most nuclear installations are located.

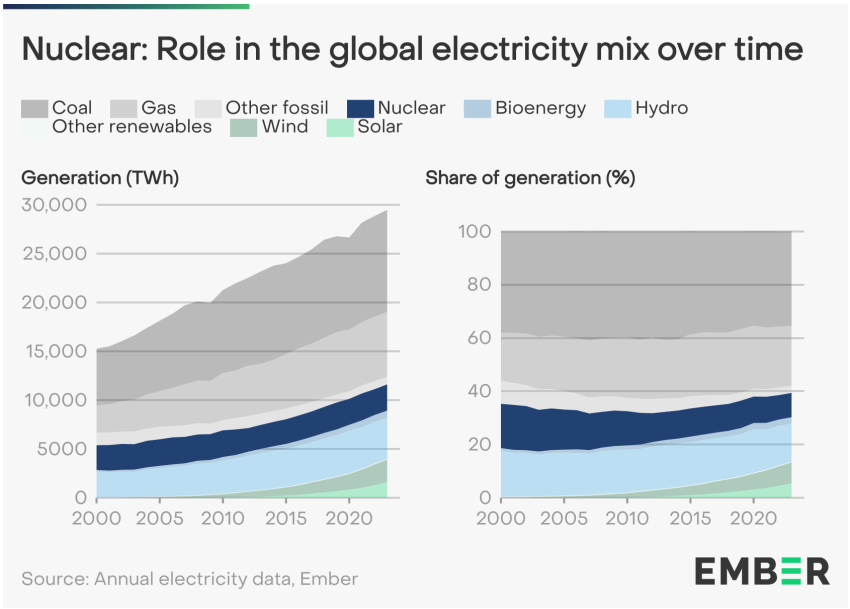


Nuclear: Long-term trend

Nuclear's role in the electricity mix has declined since 2000

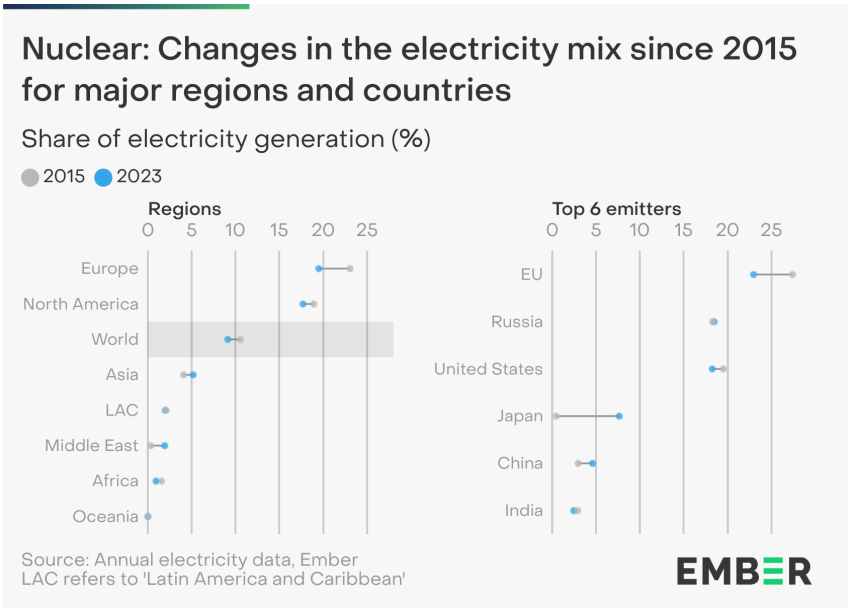
Nuclear generation in 2023 was only slightly higher than in 2000, increasing by 145 TWh (+6%), from 2,541 TWh to 2,686 TWh. However, 2023 levels are the result of a fall and recovery after the Fukushima disaster in 2011 which resulted in generation dropping significantly in 2011 and 2012, primarily in Japan.

Due to global electricity demand nearly doubling over the same period, the share of nuclear power in the global electricity mix has declined significantly. In 2000, 16.6% of global electricity came from nuclear power. This had shrunk to 9.1% by 2023.



The global share of nuclear generation declined from 10.6% in 2015 to 9.1% in 2023. Asia and the Middle East were the only two regions that saw an increase in nuclear share, with new reactors coming online in the UAE, Japan and China.

Europe saw a stronger decline due to Germany's nuclear phaseout as well as lower output in France.



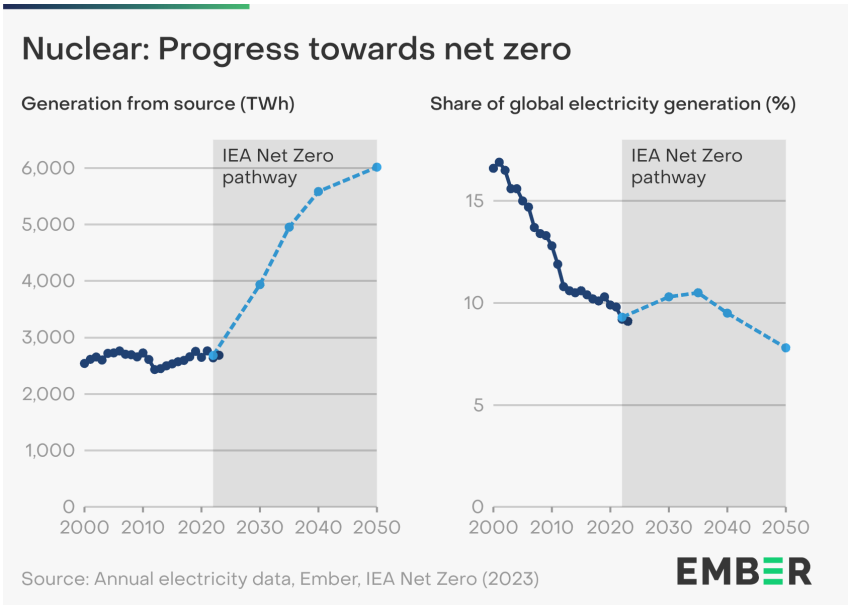
Japan's nuclear share increased rapidly from just 0.4% in 2015 to 7.6% in 2023 as the country restarted reactors. All of Japan's nuclear reactors were shut down after the Fukushima nuclear disaster in 2011.

Nuclear: Progress towards net zero

Nuclear needs to grow nearly three times faster than 2023's rate to achieve net zero

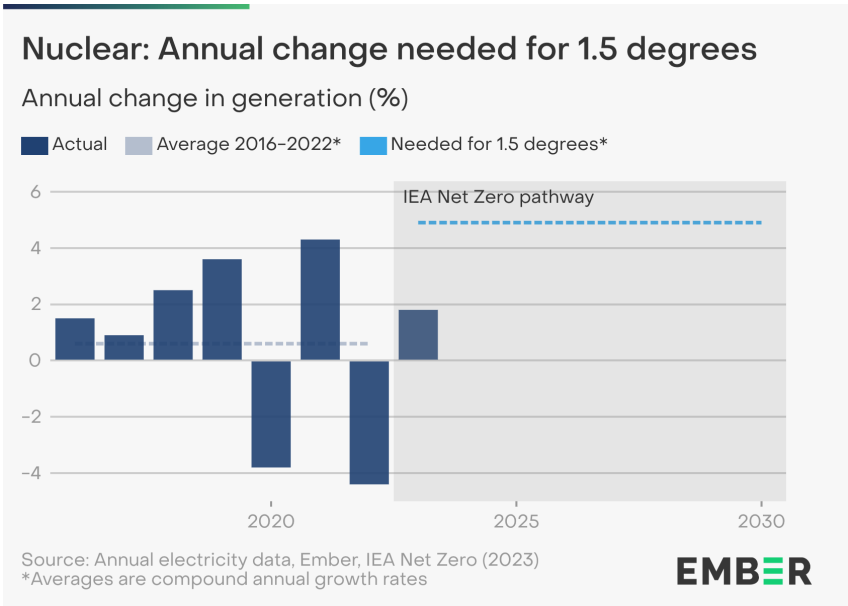
The [IEA Net Zero Emissions scenario] sees nuclear generation growing significantly, from 2,686 TWh in 2023 to 3,936 TWh in 2030 and 6,015 TWh in 2050.

With electricity demand growing as well, the share of nuclear power would remain roughly stable over the next three decades. By 2030, the share would reach 10.3%, up slightly from 9.1% in 2023, and would fall to 7.8% by 2050.



Slow build up of new nuclear plants may mean that additional wind and solar growth is needed to meet the clean electricity additions required in a net zero scenario.

In the IEA scenario, nuclear generation would grow 4.9% annually until 2030. The average annual growth rate from 2016 to 2022 was significantly below this at 0.6%. Even 2023's growth rate of 1.8% is more than three times slower than required in the scenario. 2021 almost reached the required level, with growth of 4.3%, but this happened in the context of a rebound from low generation in 2020.



4.7 Bioenergy

Key highlights

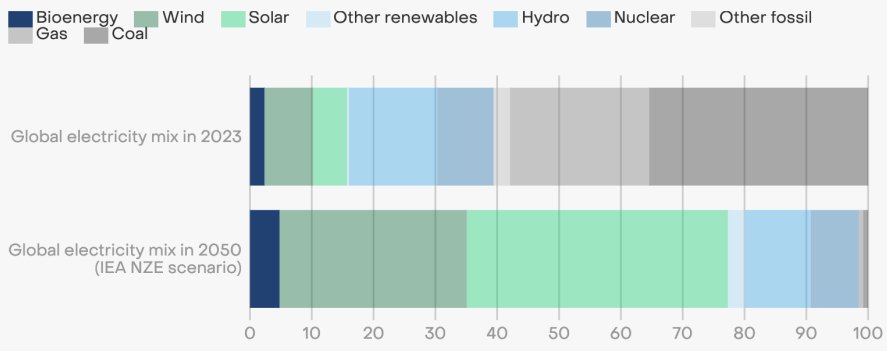
01 The share of bioenergy more than doubled since 2000, but remains low at 2.4%

02 Electricity generation from bioenergy increased most in China and Japan in 2023 and fell most in the US

03 Further expansion of bioenergy in net zero pathways presents an emissions risk

The role of bioenergy will remain limited in a net zero power sector

Share of global electricity generation (%)



Source: Annual electricity data, Ember, IEA NZE (2023)

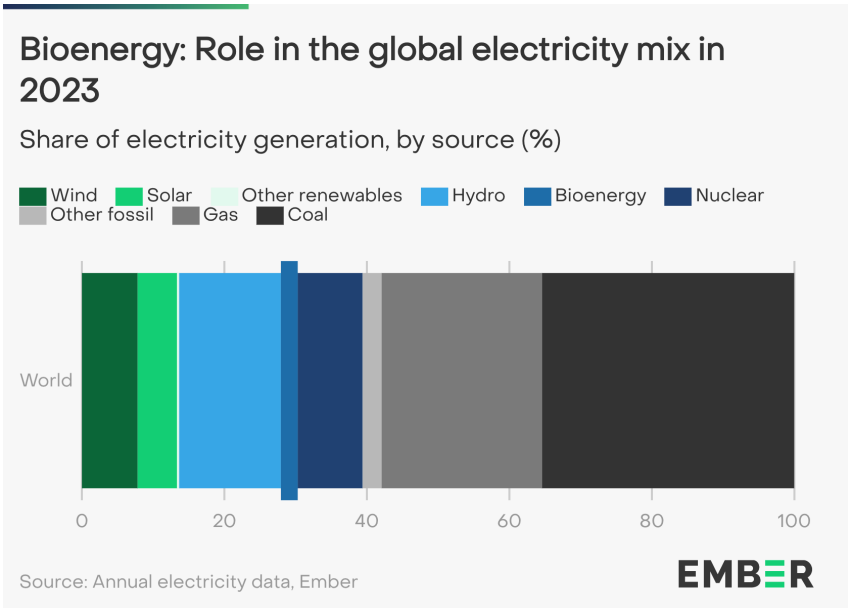
EMBER

Bioenergy: Current status

Bioenergy produces 2.4% of global electricity

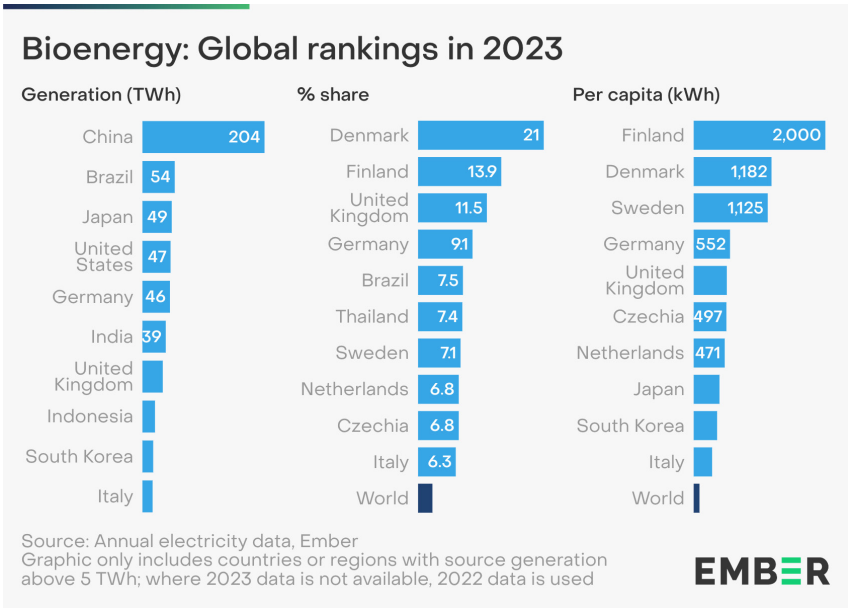
Bioenergy power produced 2.4% (697 TWh) of global electricity in 2023.

Although bioenergy is categorised as a renewable source in this report, its climate impact is highly dependent on the type of feedstock used and how it was sourced. Scientific evidence is mounting that in some cases using bioenergy for power contributes to climate change. Wider social and ecological impacts also constrain its use, which renders bioenergy a questionable approach for power sector decarbonisation. Other clean power generation will likely be a more viable option.



China produced the most electricity from bioenergy in 2023 with 204 TWh, representing more than a quarter of global generation from bioenergy, followed by Brazil (54 TWh) and Japan (49 TWh).

18 countries generated more than 10% of their electricity from bioenergy in 2023. Denmark had the highest share of bioenergy in its electricity mix at 21%, ahead of Finland (14%) and the UK (12%).



Finland had the highest per capita electricity generation from bioenergy at 2,000 kWh, ahead of Denmark (1,182 kWh) and Sweden (1,125 kWh).

Bioenergy: Change in 2023

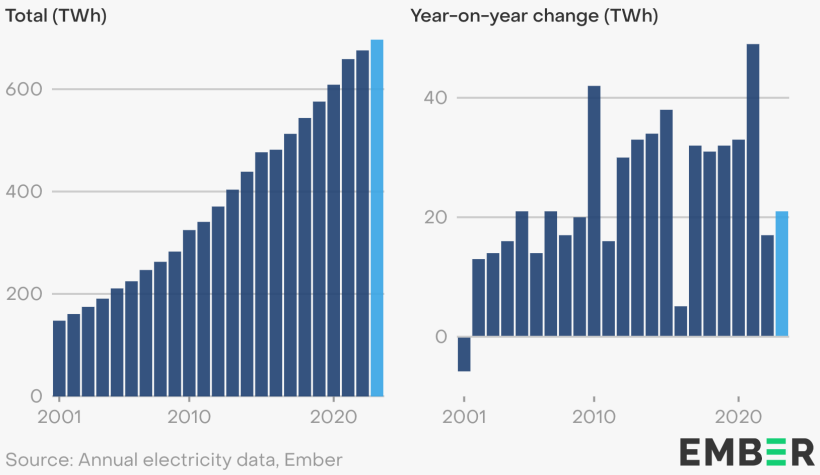
In 2023, electricity generation from bioenergy increased most in China and Japan and fell most in the US

Bioenergy reached a new record high of 697TWh in 2023.

Electricity generation from bioenergy increased by 21 TWh (+3.1%) from 2022 levels (676 TWh). The share of bioenergy in the global electricity mix remained unchanged at 2.4%.

The increase in bioenergy in 2023 was slightly larger than in 2022, but smaller than annual increases from 2017 to 2021. However, this does not represent a structural slowdown but rather a correction from record growth in 2021 during the energy crisis, when high fossil prices led to an increase in bioenergy.

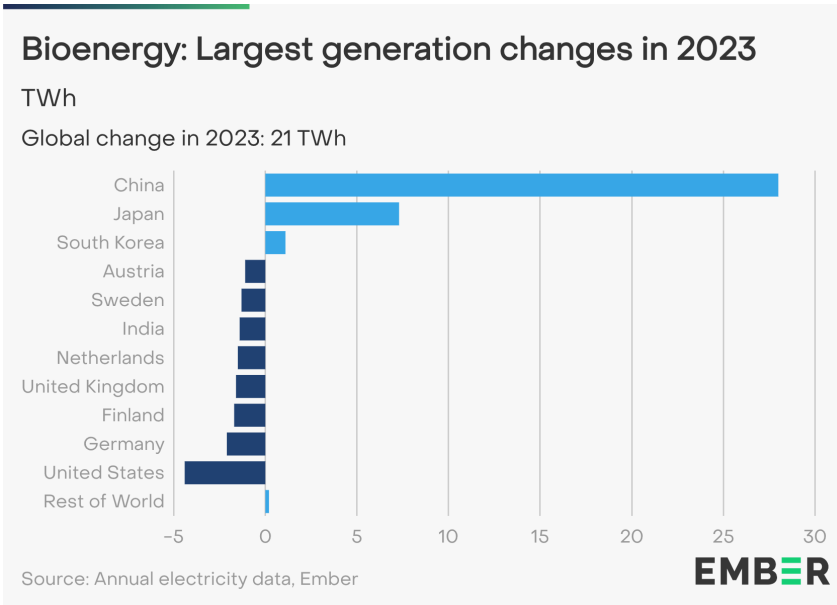
Bioenergy: Global generation in 2023 compared to the historical trend



The biggest increase in bioenergy in 2023 came from China which added 28 TWh (+16%), followed by Japan (+7.3 TWh, +18%).

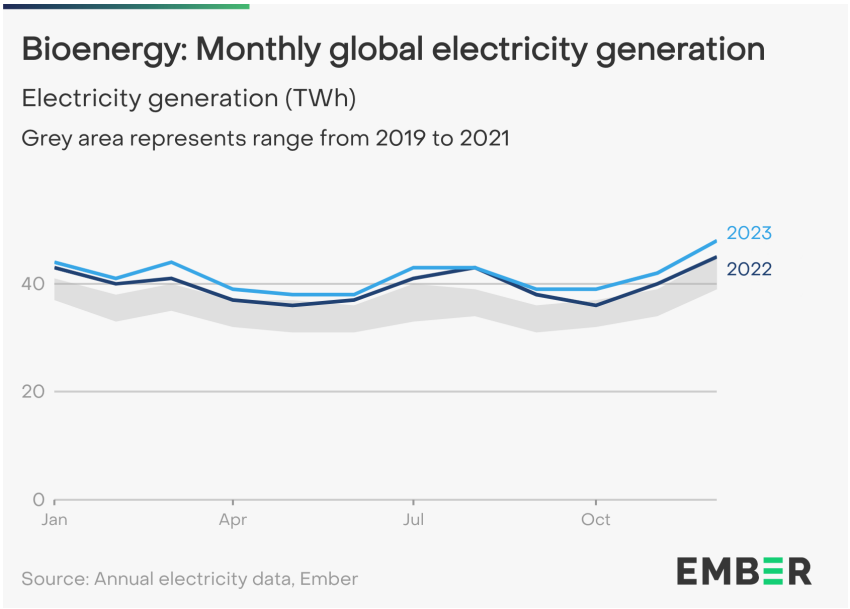
The largest decline in bioenergy generation occurred in the US, falling by 4.4 TWh (-8.5%). In Germany, bioenergy fell 2.1 TWh (-4.4%).

Bioenergy: Largest generation changes in 2023



In 2023, global bioenergy generation was higher in every month compared to previous years. Bioenergy generation reached an all-time monthly record in December 2023 at 48 TWh.

Bioenergy only shows small seasonal variations in generation. Generation in the peak month of December was only 9.1 TWh higher than in June – the month with the lowest values.

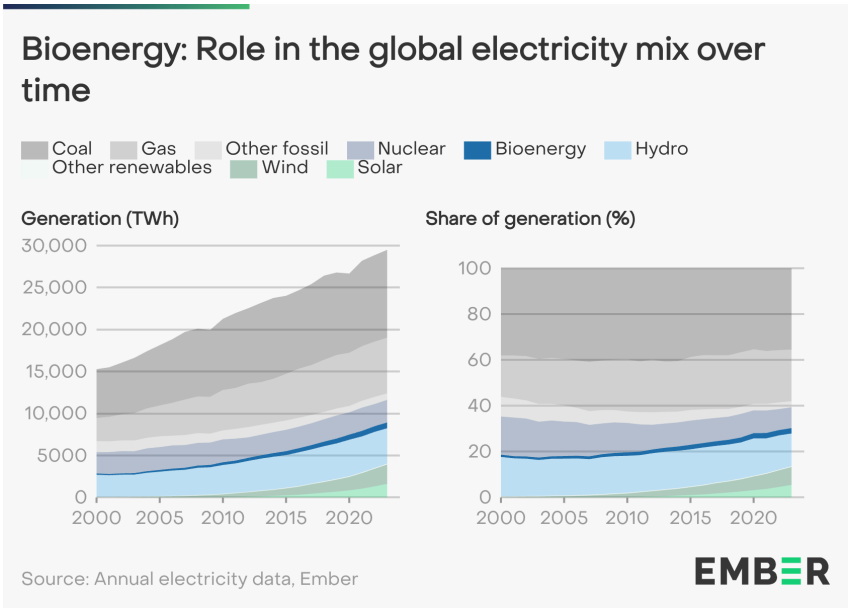


Bioenergy: Long-term trend

The share of bioenergy more than doubled since 2000, but remains low at 2.4%

Bioenergy generation has more than quadrupled since 2000, from 154 TWh to 697 TWh in 2023.

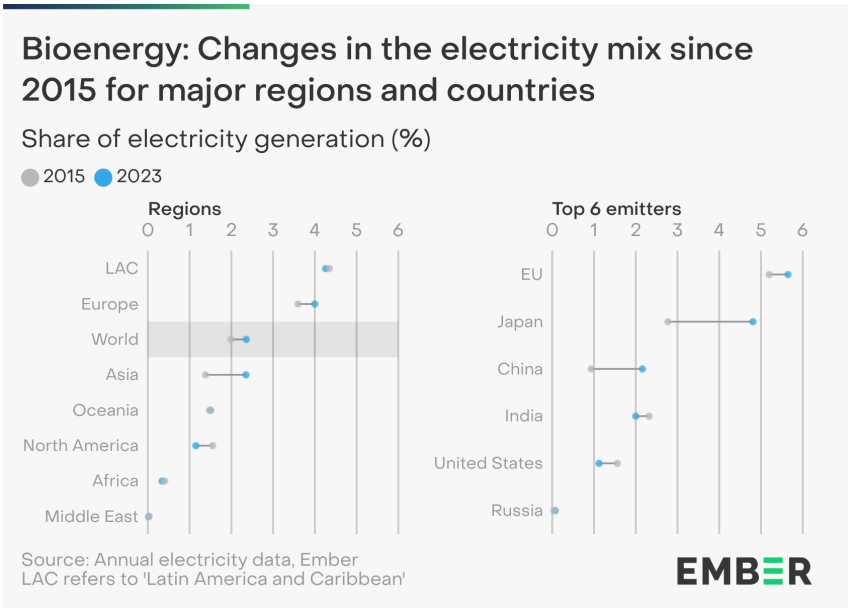
While generation has increased significantly, bioenergy still only represents a small part of the global electricity mix. The share of bioenergy increased from 1% in 2000 to 2.4% in 2023.



The share of bioenergy increased slightly in most regions. The largest increase was in Asia, with the share increasing from 1.4% to 2.4%.

Japan saw a significant increase in its bioenergy share, from 2.8% in 2015 to 4.8% in 2023.

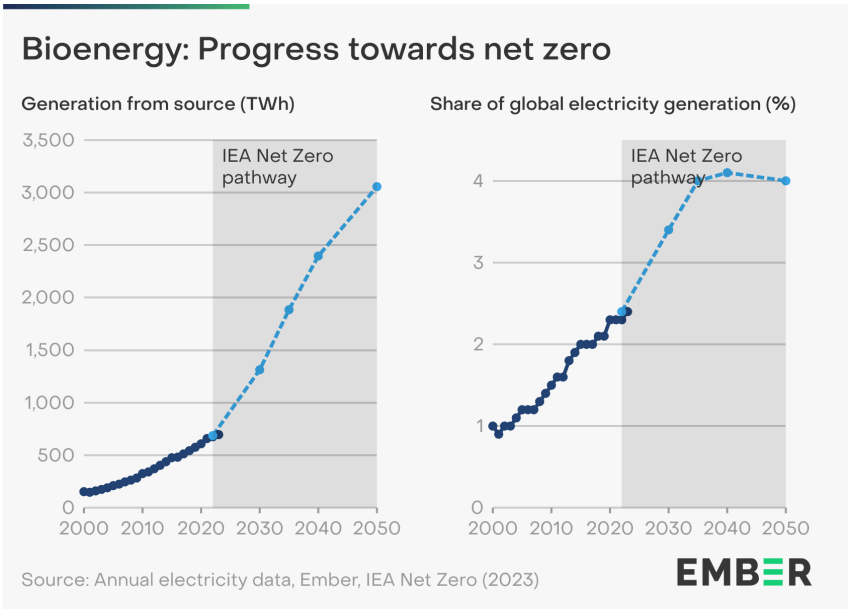
In China, the share of bioenergy increased slightly from 0.9% to 2.2% over the same period.



Bioenergy: Progress towards net zero

Reliance on bioenergy in net zero pathways presents an emissions risk

Despite concerns around emissions from bioenergy generation, the IEA Net Zero Emissions scenario sees a somewhat increased role for bioenergy in the electricity mix as a flexible source of electricity. Some models rely on bioenergy with carbon capture and storage (BECCS) to deliver negative emissions. In the IEA scenario, BECCS would only account for 17% of bioenergy generation in 2050.

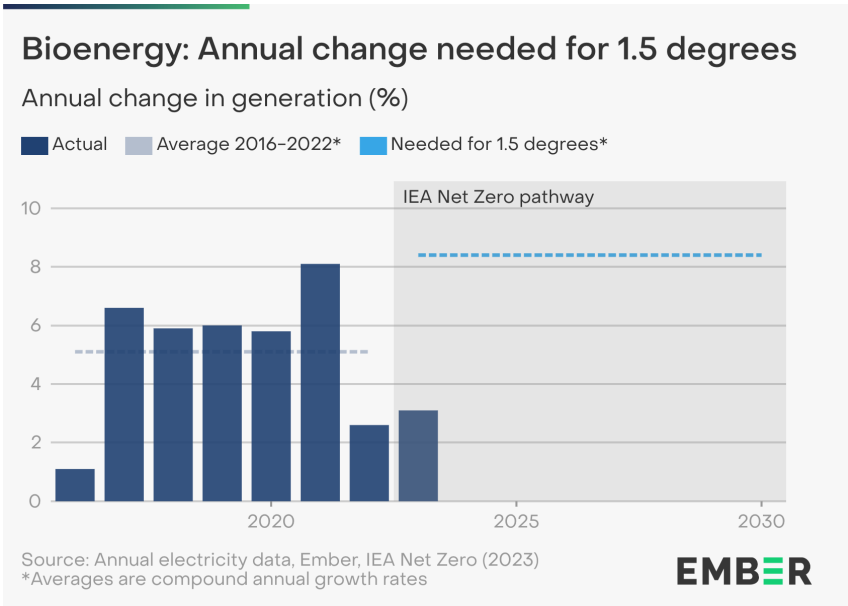


In the pathway, bioenergy's share in the mix would increase to 3.6% by 2030 and 4% by 2050, from a current share of 2.4%. This would see bioenergy generation grow from the current 697 TWh to 1,313 TWh by 2030 and 3,056 TWh in 2050.

To align with the IEA NZE scenario, bioenergy generation would have to grow at an average annual rate of 8.4% between 2023 and 2030.

This rate is not only significantly above 2023's growth rate of 3.1%, but crucially also above the longer term growth rate of 5.1% observed between 2016 and 2022.

The risk of emissions, plus wider social and ecological impacts, constrains the use of bioenergy for decarbonising the power sector.



Analysis of key power sector emitters in 2023

This chapter provides a deeper analysis of what has happened in countries and regions that are the world's top six emitters from the electricity sector. Collectively, they are responsible for around 72% of global emissions from the electricity sector.

We have ordered the sections in this chapter according to the amount of emissions produced from the electricity sector of the given country or region in 2023.

A summary analysis of the current state of play of the electricity transition in a further twenty-five countries and regions that are among the world biggest absolute CO2 emitters can be found in the Annex – Country Snapshots.

Chapter contents

5.1 China

Key highlights

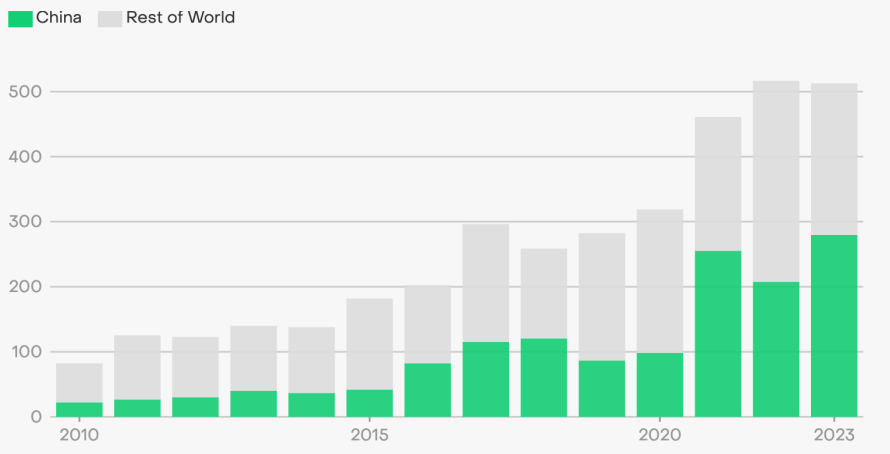
01 China accounted for 37% of global generation from solar and wind and more than half of global coal-fired electricity in 2023

02 China added more than half of the world's new wind and solar generation in 2023

03 Without wind and solar growth since 2015, China's power sector emissions would have been 21% higher in 2023

China added more than half of the world's new wind and solar generation in 2023

Annual additions of electricity generation from wind and solar (TWh)



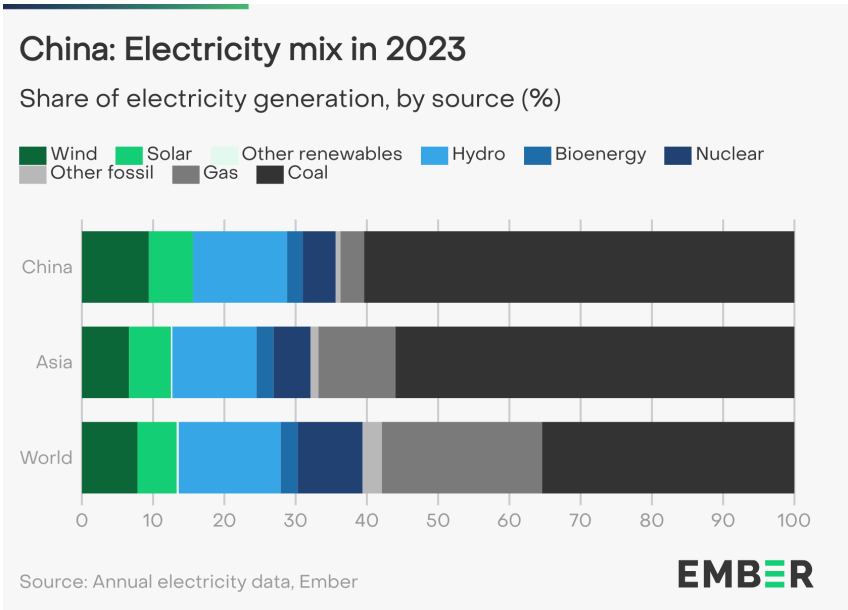
Source: Annual electricity data, Ember

EMBER

China: Current status

China was responsible for 37% of global generation from solar and wind in 2023, and more than half of global coal-fired electricity

In 2023, China was the largest power sector emitter globally, emitting 5,491 million tonnes of CO2 (MtCO2) from electricity generation – more than three times as much as the US (1,570 MtCO2) and India (1,404 MtCO2). China's emissions are largely caused by its high reliance on coal for electricity generation.



In 2023, China generated 65% (6,102 TWh) of its electricity from fossil fuels. 60% of generation came from coal. China's coal share is above the regional average in Asia of 56% and significantly above the global average of 35%. In 2023, China was responsible for more than half (55%) of global coal generation.

Clean electricity made up 35% (3,353 TWh) of China's electricity mix with hydro remaining the largest single source of clean electricity at 13% (1,244 TWh).

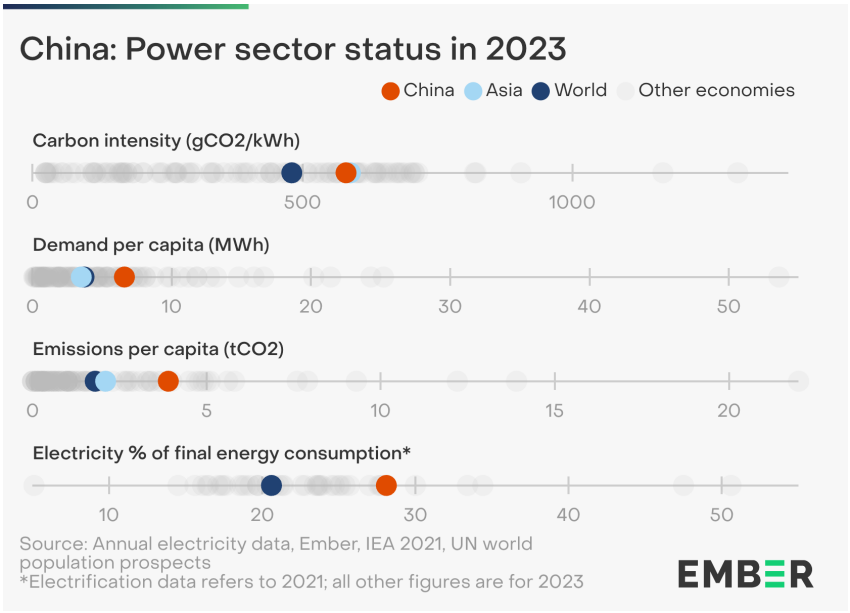
Wind and solar recorded a new record high share of 16% (1,470 TWh) in 2023, together surpassing hydro, as a result of China's rapid build out of new wind and solar capacity. China was responsible for 37% of global generation from solar and wind in 2023, and now generates enough electricity from these two sources to power the whole of Japan.

At 581 gCO2 per kWh, the carbon intensity of China's electricity generation is significantly above the global average of 480 gCO2/kWh.

China's electricity demand has grown rapidly over the last decade while population growth has stalled. At 6.6 MWh in 2023, China's per capita demand was nearly twice the world average (3.7 MWh) and that of Asia (3.5 MWh).

China's per capita emissions from electricity generation (3.9 tCO2) were more than twice the world average of 1.8 tCO2.

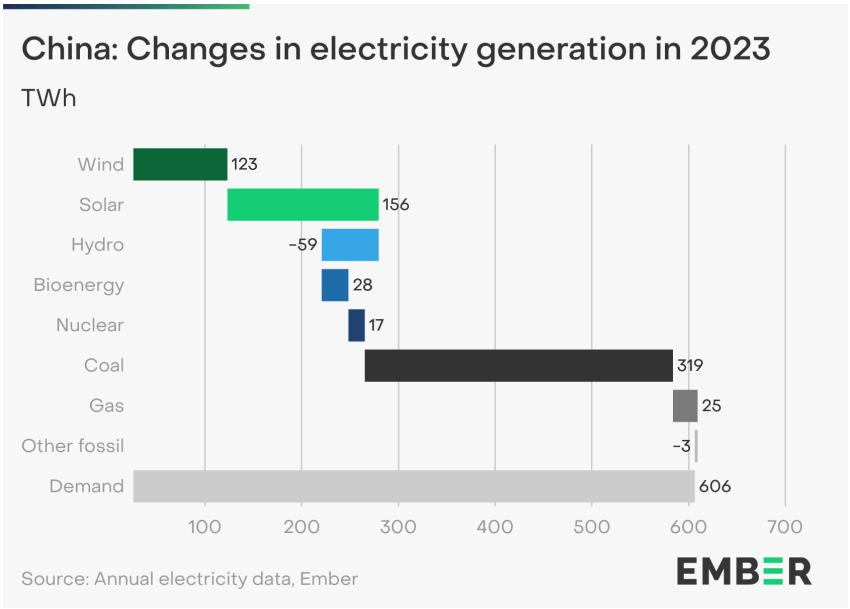
Electricity provided 28% of China's final energy consumption in 2022, compared to the world average of 21%. China is ahead of the curve in electrification of its wider economy, deploying key technologies such as EVs and heat pumps faster than any other country. This added almost 120 TWh to its electricity demand in 2023, compared to less than 90 TWh in the rest of the world combined.



China: Change in 2023

China added more than half of the world's new wind and solar generation in 2023

China's electricity demand continued to grow in 2023, increasing by 6.9% (+606 TWh) compared to the previous year. This was higher than the average annual demand growth of 5.9% between 2013 and 2022 and well above the low demand growth in 2022 of 3.7% (+314 TWh).



Wind (+123 TWh, +16%) and solar (+156 TWh, +37%) met 46% of the demand increase. They continued to be the sources with the fastest relative growth in generation. China made up 51% of global growth in solar and 60% of global growth in wind in 2023.

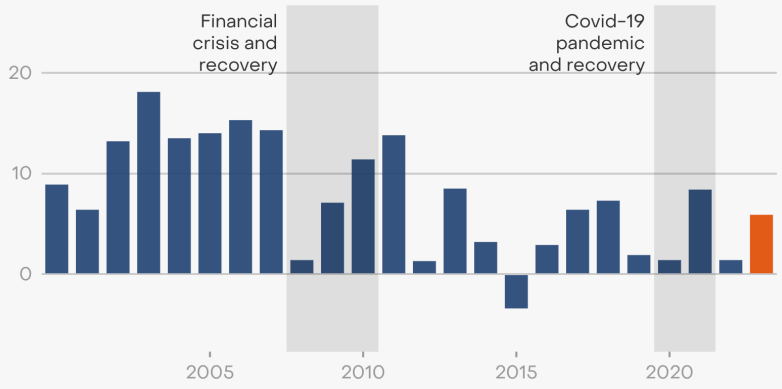
Coal generation (+319 TWh, +5.9%) met most of the remaining increase (53%). Poor hydro conditions meant that hydro generation fell 59 TWh (-4.5%), resulting in greater use of fossil fuels. China's increase in coal generation was more than twice the global increase of 146 TWh.

With coal generation increasing in 2023, China's power sector emissions rose by 5.9% (+307 MtCO2) – six times higher than the global average of 1%. Between 2016 and 2022, average annual emissions growth in China was at 4.2%.

The 2023 emissions growth comes after a near plateau in 2022, with an increase of just 1.4% that year. This was due to lower demand growth in 2022 (+314 TWh) caused by the ongoing impact of China's 'zero-Covid' policy. Furthermore, wind and solar met two-thirds of China's electricity demand increase in 2022, compared to 46% in 2023, resulting in a reduced need for additional coal generation.

China: Annual changes in power sector emissions

Year-on-year change in emissions from electricity generation (%)



Source: Annual electricity data, Ember

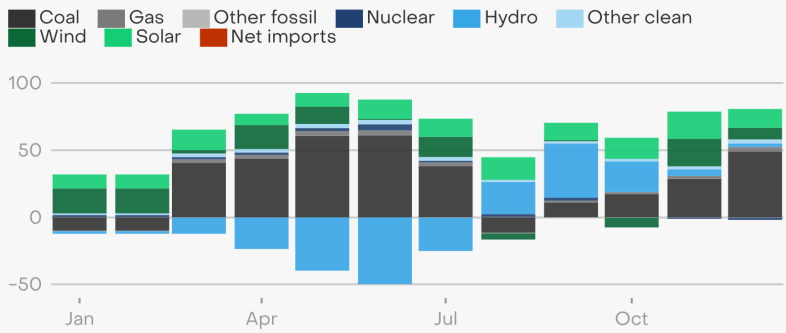
EMBER

March to July saw large falls in hydro generation in China as droughts led to low reservoir levels and lower output. Consequently, coal generation increased most during this period. In the second half of the year, hydro rebounded slightly, although some of this rebound can be explained by low generation during the same months in 2022, when droughts had already started to impact hydro generation.

Solar and wind grew consistently throughout the year. The largest increase was recorded in November. Solar generation grew by 20 TWh compared to November 2022 – equivalent to more than the annual solar generation of the Netherlands.

China: How electricity generation changed during 2023

Year-on-year change (TWh)



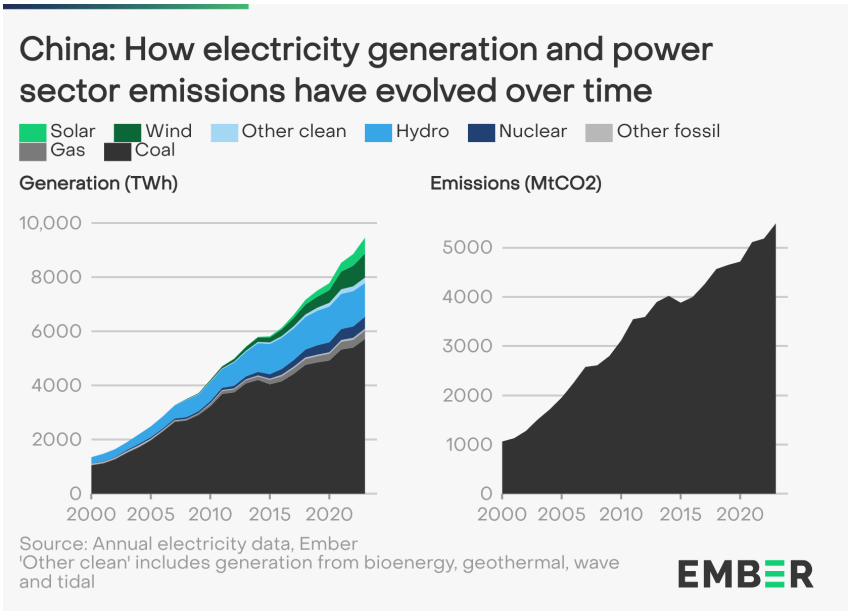
Source: Annual electricity data, Ember
'Other clean' includes generation from bioenergy, geothermal, wave and tidal

EMBER

China: Long-term trend

China's coal generation has increased fivefold since 2000, meeting more than half of the rise in demand

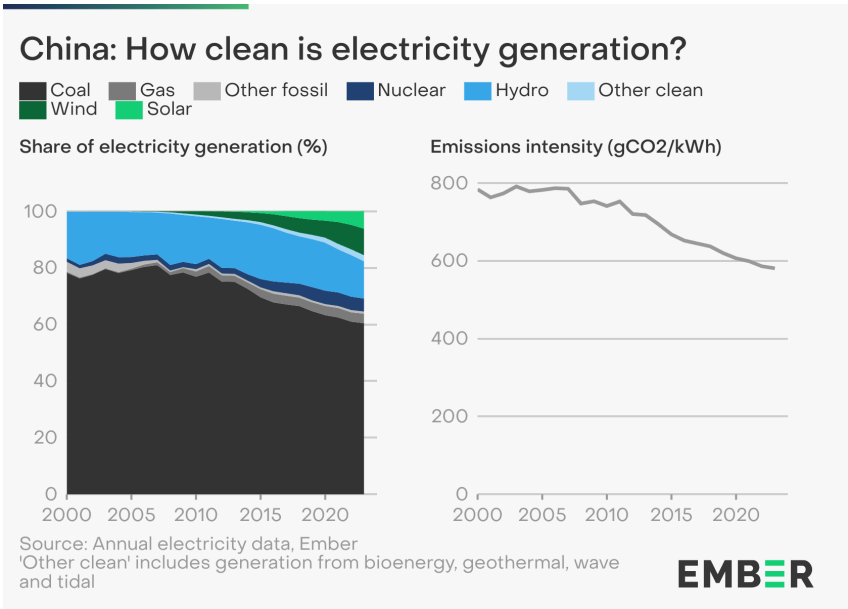
Alongside sustained strong growth in electricity demand, China's power sector emissions have also increased substantially over the last two decades. Rapid economic growth meant that electricity demand was more than seven times higher in 2023 (9,441 TWh) than in 2000 (1,347 TWh).



Over the same period, coal generation increased by more than five times from 1,060 TWh to 5,716 TWh to meet more than half of the increase in demand. This resulted in emissions rising from 1,062 MtCO2 in 2000 to 5,491 MtCO2 in 2023.

However, emissions increases have slowed down in recent years. While emissions grew an average of 9% annually between 2001 and 2015, this rate has dropped to 4.4% annually between 2016 and 2023. Generation from clean sources has increased more than 13 times since 2000 to 3,353 TWh in 2023 with particularly strong growth in wind and solar in recent years. In fact, had wind and solar generation not increased since 2015, and demand had instead been met by coal, emissions would have been 20% higher in 2023.

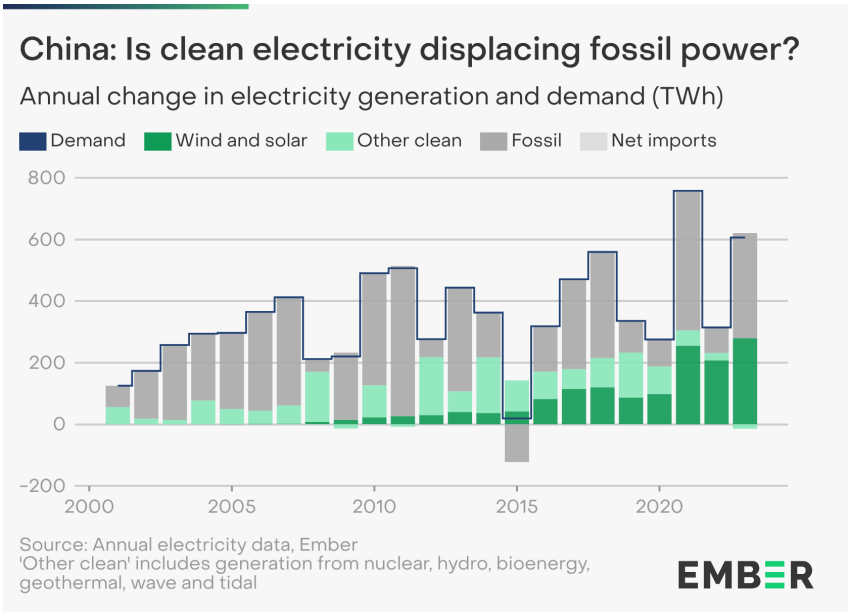
In 2000, China produced 18% (242 TWh) of its electricity from clean sources. The share has doubled since then, reaching 35% in 2023. Most of the growth in the share of clean sources happened in recent years. The rapid addition of wind and solar, as well as additions of nuclear power, increased the share of clean electricity by nine percentage points since 2015.



Wind and solar power grew from just 3.9% of generation in 2015 to reach 15.6% in 2023. This meant that wind and solar combined produced more of China's electricity than hydro for the first time.

As a result of the higher share of clean generation in the mix, the carbon intensity of China's electricity declined from 783 gCO2/kWh in 2000 to 581 gCO2/kWh.

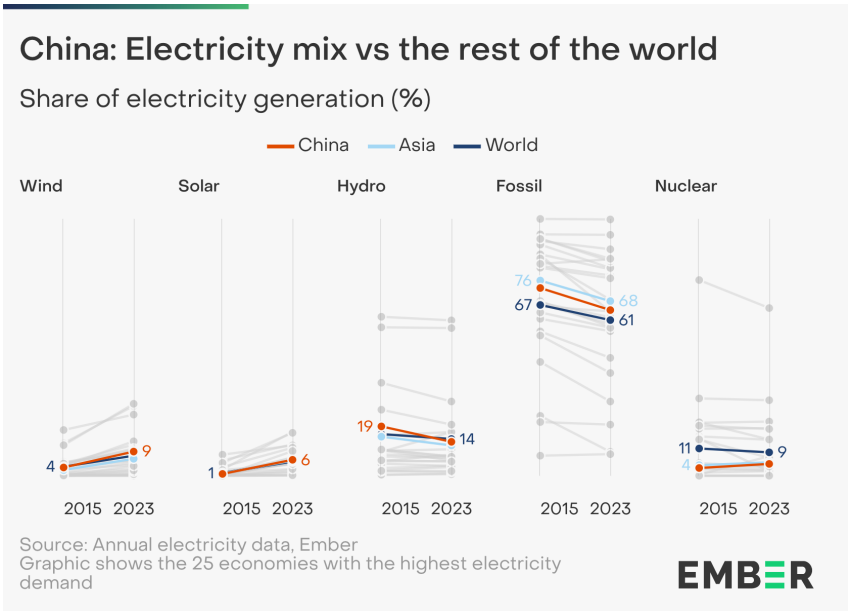
Despite significant additions of wind and solar generation, clean electricity growth is not yet displacing fossil fuels, but simply meeting part of new electricity demand. With the exception of 2015, when electricity demand growth was exceptionally low, China has not yet seen clean generation growth surpass demand growth in a single year.



Strong wind and solar additions in recent years have brought the country closer to a power sector emissions peak. But the fall in output from other clean generation, plus strong demand growth, prevented this from happening in 2023. This fall was principally due to the poor performance from hydro power as a result of droughts, despite significant hydro capacity additions. Additionally, growth of clean sources other than wind and solar in 2021 and 2022 was at the lowest level in a decade.

Since the Paris Agreement in 2015, trends in China's electricity mix have been similar to global trends. At the same time, due to its size, China's power sector is shaping world trends.

China's wind share grew from 3.2% in 2015 to 9.4% in 2023, compared to a global increase from 3.5% to 7.8%. Similarly, its solar share increased from 0.7% in 2015 to 6.2%, against a global change from 1.1% to 5.5%.



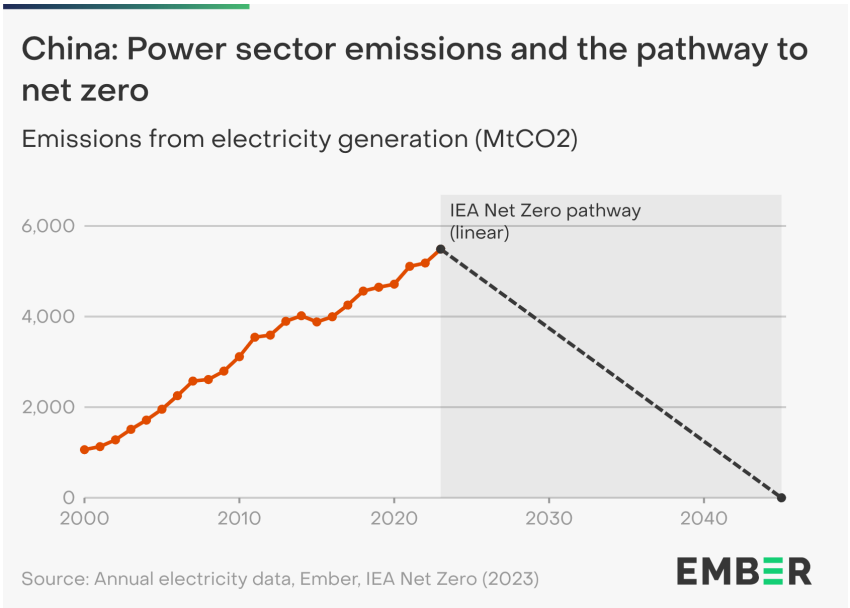
China's share of hydro declined faster than the global trend over the period. At the same time, China is one of the few countries showing growth in nuclear share – up from 3% to 4.6%. Globally, nuclear generation has fallen from 11% of the mix to 9%.

China's fossil generation fell from 73% in 2015 to 65% in 2023, while globally, it declined from 66% to 61% over the same period.

China: Progress towards net zero

China may have reached peak power sector emissions in 2023

According to the IEA Net Zero Emissions scenario, China's power sector emissions and those of other emerging economies would have to reach zero by 2045. This requires a rapid reversal from the current trend of rising emissions.



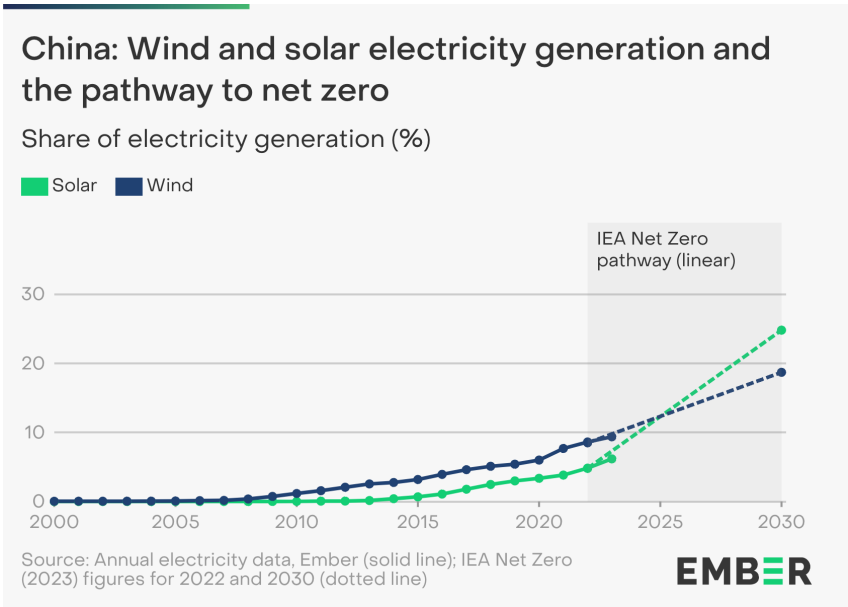
However, due to the speed and scale of China's buildup of clean sources, particularly wind and solar, the country may have already reached a peak in power sector emissions in 2023 or will reach this milestone in 2024 or 2025. China's strong growth in solar and wind power deployment in the last months of 2023 as well as an expected recovery in hydro generation led the IEA to forecast a 3% fall in coal generation in China in 2024. This is a substantial change from a year before, when the IEA forecast a rise in 2024.

In 2023, China was responsible for 39% of global power sector emissions. Peaking and declining power sector emissions in China will contribute significantly to global progress towards net zero.

The IEA NZE scenario sees rapid growth in wind and solar continuing in China with solar increasing to make up a quarter of the power mix by 2030 and wind rising to 19%.

Despite large increases in 2023, the pace of wind and solar additions in China needs to continue to accelerate to meet these targets.

According to [Ember's renewable target tracker], China does not have an official updated target for renewables capacity by 2030, but national modelling projects 1,025 GW of solar and 800 GW of wind by 2030.



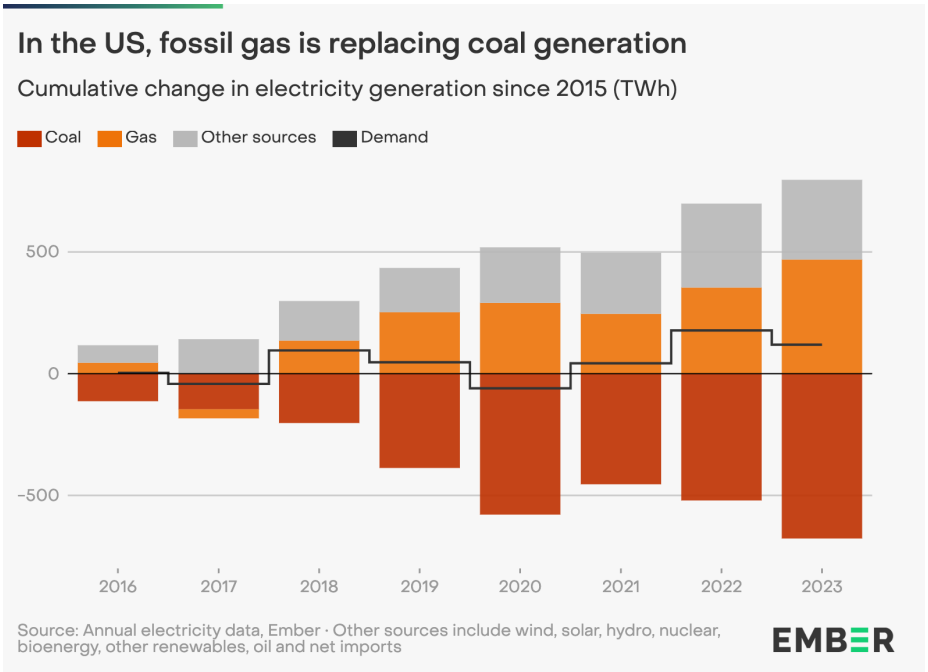
5.2 United States

Key highlights

01 US per capita power sector emissions are nearly three times higher than the global average, due to high demand and a reliance on gas

02 US gas growth prevented a global fall in gas generation in 2023

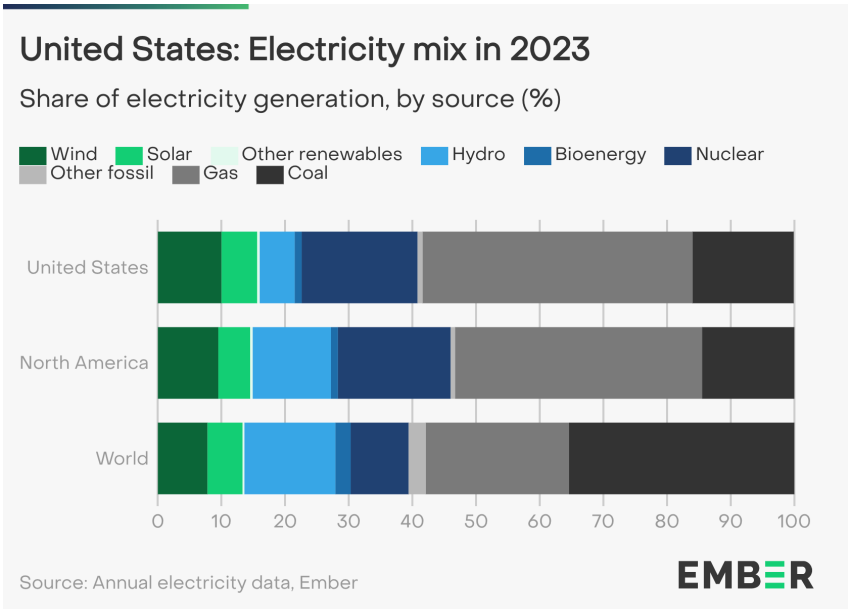
03 US power sector emissions peaked in 2007 and have since fallen 33%



United States: Current status

US per capita power sector emissions are nearly three times higher than the global average, due to high demand and a reliance on gas

In 2023, the United States was the second largest power sector emitter globally, emitting 1,570 million tonnes of CO2 from electricity generation, behind China (5,491 MtCO2). This was driven mostly by a high reliance on fossil fuel generation, predominantly gas, as well as high per capita power demand.



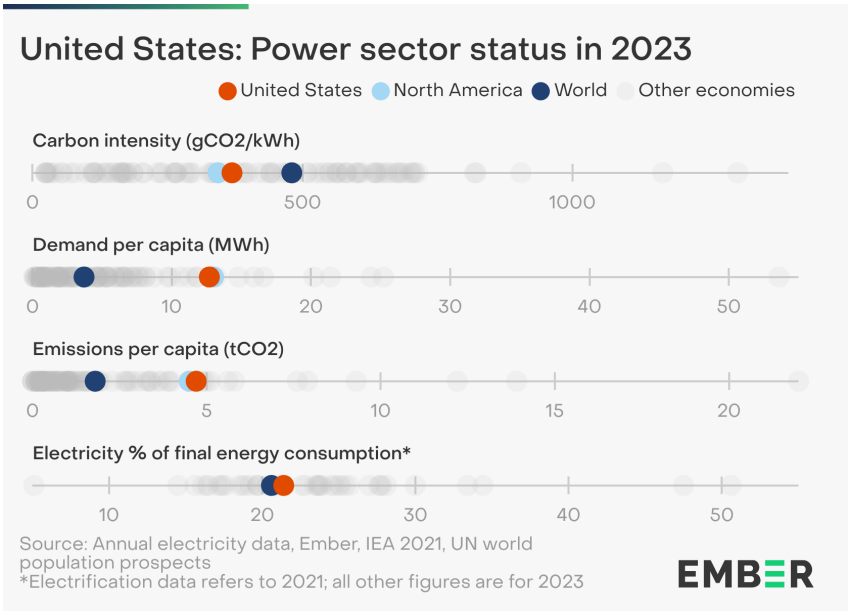
In 2023, the US generated 59% (2,510 TWh) of its electricity from fossil fuels, which is similar to the global average of 61%. Gas had the largest share at 42% (1,802 TWh), followed by coal (16%, 675 TWh) and other fossil fuels (0.8%, 33 TWh).

Clean electricity made up 41% of the US electricity mix, similar to the global average of 39%.

The share of wind and solar reached a record 16% (663 TWh), slightly higher than the global average of 13%.

Electricity generation in the US is less carbon-intensive (369 gCO2/kWh) than the global average (480 gCO2/kWh) due to a lower reliance on coal.

However, per capita power sector emissions are nearly three times higher than the global average (4.7 tCO2 vs. 1.8 tCO2). This is because the US has a high per capita power demand of 12.7 MWh, which is more than three times the global average of 3.7 MWh.

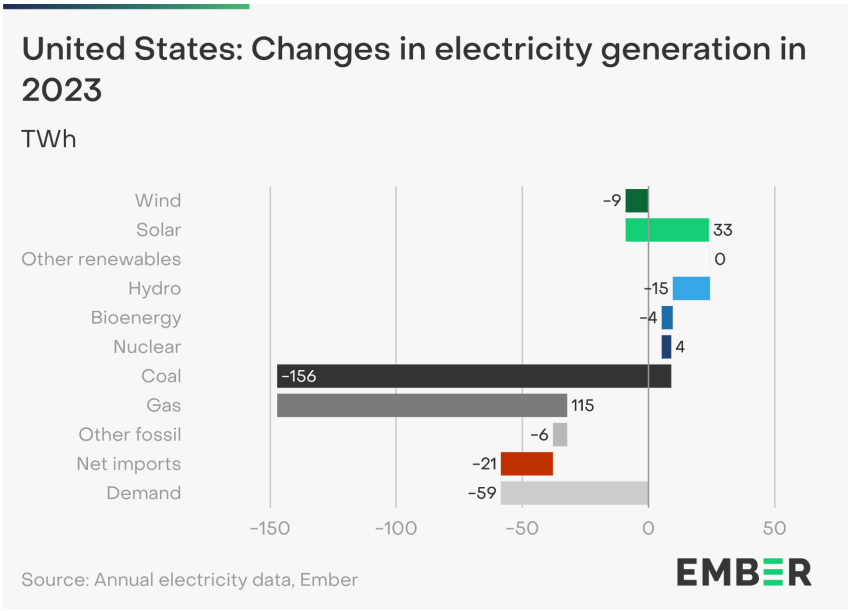


Electricity provided 21% of final energy consumption in the US in 2021, the same as the world average of 21%. This is expected to increase as sectors like transport and industry electrify.

United States: Change in 2023

US gas growth prevented a global fall in gas generation in 2023

In 2023, US electricity demand decreased by 1.4% (-59 TWh), while global demand increased by 2.2%. Demand in the US has grown, at an average rate of 0.6% between 2013 and 2022. The drop in 2023 was largely caused by a 3.6% fall in demand from the residential sector (Ember calculation from US electricity sales), mostly due to rising utility prices, inflation and a relatively mild winter.



Coal generation saw a steep fall of 19% (-156 TWh) in 2023 as coal power plants in the US continued to close. Accordingly, the share of coal (16%) was down three percentage points in the US electricity mix compared to 2022 (19%). In line with the trend of gas replacing coal generation in the US, gas experienced the largest absolute increase out of all generation sources in 2023, rising by 6.8% (+115 TWh).

US gas growth prevented a global fall in gas generation in 2023. Excluding the US, the rest of the world recorded a 62 TWh fall in gas generation in 2023, whereas the US increased by almost twice that amount (+115 TWh).

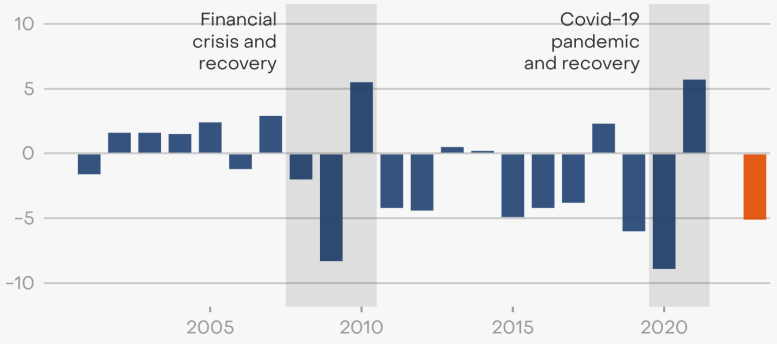
US solar generation grew 33 TWh (+16%) in 2023, the second largest absolute increase of any country, behind only China. The US contributed 11% of global growth in solar. Wind generation fell by 2.1% (-9.1 TWh) due to poor wind conditions, but growing capacity installations in 2023 and onwards suggest growth in 2024.

In 2023, emissions from the US power sector dropped by 5.1% (-85 MtCO2) compared to 2022, similar to the decline seen in Japan (-7.3%) but slower than the EU (-19%). This reduction was the result of a steep decline in coal generation, an increase in solar generation and lower overall power demand. This was in contrast to the emissions increases of 1% globally and a fall of 7.6% in the G7.

In 2023, the US recorded the 7th annual fall in power sector emissions in the last 10 years. The drop in emissions in 2023 was twice its average annual emissions decrease (-2%) for the ten years between 2013 and 2022.

United States: Annual changes in power sector emissions

Year-on-year change in emissions from electricity generation (%)



Source: Annual electricity data, Ember

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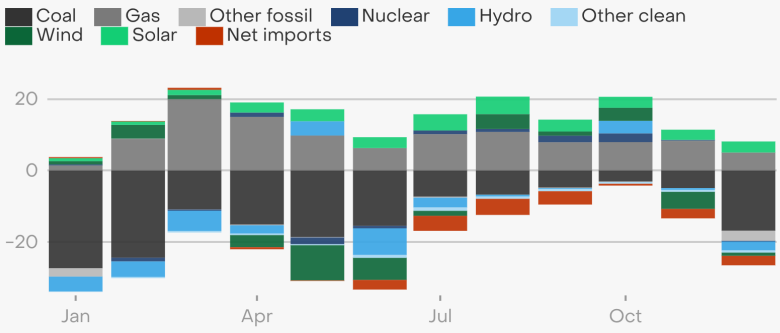
US coal generation declined most compared to 2022 during the first half of the year where it was largely replaced by additional gas generation. The first half of the year also saw falls in hydro generation in most months due to drought conditions.

Solar generation saw consistent year-on-year increases throughout the year with additions strongest during the US summer. Poor wind conditions meant monthly wind generation remained below 2022 levels for most of the year. The largest drop in wind generation was recorded in May (-9.9 TWh).

United States: How electricity generation changed during 2023

Year-on-year change (TWh)



Source: Annual electricity data, Ember
'Other clean' includes generation from bioenergy, geothermal, wave and tidal

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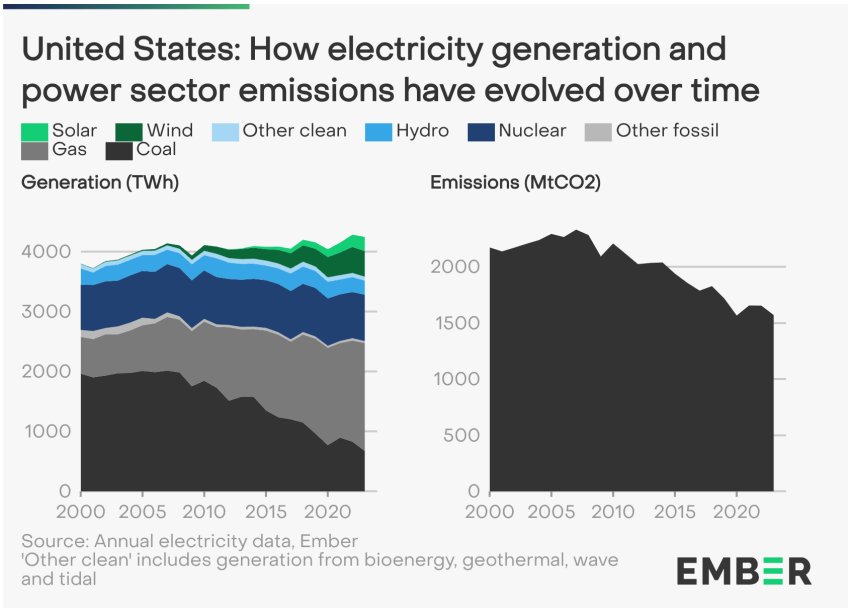
United States: Long-term trend

US power sector emissions peaked in 2007 and have since fallen 33% due to the decline in coal generation

US power sector emissions have been falling since reaching their peak in 2007. In 2023, emissions were 1,570 MtCO2, about 33% lower than the peak level of 2,331 MtCO2. The reduction in US power sector emissions since 2007 was driven by growth in wind and solar, as well as gas replacing coal. The fall in emissions has been achieved despite the increase in electricity demand. In 2023, power demand stood at 4,270 TWh, about 11% higher than in 2000.



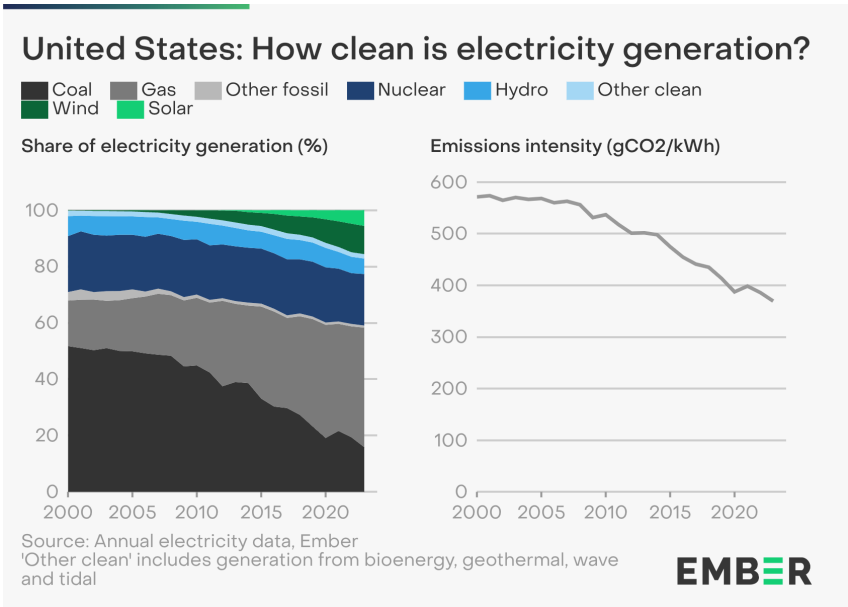
Until 2015, coal was the main source of electricity in the US. However, as coal generation became less economically viable and more tightly regulated, increasing numbers of coal power plants were retired throughout the 2010s.

Most of the retired plants' output was replaced with gas, along with growing amounts of wind and solar. By 2015, gas had overtaken coal as the largest source of electricity in the US. In fact, 69% of the fall in coal generation since 2015 was met by an increase in gas. The increase in gas generation in the US over that period contributed 43% to the total global gas growth.

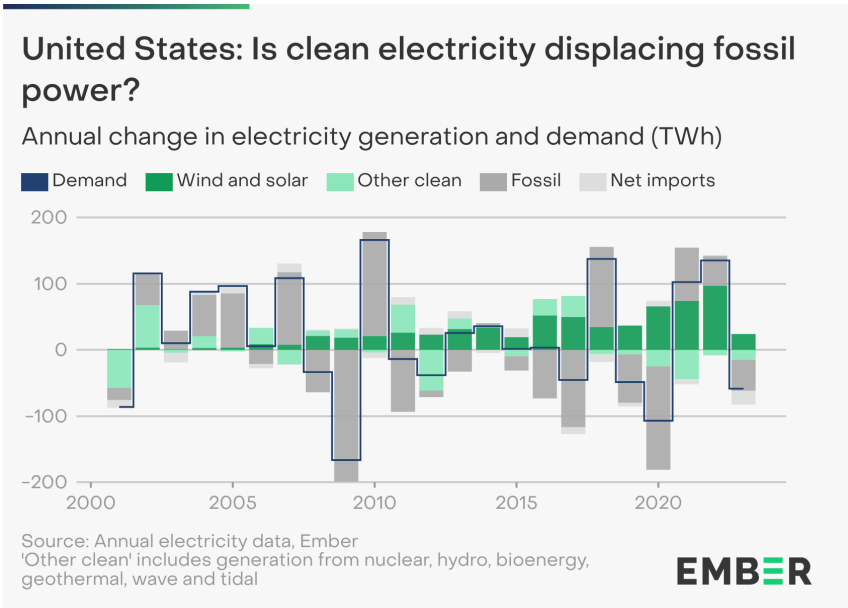
Among clean power sources, wind has shown the highest growth since 2000, followed by solar. Wind generation grew from 5.6 TWh in 2000 to 425 TWh in 2023. Meanwhile, solar generation hit a record high of 238 TWh in 2023, up from 0.5 TWh in 2000.

Since 2000, the share of clean generation in the US electricity mix has increased significantly. In 2000, wind and solar accounted for only 0.2% of the country's power generation, yet by 2023 they had reached 16%.

The emissions intensity of the US power sector fell significantly to 369 gCO2/kWh in 2023, a 35% decline from 2000 levels (571 gCO2/kWh). This was due to a number of factors, with increased solar and wind deployment and the reduction of coal generation being the major contributors.



In 2023, US fossil generation fell as a result of falling electricity demand. The increase in solar output further reduced the need for fossil generation, but the fall could have been even larger if other clean generation – mainly hydro and wind – had not decreased. In fact, every year since 2018 has seen falls in clean generation other than wind and solar, which was largely driven by falls in hydro power due to ongoing droughts.



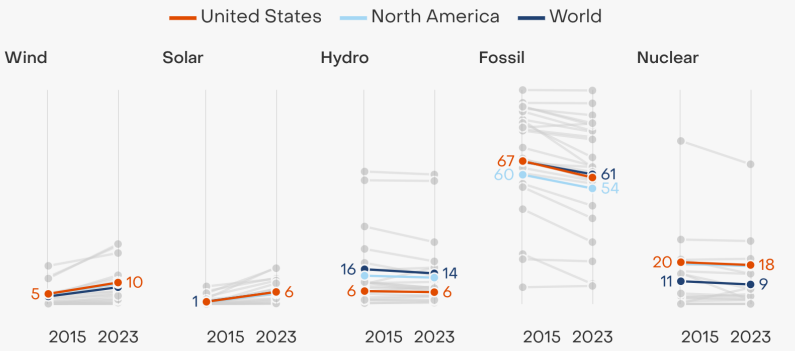
Additionally, 2016 was the last year with increasing electricity demand that simultaneously saw a fall in fossil generation. With electricity demand expected to increase due to the electrification of transport and industry, accelerating the deployment of wind and solar, as well as avoiding further falls in other clean generation, is key to reducing fossil generation and emissions.

The electricity mix in the US has become cleaner since the Paris Agreement in 2015. The share of fossil fuels in the electricity mix dropped by eight percentage points, from 67% in 2015 to 59% in 2023.

Over the same timeframe, wind and solar grew by ten percentage points in the US, from 5.6% in 2015 to 15.6% in 2023, which is faster than the global change over the same period. Globally, wind and solar grew from 4.5% in 2015 to 13.3% in 2023 (+8.8 percentage points). Shares from other clean sources decreased, with hydro and nuclear dropping by 0.5 and 1.3 percentage points, respectively.

United States: Electricity mix vs the rest of the world

Share of electricity generation (%)



Source: Annual electricity data, Ember
Graphic shows the 25 economies with the highest electricity demand

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United States: Progress towards net zero

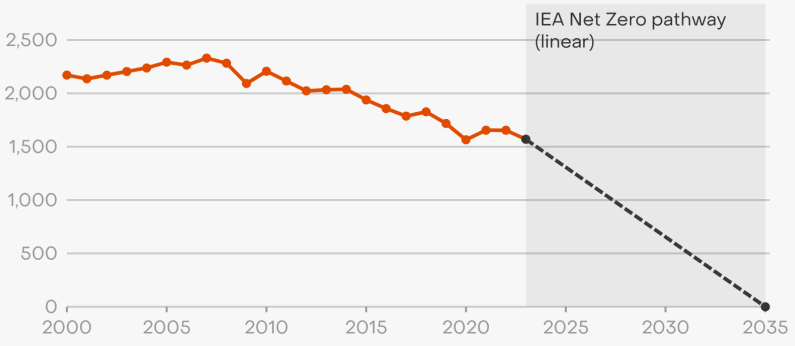
US power sector emissions need to decline three times faster to be on track for net zero

According to the IEA Net Zero Emissions scenario, power sector emissions in the US and other advanced economies need to reach zero in 2035.

Since 2015, emissions have been falling by an average of 50 MtCO2 every year. To align with the IEA NZE scenario, this would have to accelerate to a fall of 139 MtCO2 annually from 2024 onwards.

United States: Power sector emissions and the pathway to net zero

Emissions from electricity generation (MtCO2)



Source: Annual electricity data, Ember, IEA Net Zero (2023)

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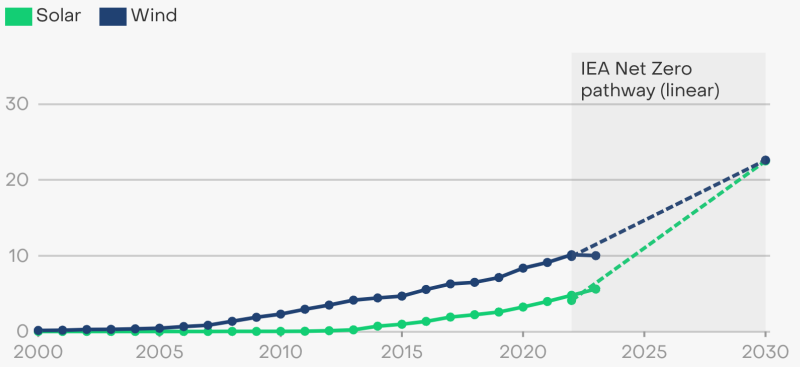
The IEA estimates that wind generation needs to reach 22.6% of the US electricity mix in 2030, more than doubling from 10% in 2023. Similarly, solar generation needs to reach 22.5%, compared to a share of 5.6% in 2023.

The Inflation Reduction Act, along with other policies that support clean energy such as the Bipartisan Infrastructure Law, are expected to set the US on course for 938 GW of renewable capacity by 2030. To meet this implicit target, as defined in Ember's renewable energy tracker, the US needs to add 73 GW of renewable capacity on average every year to 2030, which is three times the capacity added in 2022.

United States: Wind and solar electricity generation and the pathway to net zero

Share of electricity generation (%)



Source: Annual electricity data, Ember (solid line); IEA Net Zero (2023) figures for 2022 and 2030 (dotted line)

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5.3 India

Key highlights

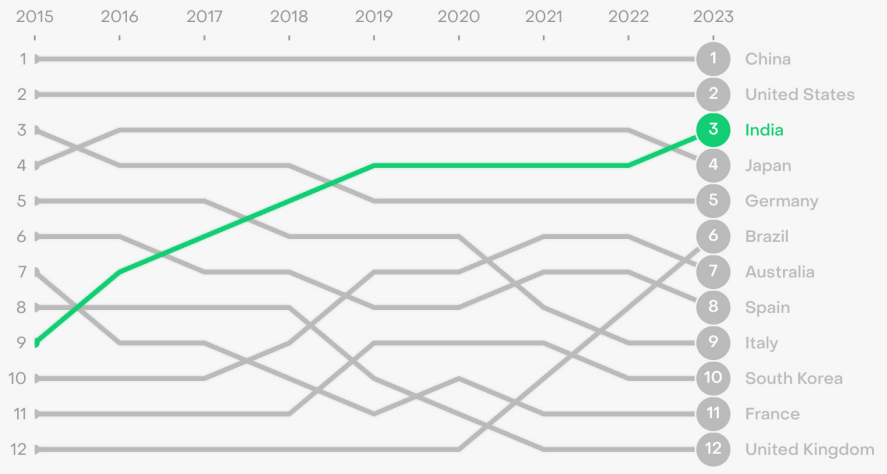
01 India overtook Japan to become the third-largest solar power generator in 2023, providing 5.9% of global growth in solar

02 Solar generation in 2023 was 17 times higher than in 2015, but coal is still meeting the majority of India's demand growth

03 India's per capita emissions from the power sector are the fourth lowest in the G20, despite high coal reliance

India is now the third largest solar generator

Global rankings of solar electricity generation (TWh)



Source: Annual electricity data, Ember

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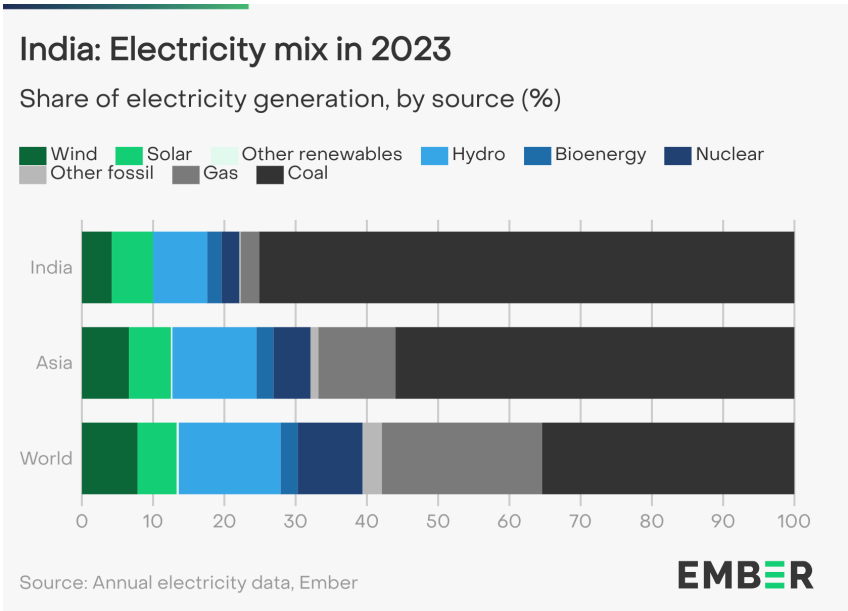
India: Current status

India's per capita emissions from the power sector are the fourth lowest in the G20, despite high coal reliance

In 2023, India was the third-largest power sector emitter globally, emitting 1,404 million tonnes of CO2 from electricity generation, behind China (5,491 MtCO2) and the US (1,570 MtCO2).



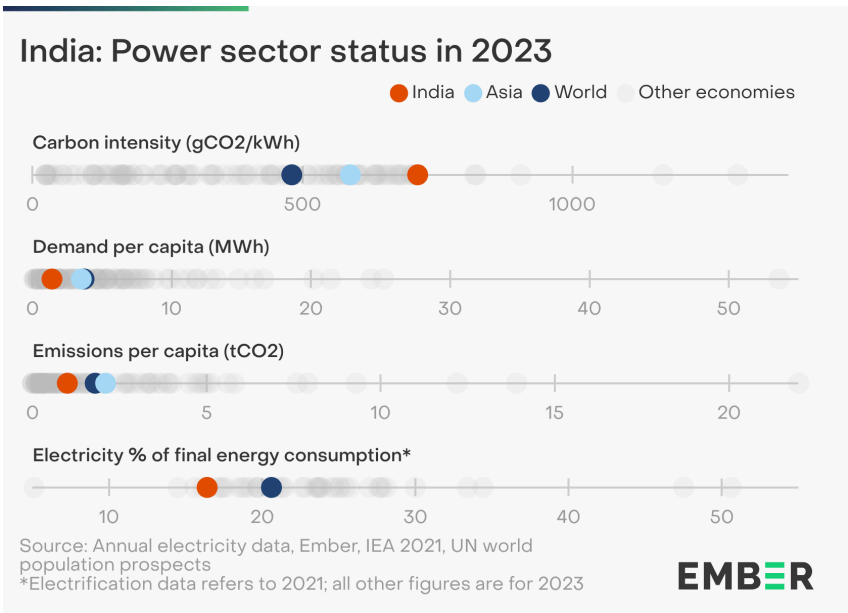
In 2023, India generated 78% (1,536 TWh) of its electricity from fossil fuels, which is higher than the global average of 61% and the regional average of 68% in Asia. Coal had the largest share at 75% (1,480 TWh) – the second highest share of coal generation in the G20 behind South Africa. Gas contributed 2.6% (51 TWh) while other fossil fuels contributed 0.2% (4.0 TWh).

Clean generation made up 22% of India's electricity mix, compared to the global average of 39% and 32% in Asia.

The share of wind and solar reached a record high of 9.9% (196 TWh), though India remained 3.5 percentage points behind the global average of 13.4%. In Asia, China (16%), Japan (12%) and Viet Nam (13%) have higher shares of wind and solar power in their electricity mix.

India's electricity generation is more carbon-intensive (713 gCO2 per kWh) than the global average (480 gCO2/kWh), with coal accounting for three-quarters of generation in 2023.

However, India's per capita emissions from the power sector are just over half the global average (1.0 tCO2 vs. 1.8 tCO2) and even further below the average in Asia (2.1 tCO2). They are also the fourth lowest in the G20.



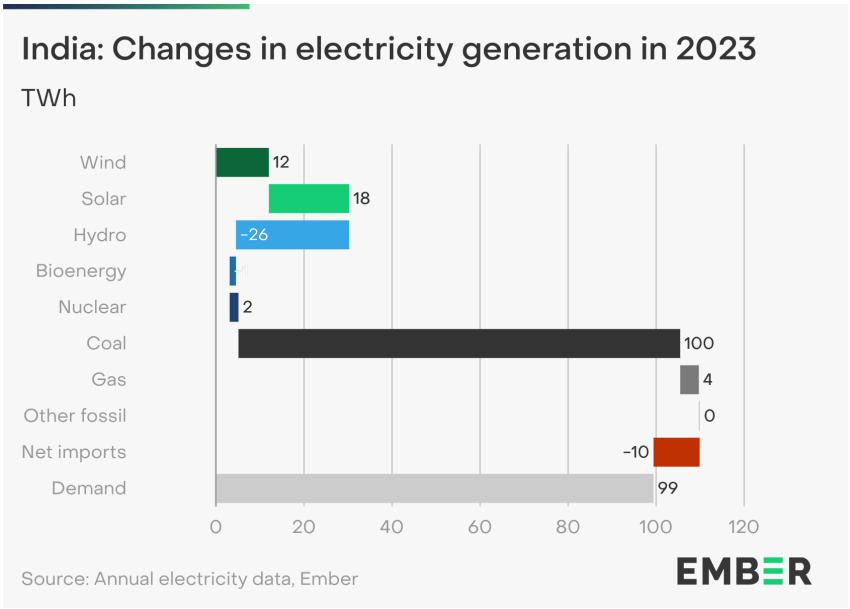
This is because India's per capita power demand (1.4 MWh) is significantly below the global average (3.7 MWh) and less than half of the average in Asia (3.5 MWh).

Electricity provided 16% of India's final energy consumption in 2022, significantly below the world average of 21%. This is expected to increase as India's economy electrifies.

India: Change in 2023

India overtook Japan to become the third-largest solar power generator in 2023, providing 5.9% of global growth in solar

India's power demand increased by 5.4% (99 TWh) in 2023 compared to the previous year – more than twice as fast as the global increase (+2.2%). This was in line with the country's average annual demand growth rate for the last decade (+5.4%) and lower than in 2022, when it rose significantly (+8.3%) as the economy rebounded from the Covid-19 pandemic.



Wind and solar generation increased by a combined 30 TWh. This met 30% of India's demand increase. India reported the third largest increase in wind and solar globally behind China and Brazil. Solar generation alone grew 18 TWh, providing 5.9% of global solar growth in 2023. Consequently, India overtook Japan to become the third-largest solar power generator in 2023.

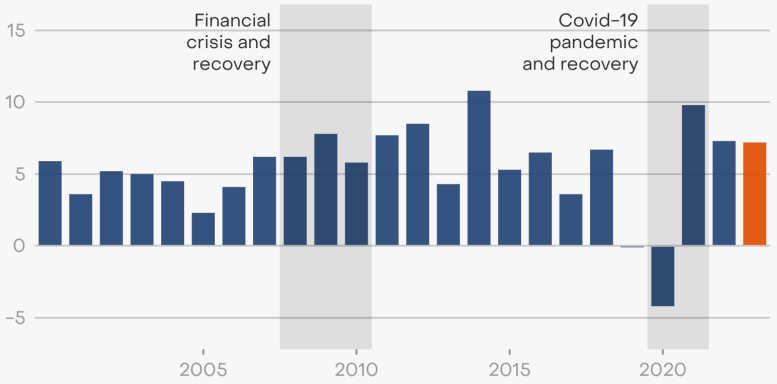
Coal generation saw the largest absolute increase among India's generation sources (+7.3%, +100 TWh). India also saw the second-highest increase in coal generation globally, behind China, and was among just four countries with an increase greater than 10 TWh. 26% of the rise in coal generation in India was caused by the 26 TWh deficit in hydropower generation due to droughts. As a result, the share of coal in India's power generation rose one percentage point from 2022 to 75% in 2023.

Due to the increased generation from coal, India's power sector emissions rose by 7.2% in 2023 (+94 $MtCO_2$) compared to 2022. This was far higher than the global increase of 1% and also higher than in most G20 countries including China (+5.9%). The only G20 country with a larger relative emissions increase in 2023 was Mexico (+11%, +17 $MtCO_2$).

This is the third consecutive annual increase in India's power sector emissions since the Covid-19 pandemic and the consequent fall in electricity demand, which caused emissions to decline 4.2% in 2020.

India: Annual changes in power sector emissions

Year-on-year change in emissions from electricity generation (%)



Source: Annual electricity data, Ember

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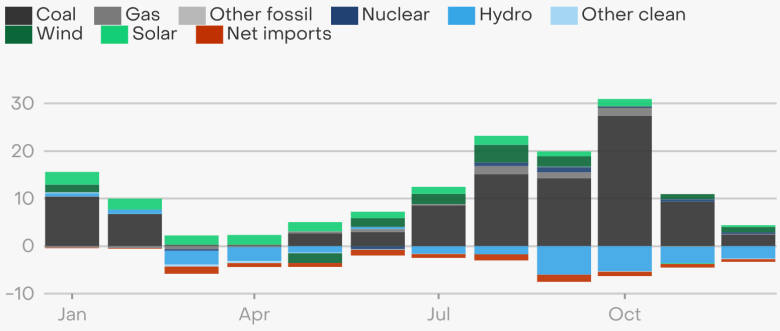
India's hydro generation fell throughout most of 2023 compared to 2022, but particularly in the second half of the year due to droughts. As a result, increases in coal generation were larger to make up the hydro fall. Coal generation grew most from August to October, with generation in October 2023 27 TWh above October 2022 levels.

Solar generation also increased throughout the year, with January showing the largest increase of 2.7 TWh.

India: How electricity generation changed during 2023

Year-on-year change (TWh)



Source: Annual electricity data, Ember
'Other clean' includes generation from bioenergy, geothermal, wave and tidal

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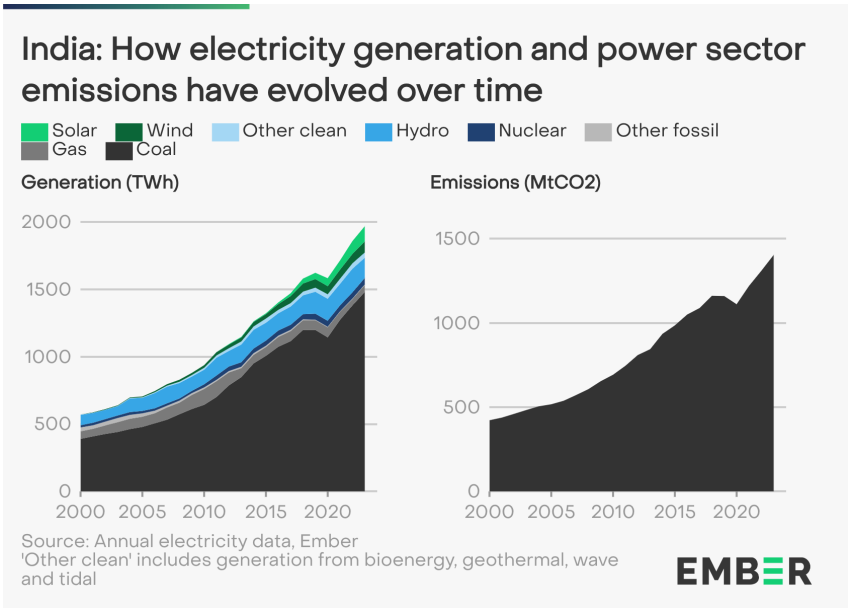
India: Long-term trend

Solar generation in 2023 was 17 times higher than in 2015, but coal is still meeting the majority of India's demand growth

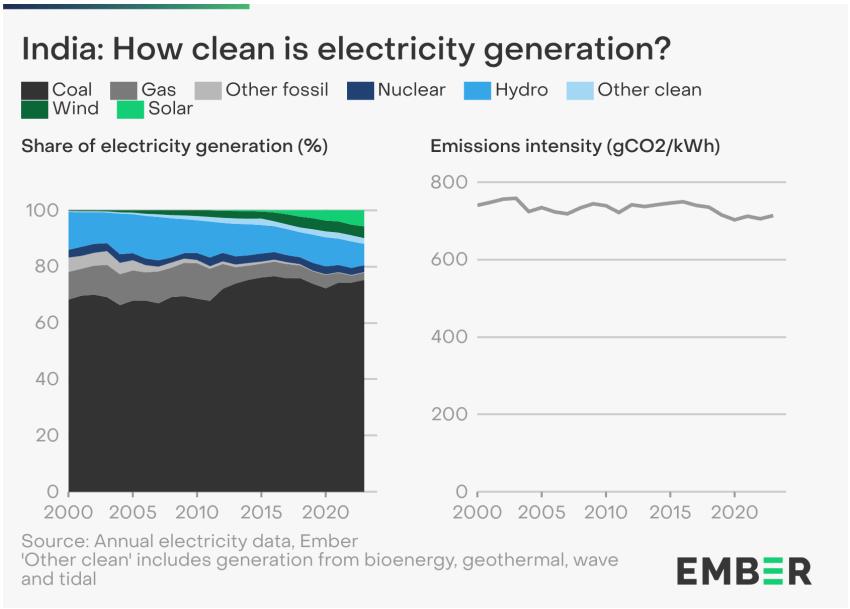
India's solar generation has been increasing significantly over the last two decades, from just 0.01 TWh in 2000 to 113 TWh in 2023. Most of the growth came in the past five years. Generation in 2023 was 17 times larger than in 2015 (6.6 TWh). Solar more than doubled (+145%, +67 TWh) since 2019.



However, coal has accounted for the largest rise since 2000, increasing by nearly four times (+1,090 TWh) from 390 TWh in 2000 to 1,480 TWh in 2023. As a result, India's power sector emissions have also more than tripled since 2000. However, had wind and solar generation not grown over the last two decades and this demand had been met by coal, India's power sector emissions in 2023 would have been 13% higher. Given the current growth of electricity demand and coal generation, emissions are unlikely to peak soon.

Although India's total power sector emissions have increased, the emissions intensity of electricity has declined slightly.

The share of coal generation increased from 68% in 2000 to 75% in 2023. Generation from gas and from other fossil fuels declined.

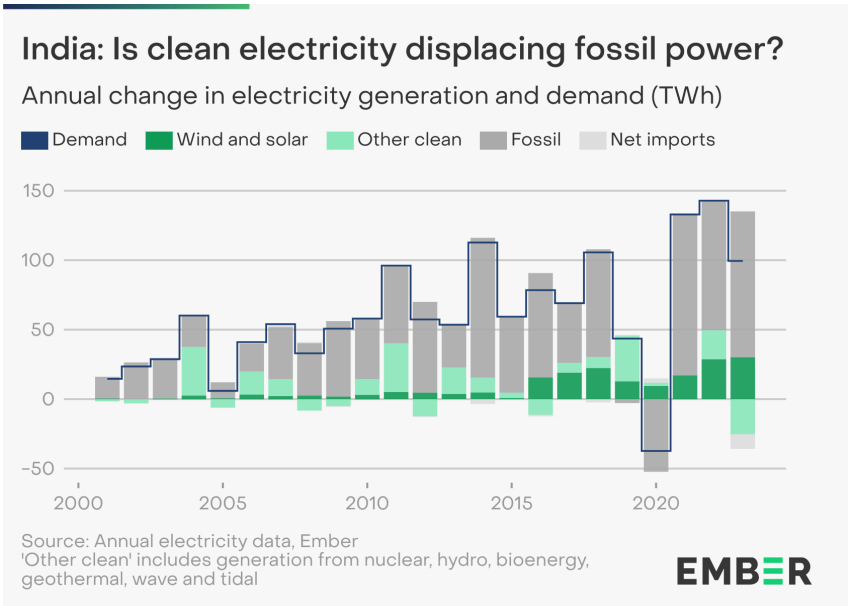


In 2000, wind and solar accounted for only 0.3% of India's power generation, but jumped to 9.9% in 2023. Other clean generation fell, with the share of hydro declining from 13% to 7.6%. Nuclear has remained between 2-3% of India's electricity generation.

However, additions of wind and solar were enough to increase the overall share of clean electricity from 17% in 2000 to 22% in 2023.

Consequently, the emissions intensity of India's power sector fell slightly to 713 gCO2/kWh, below the level in 2000 (740 gCO2/kWh).

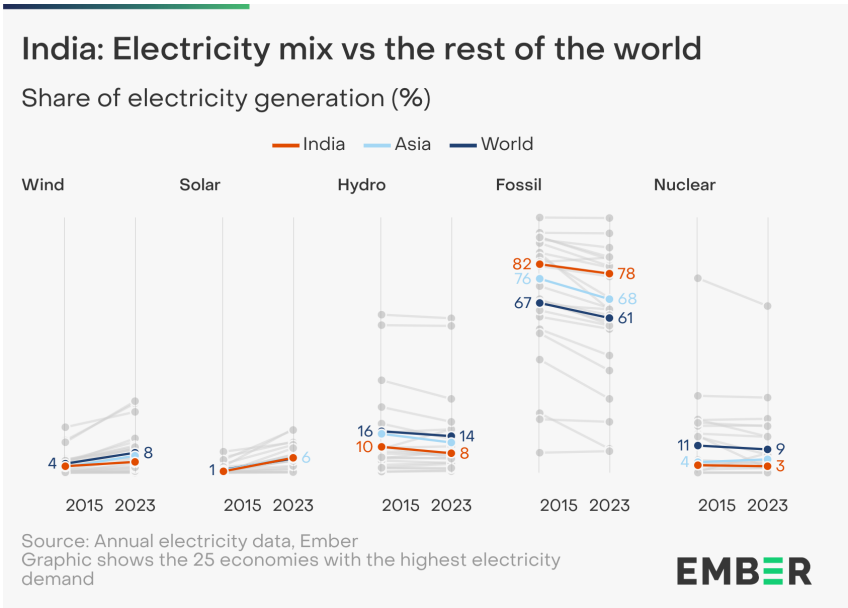
Despite progress, wind, solar and other low-carbon sources are not yet growing fast enough to meet India's rapidly growing electricity demand, leading to continuously rising power sector emissions.



In 2023, growth in clean generation met just 5.2% of India's demand rise. While solar and wind met 30% of the increase, low hydro output created a shortfall. There have been only two years where clean electricity growth surpassed demand increases: in 2019 due to good hydro conditions and low demand growth and in 2020 because of a pandemic-induced demand fall.

Accelerating clean electricity additions will be key to meeting rising electricity demand. The recent volatility in hydro conditions puts even more emphasis on the case for growth of other clean sources such as wind and solar.

Although clean power growth is not rising quickly enough to meet the increase in demand, India's electricity grid has become cleaner since the Paris Agreement in 2015. The share of fossil fuels in India's electricity mix dropped by four percentage points, from 82% to 78%. However, by comparison, the share of fossil generation in the global electricity mix fell faster, dropping six percentage points.



The share of hydro generation fell over this period in India (2.5 percentage points) but by less than the average fall across Asia (3.4 percentage points).

Wind and solar both increased their share of power generation. Solar generation grew from just 0.5% in 2015 to 5.8% in 2023. This is in line with the trend globally and in Asia. India's wind generation increased slightly from 2.5% to 4.2%, but lagged behind the global growth in wind.

India: Progress towards net zero

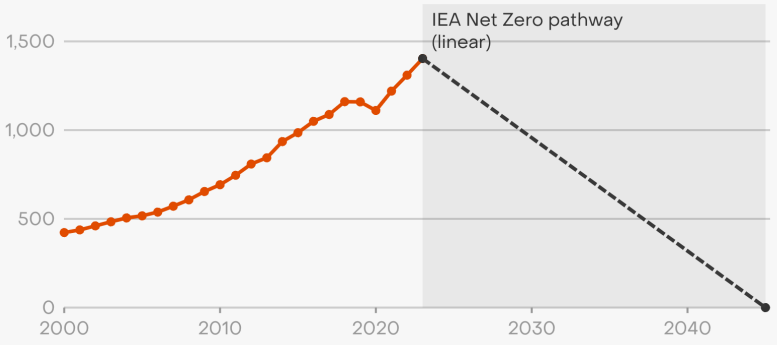
India's emissions continue to increase as demand growth outpaces clean growth

India's power sector emissions are expected to increase for several years until clean sources grow fast enough to meet all of the rise in electricity demand, which would lead to a peak in fossil emissions and the beginning of their decline.

However, to align with the IEA Net Zero Emissions scenario, the power sector would need to decarbonise by 2045. This would require a reversal of India's current emissions trajectory.

India: Power sector emissions and the pathway to net zero

Emissions from electricity generation (MtCO2)



Source: Annual electricity data, Ember, IEA Net Zero (2023)

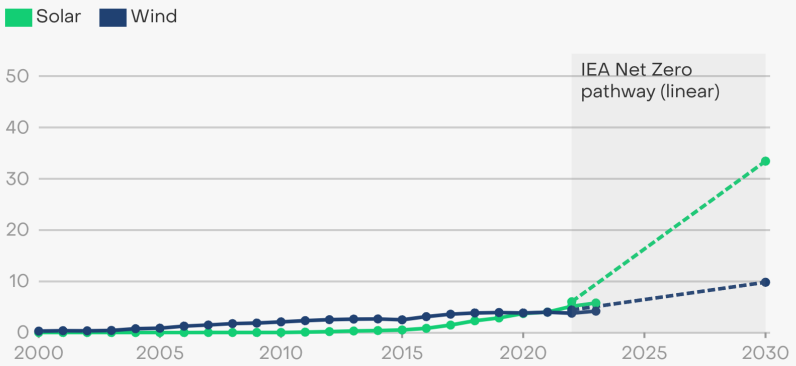
EMBER

The Indian government has set out ambitious renewables targets, which will see solar generation reach 602 TWh and wind generation reach 237 TWh by 2030. Achieving these targets would require an annual growth rate of 27% for solar and 16% for wind, which was achieved in 2023.

According to Ember's calculations, these targets would need to increase further to be compatible with the IEA NZE scenario, requiring $101 billion in additional financing.

India: Wind and solar electricity generation and the pathway to net zero

Share of electricity generation (%)



Source: Annual electricity data, Ember (solid line); IEA Net Zero (2023) figures for 2022 and 2030 (dotted line)

EMBER

Generation would need to grow to 819 TWh for solar and 259 TWh for wind to reach the IEA scenario's 2030 target for India of a 33% share for solar and a 9.8% share for wind generation.

India is one of the few countries planning to triple renewable capacity by 2030, aiming for 509 GW. According to Ember analysis, annual capacity additions need to significantly increase for India to meet this capacity target.

5.4 European Union

Key highlights

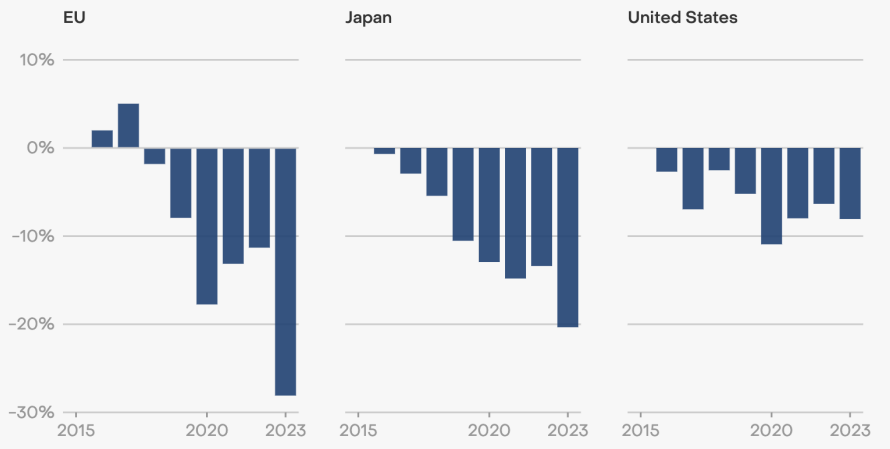
01 Wind overtook gas in the EU in 2023 to become the second-largest source of electricity at 17.5% – more than twice the global average of 7.8%

02 The EU contributed 17% of the global growth in solar and wind in 2023

03 In the last ten years, the EU has seen the second-largest decline in coal generation, after the US, which has driven down emissions

The EU has seen the largest shift away from fossil fuels among major OECD emitters

Change in electricity generation from fossil fuels since 2015



Source: Annual electricity data, Ember

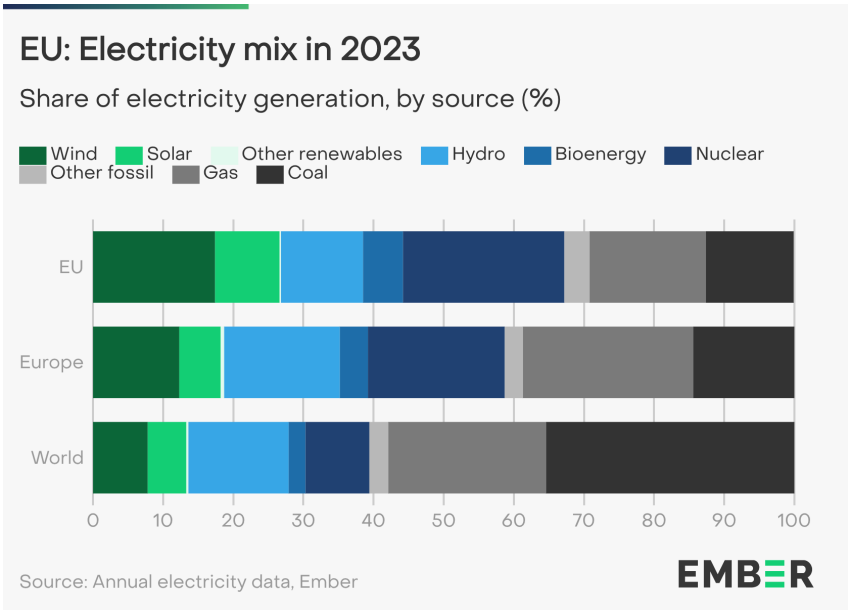
EMBER

European Union: Current status

Wind overtook gas in the EU in 2023 to become the second-largest source of electricity at 17.5% – more than twice the global average of 7.8%

In 2023, the European Union was the fourth-largest power sector emitter globally, behind China, the US and India, emitting 657 million tonnes of CO2 from electricity generation.

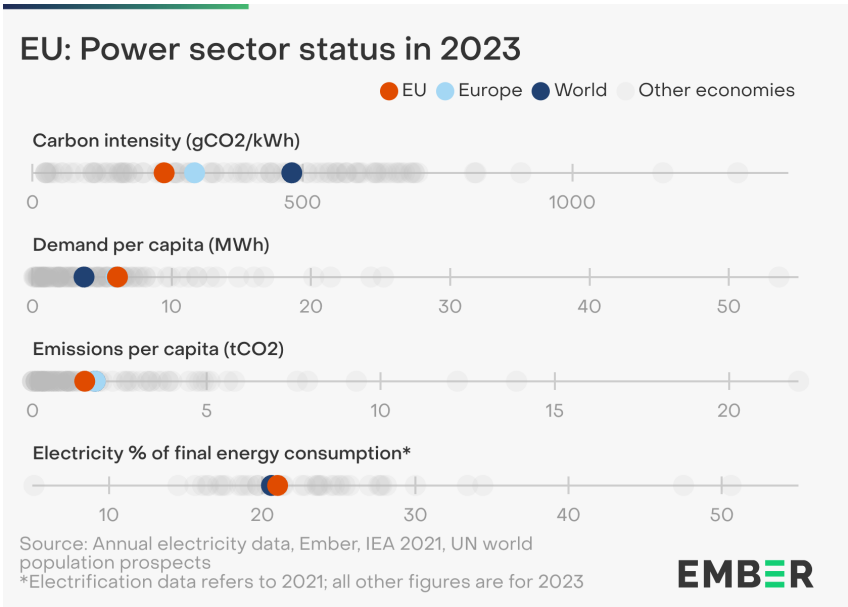
The EU has the lowest share of fossil fuels in its electricity mix out of the top four emitters, at only 33%. This is about half of the share of fossil fuels in global electricity production (61%). In the EU, gas plays a bigger role (16.7%, 449TWh) than coal (12.5%, 336TWh). Compared to the whole of Europe – which includes Russia and Türkiye among others – the EU is less reliant on fossil fuels.



Clean power made up 67% of the EU's electricity mix. Nuclear remained the largest single source of electricity (23%, 619 TWh). Wind became the second-largest source of electricity in the EU with a share of 17.5%, higher than gas for the first time at 16.7%. The share of wind and solar reached a record high of 26.6% (718 TWh) in 2023, almost twice the global share of 13.4%.

The carbon intensity of electricity generation in the EU is 244 gCO2 per kWh – almost half the global average (480 gCO2/kWh). This is because the EU has a higher share of clean electricity than the global average.

The EU's per capita power sector emissions are 1.5 tCO2, less than the world average of 1.8 tCO2.



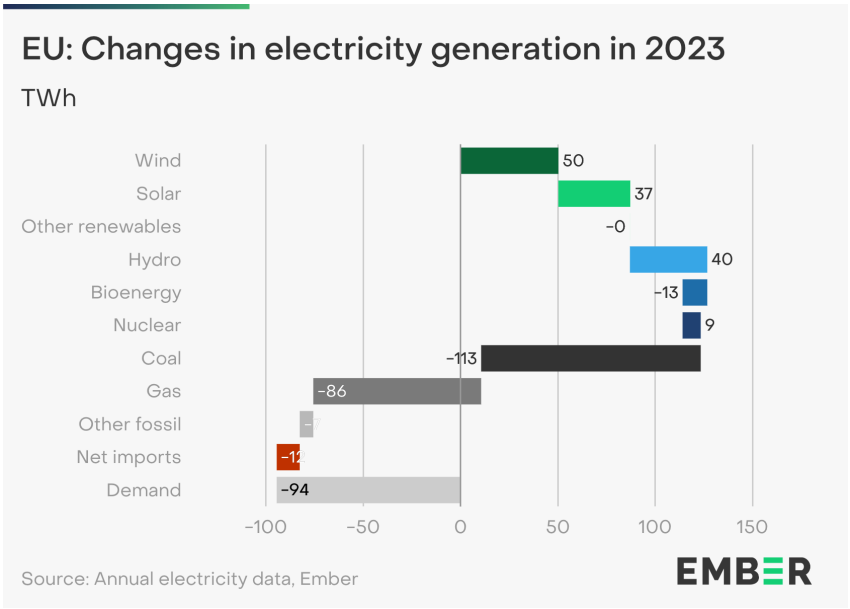
Meanwhile, the EU's per capita power demand (6.1 MWh) is almost two-thirds higher than the world average (3.7 MWh).

Electricity provided 21% of the EU's final energy consumption in 2021, similar to the world average. This is expected to increase as member states electrify further.

European Union: Change in 2023

The EU contributed 17% of the global growth in solar and wind in 2023

The EU's power demand decreased by 3.4% (-94 TWh) in 2023. The drop was mostly driven by reductions in output in energy-intensive industries. Over the past decade, the EU's power demand has decreased at an average annual rate of 0.4%. The percentage fall in 2023 was similar compared to 2022, when the EU started grappling with the gas crisis caused by Russia's invasion of Ukraine.



Thanks to a strong rise in clean power (+123 TWh, +7.3%), both coal and gas generation dropped significantly, by 25% (-113 TWh) and 16% (-86 TWh), respectively. This was the largest absolute drop in fossil generation in the EU since at least 2000. Wind saw the highest absolute rise in generation in the EU's history, growing by 50 TWh (+12%). Solar also saw substantial growth of 37 TWh (+18%).

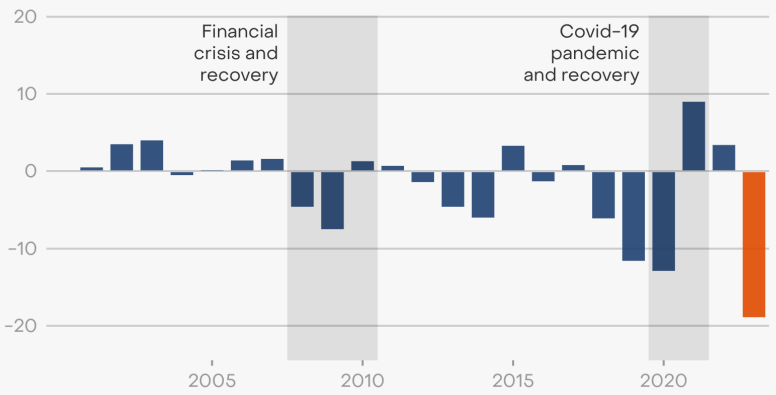
Wind and solar grew most in France (+14 TWh), Germany (+13 TWh), Spain (+12 TWh) and the Netherlands (+12 TWh). As a result, the EU contributed 17% of global growth in solar and wind in 2023.

In 2023, the EU's power sector emissions decreased by 19% (-154 MtCO2) compared to 2022, as a result of a drop in coal and gas generation, a decrease in total power demand and the growth of clean power generation. This was in contrast to the world and the G20, where power sector emissions both increased by 1%.

This is the largest absolute reduction in power sector emissions that the EU has seen since 2000.The year-on-year percentage change in emissions (-19%) was nearly seven times greater than the average emissions decrease between 2013 and 2022 (-2.8%).

EU: Annual changes in power sector emissions

Year-on-year change in emissions from electricity generation (%)



Source: Annual electricity data, Ember

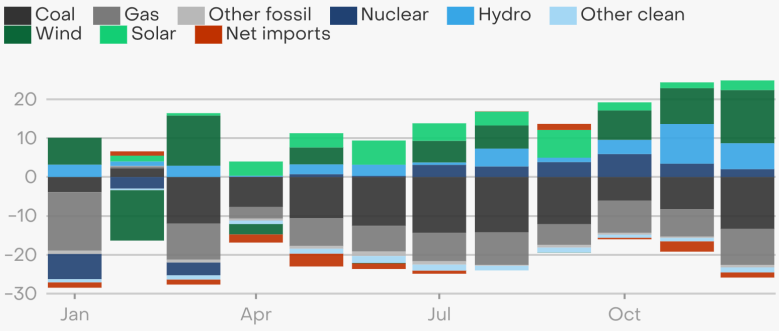
EMBER

Lower electricity demand alongside strong wind and solar growth in the EU led to falls in coal and gas generation throughout 2023. EU fossil generation fell most in December due to good wind and hydro conditions, with a fall of 23 TWh (-24%) compared to December 2022.

The highest increases of solar generation were recorded in the summer, with September (+7.1 TWh) and June (+6.2 TWh) showing the strongest year-on-year increases.

EU: How electricity generation changed during 2023

Year-on-year change (TWh)



Source: Annual electricity data, Ember
'Other clean' includes generation from bioenergy, geothermal, wave and tidal

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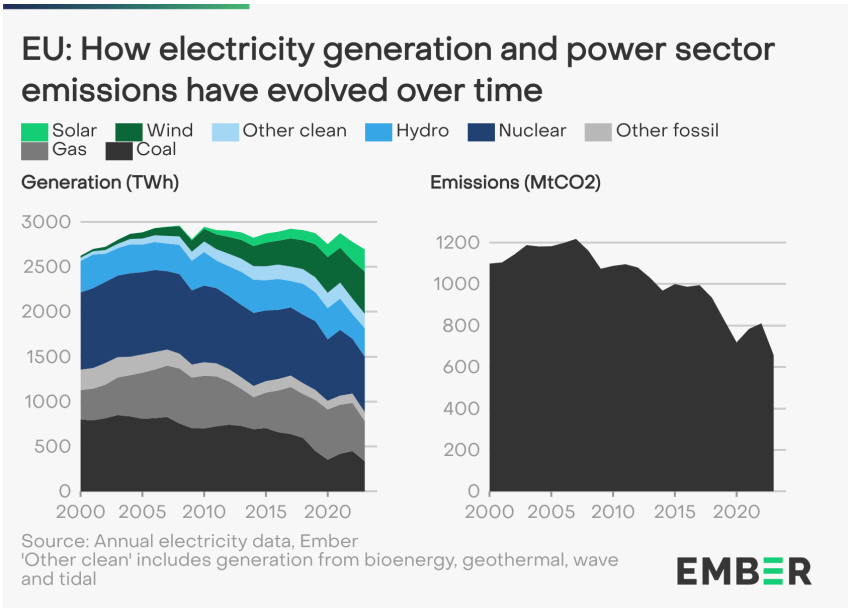
European Union: Long-term trend

Over the last decade, the EU has seen the second-largest decline in coal generation, after the US, driving down emissions

In the early 2000s, electricity demand in the EU was on an upward trend, growing at an average annual rate of 1.5%. However, since the global financial crisis this trend has reversed, to an average decrease of 0.6% annually between 2008 and 2023.

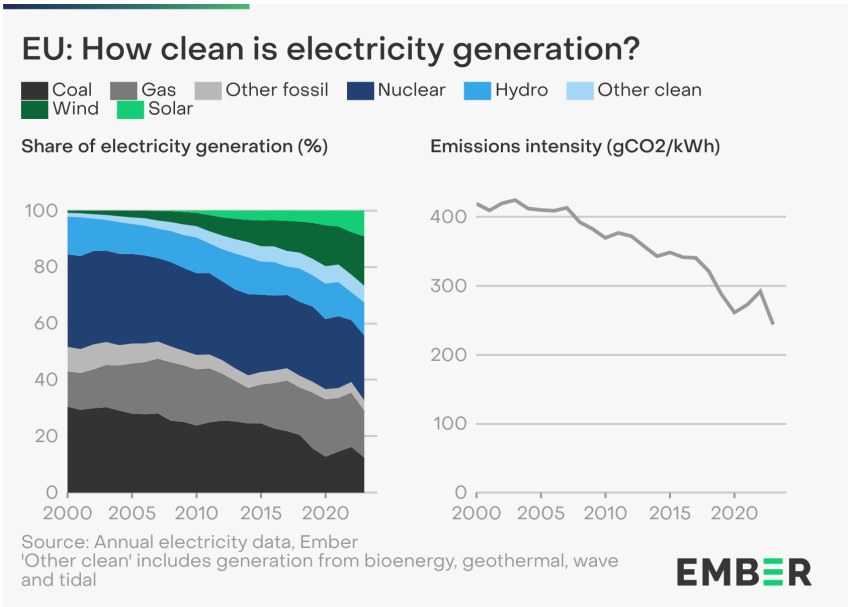
Electricity demand also fell sharply in 2020 due to the Covid-19 crisis. Demand in the EU rebounded to 2019 levels in 2021, but fell by more than 3% in both 2022 and 2023.



In contrast, clean power generation has grown remarkably, up by 43% from 2000 to 2023. Wind and solar are the largest contributors to growth in clean generation, especially in the last ten years. Wind grew from 209 TWh in 2013 to 470 TWh in 2023. Solar tripled from 84 TWh in 2013 to 248 TWh in 2023.

In the last ten years, EU coal generation fell by 393 TWh, the second-largest fall after the US (-906 TWh). EU power sector emissions peaked in 2007 and have been on a downward trajectory ever since, reaching their lowest level in 2023, 46% below the peak.

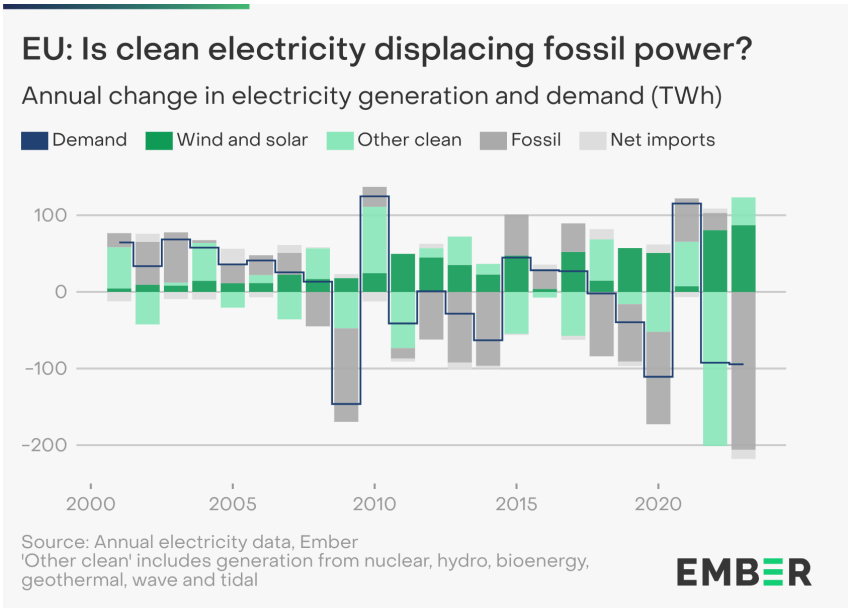
While the EU's share of hydro generation remained steady at 10-14% from 2000 to 2023, the share of nuclear power in the EU mix began to drop gradually after 2010, from 29% in 2010 to 23% in 2023. Wind and solar grew from 0.8% to 27% of the total electricity mix from 2000 to 2023. Fossil generation declined from 52% of the mix in 2000 to 33% in 2023.



The EU's power sector emissions intensity fell to 244 gCO2/kWh in 2023, 58% lower than the level in 2000 (419 gCO2/kWh). The world average saw a decline of 7% in the same period.

The EU's power sector emissions peaked in 2007, as clean growth has consistently been large enough to displace fossil fuels. As a result, the EU's power sector is decarbonising rapidly.

However, this has been achieved mostly in the context of falling electricity demand in the EU. 2008 was the only year with growing electricity demand in the EU where clean electricity growth was higher than demand growth, resulting in a decrease in fossil generation. Apart from 2008, reductions in fossil generation have only occurred in years where demand fell.

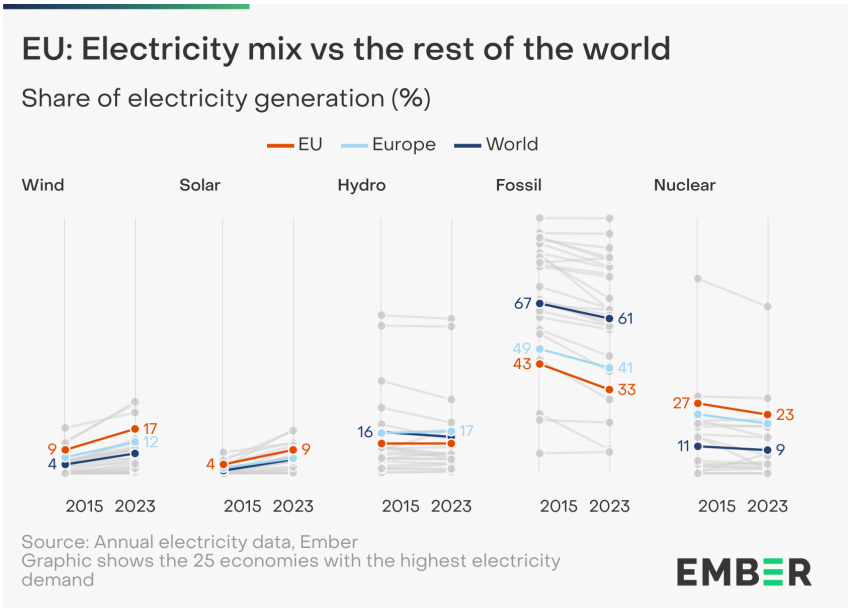


In 2023, the absolute increase in the EU's clean power generation (+123 TWh), together with the demand fall (−94 TWh), was large enough to drive the significant drop in fossil fuel generation (−206 TWh).

In 2022, poor hydro generation as a result of droughts meant fossil generation increased despite record additions of wind and solar. In 2023 generation recovered to its usual level. It is unclear whether hydro generation will stabilise, as extreme weather and conditions worsen.

The EU's electricity grid has become cleaner since the Paris Agreement in 2015. The fossil fuel electricity share dropped by ten percentage points, from 43% to 33% – twice the percentage point decrease in the world's fossil generation.

Wind power is the source that has gained the largest share of EU electricity, growing by nine percentage points from 9.2% in 2015 to 17.5% in 2023.



Solar increased by five percentage points from 3.5% in 2015 to 9.2% in 2023. The increase in wind share was much steeper in the EU compared to the world average, while the solar share increase matched worldwide trends.

European Union: Progress towards net zero

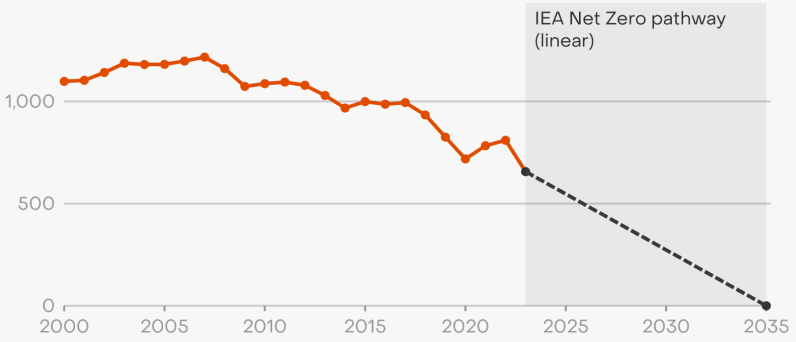
EU wind and solar growth is on track to meet targets

According to the IEA Net Zero Emissions scenario, the EU and other mature economies need to reduce their emissions from the power sector to near-zero by 2035.

Since 2015, the EU has recorded an average annual fall of 43 MtCO2. To align with the IEA NZE scenario, an average annual fall of 54 MtCO2 is needed. If the EU continues to scale up its deployment of clean energy sources at the current rate, particularly wind and solar, this trajectory is within reach.

EU: Power sector emissions and the pathway to net zero

Emissions from electricity generation (MtCO2)



Source: Annual electricity data, Ember, IEA Net Zero (2023)

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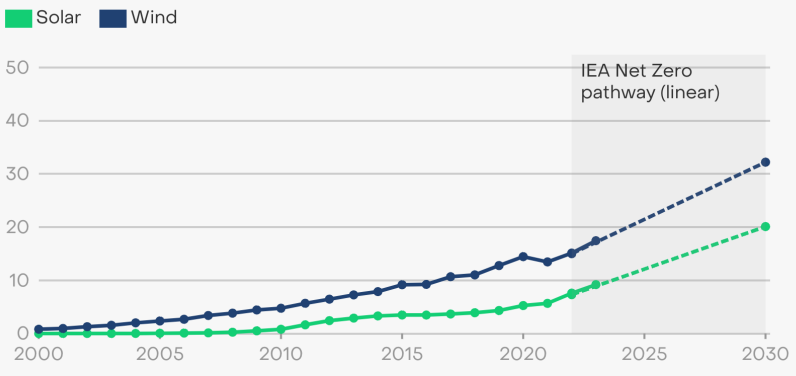
In the IEA NZE scenario, the share of wind and solar increases rapidly throughout the 2020s. Wind would grow to a share of 32% and solar to 20% by 2030. Combined, the two sources would make up more than half of EU electricity generation in 2030.

In recent years, wind and solar generation has increased in line with this trajectory.

EU: Wind and solar electricity generation and the pathway to net zero

Share of electricity generation (%)



Source: Annual electricity data, Ember (solid line); IEA Net Zero (2023) figures for 2022 and 2030 (dotted line)

EMBER

The EU aims to reach 1,236 GW of renewable capacity by 2030 and 72% of renewable share in total generation as proposed in the REPowerEU plan. This target is achievable if annual capacity additions continue on their recent growth trajectory.

5.5 Russia

Key highlights

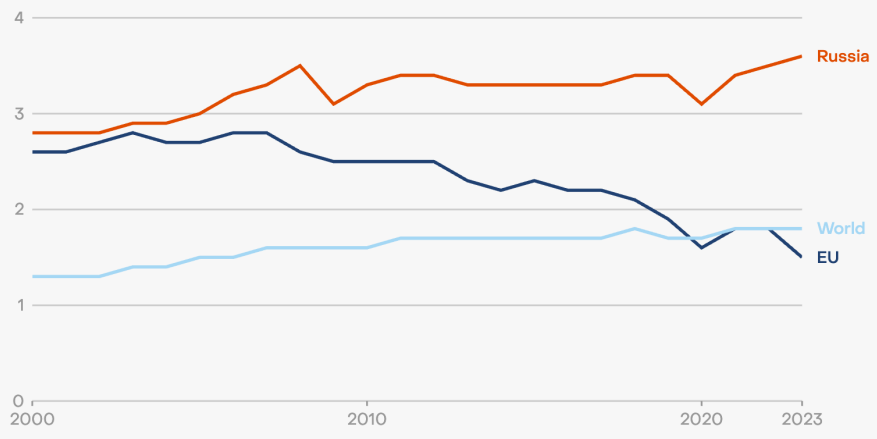
01 Russia's power sector emissions increased 2% in 2023, faster than the global average

02 Per capita emissions in Russia were double the global average in 2023

03 Russia's electricity mix remains nearly unchanged compared to two decades ago

As EU power sector emissions per capita drop below the world average, Russia's continue to grow

Tonnes of CO2 per capita from electricity generation



Source: Annual electricity data, Ember
Emissions are CO2 equivalent

EMBER

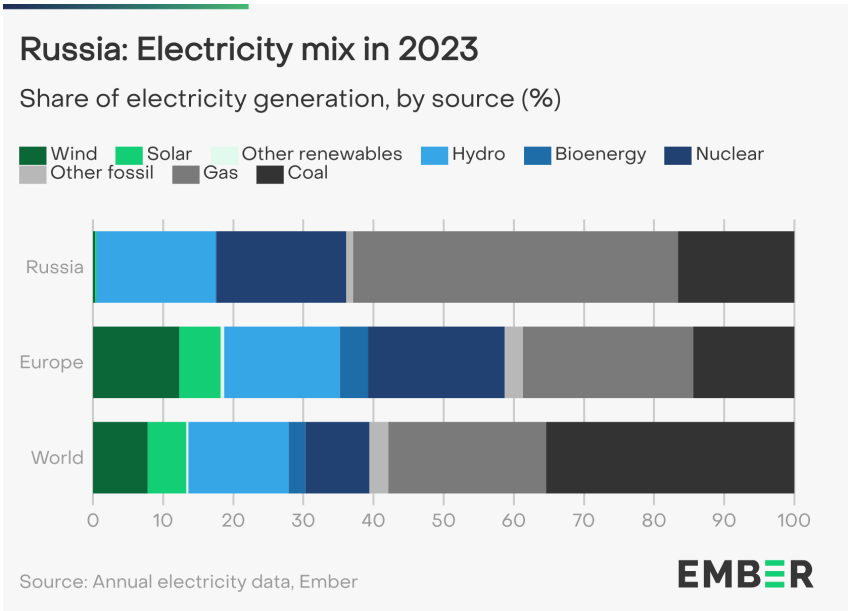
Russia: Current status

Per capita emissions in Russia were double the global average in 2023

In 2023, Russia was the fourth-largest power sector emitter globally with 519 million tonnes of CO2.

Fossil fuels make up 64% of the country's electricity mix. Gas generation is the largest fossil fuel at 46% (545 TWh), followed by coal (17%, 196 TWh).

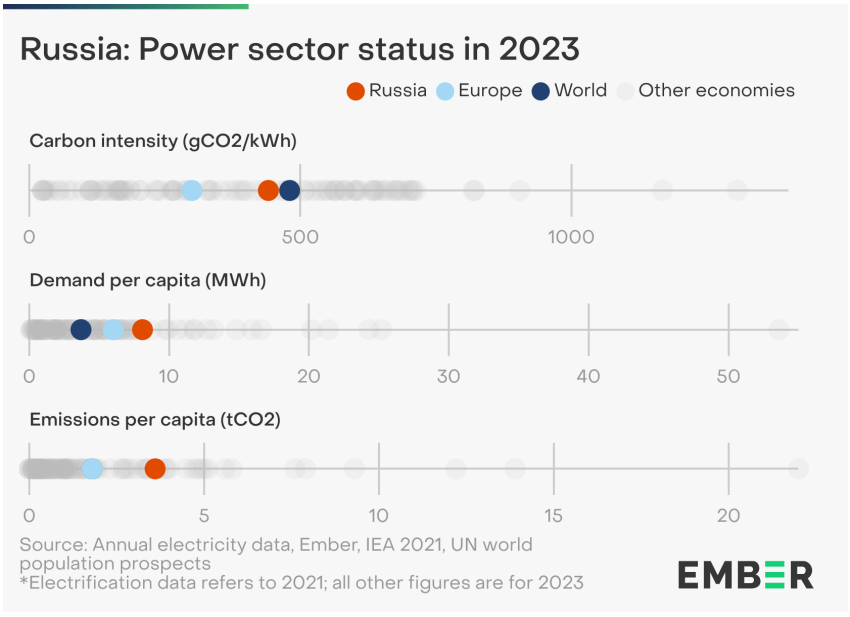
Clean power made up 36% of the mix with 18% (217 TWh) coming from nuclear and 17% (201 TWh) from hydro. Wind and solar remained marginal at just 0.5% (5.4 TWh). In contrast, wind and solar generation in its neighbour, the EU, was 133 times larger (718 TWh).



At 441 gCO2 per kWh, Russia's electricity production is slightly less carbon intensive than the global average (480 gCO2/kWh), but significantly above the average across European countries of 300 gCO2/kWh.

Per capita emissions in Russia were at 3.6 tCO2, double the global average of 1.8 tCO2.

Russia's per capita demand of 8.1 MWh in 2023 was more than double the world average of 3.7 MWh.



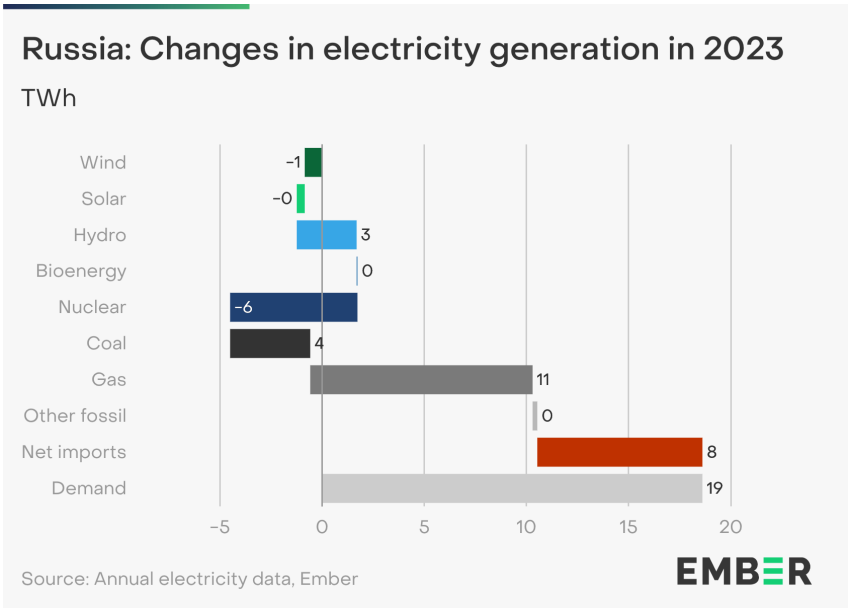
Russia: Change in 2023

Russia's power sector emissions increased 2% in 2023, faster than the global average of 1%

Changes to Russia's power sector were minimal in 2023. Power demand grew by 19 TWh which constituted a moderate 1.6% increase.

Gas generation met most of this increase, growing 11 TWh (+2%) compared to 2022. A decrease in exports (increase in net imports) met most of the additional electricity production required.

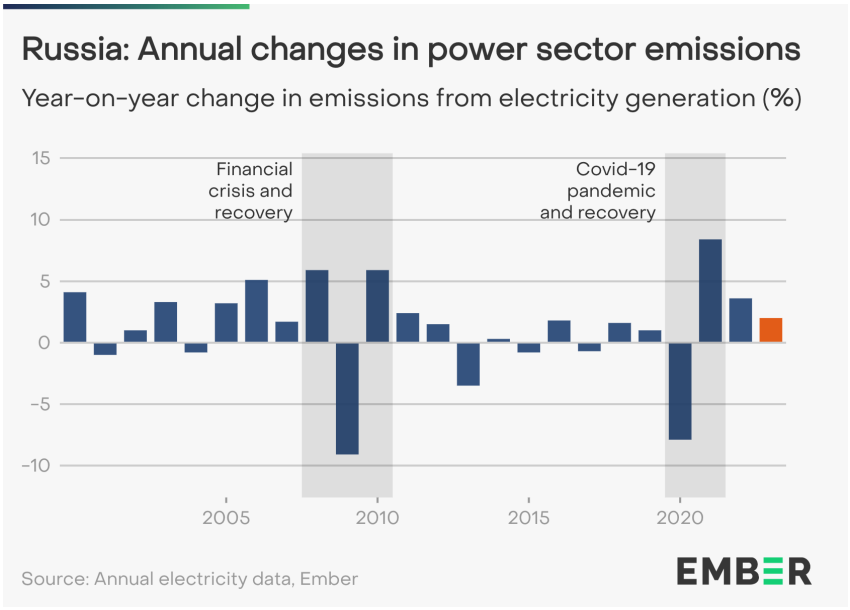
Nuclear saw a small decline of 6.2 TWh (−2.8%), while coal and hydro both grew by 3.9 TWh and 2.9 TWh respectively.



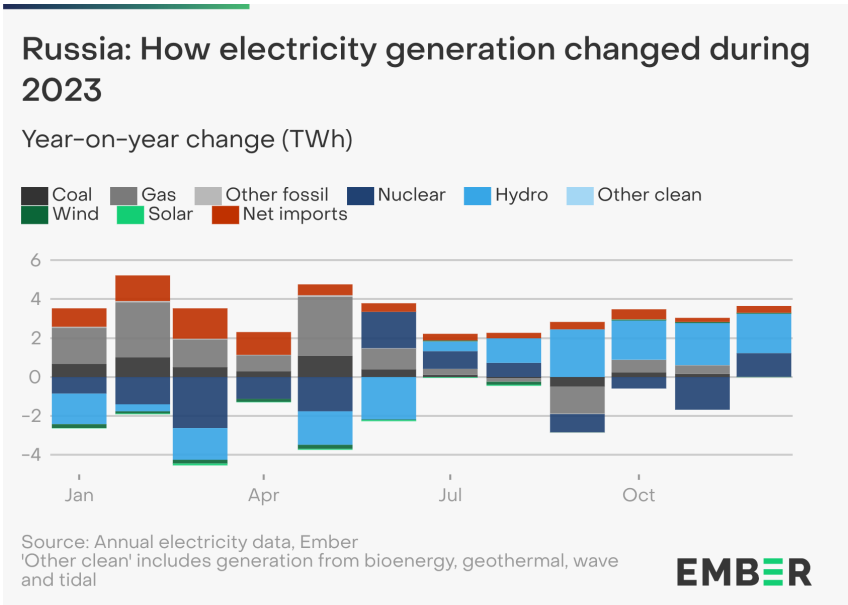
Wind and solar combined saw a small reduction of 1.2 TWh – due to poor weather conditions – from an already low baseline of just 6.6 TWh in 2022.

Russia's power sector emissions increased by 2% in 2023 as a result of the moderate rise in demand which was predominantly met by coal and gas generation.

The 2% increase in 2023 marks the third consecutive year of growing emissions, in contrast to Russia's neighbour, the EU, which recorded an unprecedented emissions drop of 19%. Russia's power sector emissions rose faster than the global increase of 1%.



Despite generation changes over 2022 remaining small throughout 2023, there is a clear pattern between the first and second half of the year. In the first half, lower output from nuclear and hydro plants in comparison to 2022 led to stronger growth in coal and gas generation as well as lower exports (higher net imports). For example, May showed a 1.8 TWh drop in nuclear and a 1.7 TWh drop in hydro generation. This was made up by a 1.1 TWh rise in coal, a reduction in exports and a 3 TWh rise in gas, the largest year-on-year gas increase of any month in 2023.



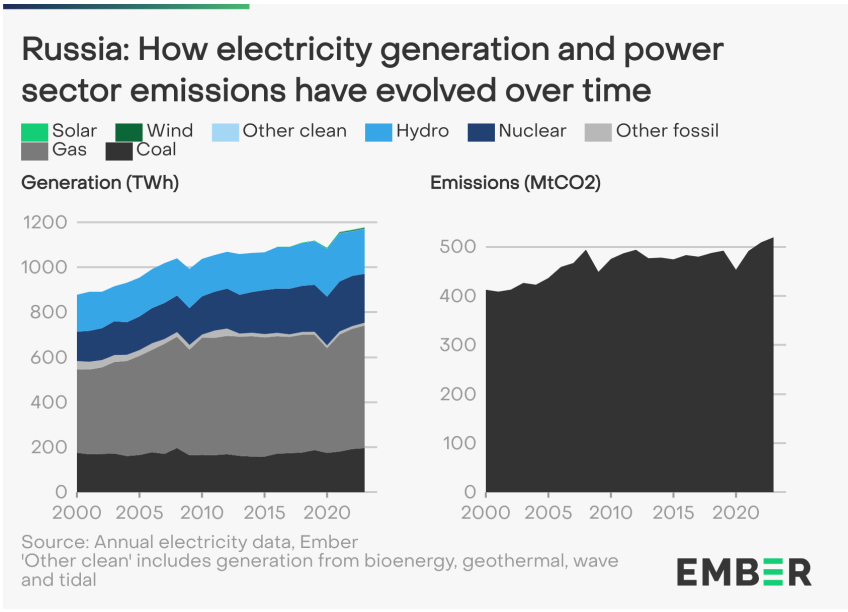
The second half of the year saw a recovery in hydro conditions compared to 2022, with generation growing consistently year-on-year from July to December.

Russia: Long-term trend

Russia's electricity mix remains nearly unchanged compared to two decades ago

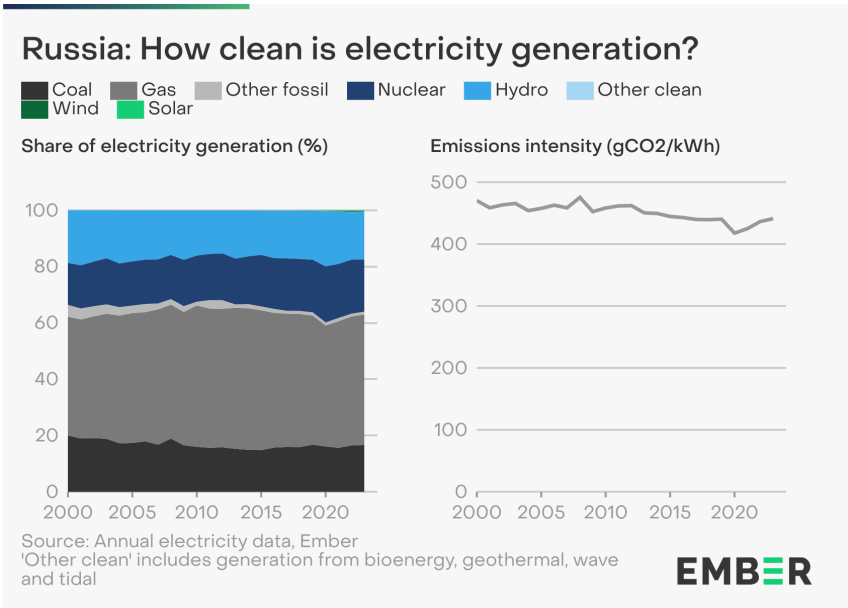
Electricity demand in Russia has been growing over the last two decades with short interruptions from the 2008 financial crisis and the 2020 Covid-19 pandemic. Electricity demand in 2023 (1,169 TWh) was 35% higher compared to 2000 (864 TWh).

Similarly, fossil generation, predominantly from gas, has increased 29% from 2000 to 2023. The increase of 170 TWh from 583 TWh to 753 TWh met more than half (56%) of Russia's increase in electricity demand over that period. The rest was met by a moderate increase in hydro and nuclear generation.



As a result of the increase in fossil generation, emissions increased 26%, from 413 MtCO2 in 2000 to 519 MtCO2 in 2023.

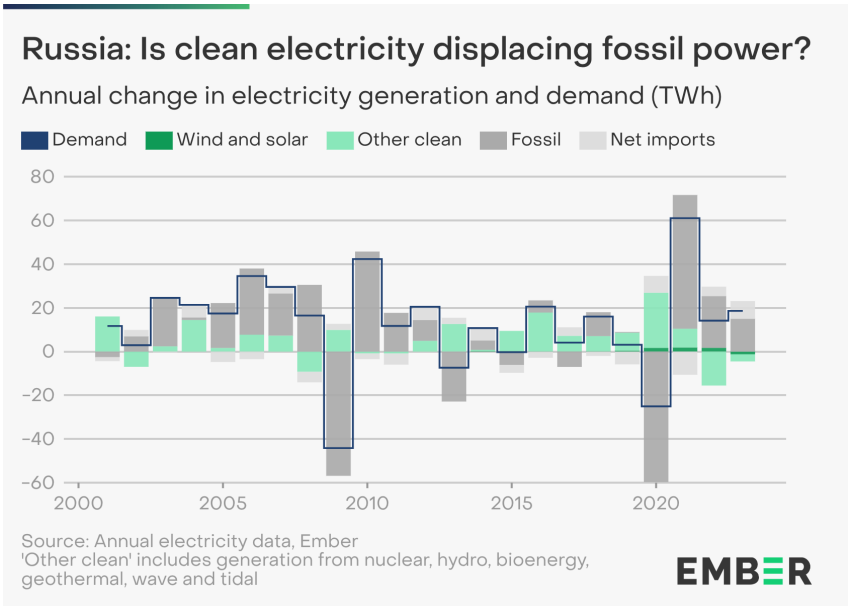
Russia's electricity mix remains nearly unchanged compared to two decades ago. As a result, the emissions intensity of electricity generation in 2023 of 441 gCO2/kWh was only 6.2% lower than it was in 2000 (470 gCO2/kWh). In contrast, the EU saw its emissions intensity fall by 42% to 244 gCO2/kWh over the same period.



Russia's continued reliance on fossil power is partially explained by the availability of domestic coal and gas resources. However, Russia is not only lagging behind the EU. Fossil fuel-rich nations in the Middle East, such as the United Arab Emirates and Saudi Arabia, have started to diversify their electricity mixes.

Clean electricity additions are dominated by changes in hydro and nuclear generation. Growing electricity demand is mostly met by additions in fossil generation. Conversely, large drops in fossil generation are generally a result of falls in electricity demand.

The last significant fall in fossil generation occurred as a result of the demand reduction during the Covid-19 pandemic in 2020.

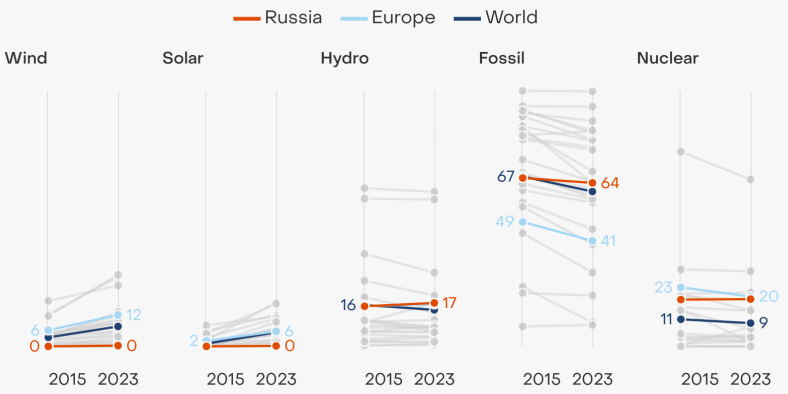


Russia's electricity mix has remained largely unchanged since the Paris Agreement in 2015. The share of fossil generation has dropped only two percentage points since 2015, from 66% to 64%, despite Russia announcing an economy-wide 70% emissions reduction target by 2030 compared to 1990 levels.

Other sources have also remained at largely the same levels as 2015. Crucially, Russia's adoption of wind and solar lags behind the world and its neighbours. Wind and solar still only made up 0.3% and 0.2% respectively in 2023. Since 2015, Europe as a whole saw the share of wind rise from 6.3% to 12.3% and the share of solar rise from 2.2% to 5.9%, with similar trends at the global level.

Russia: Electricity mix vs the rest of the world

Share of electricity generation (%)



Source: Annual electricity data, Ember
Graphic shows the 25 economies with the highest electricity demand

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Russia: Progress towards net zero

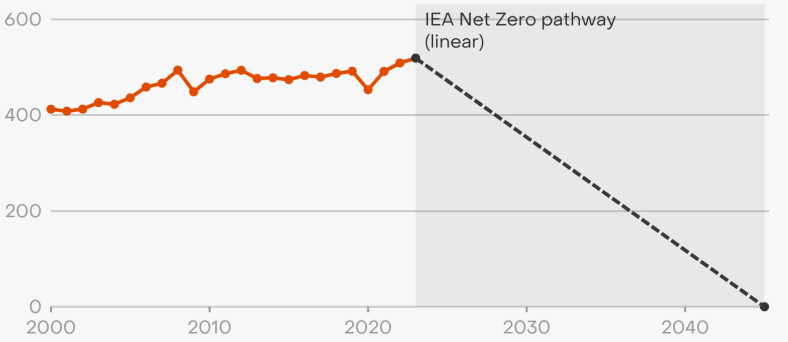
Russia's power sector emissions are rising when they should be falling

According to the IEA Net Zero Emissions scenario, Russia needs to reduce its emissions from the power sector to near-zero by 2045.

Between 2016 and 2023, Russia's power sector emissions have been rising by an average of 5.6 MtCO2 per year. This trend would need to reverse to an annual fall of 24 MtCO2 to align with the IEA NZE scenario. With growth in clean sources, and particularly wind and solar lagging behind other countries, Russia is currently at risk of missing climate targets by a wide margin if it does not accelerate the deployment of these technologies.

Russia: Power sector emissions and the pathway to net zero

Emissions from electricity generation (MtCO2)



Source: Annual electricity data, Ember, IEA Net Zero (2023)

EMBER

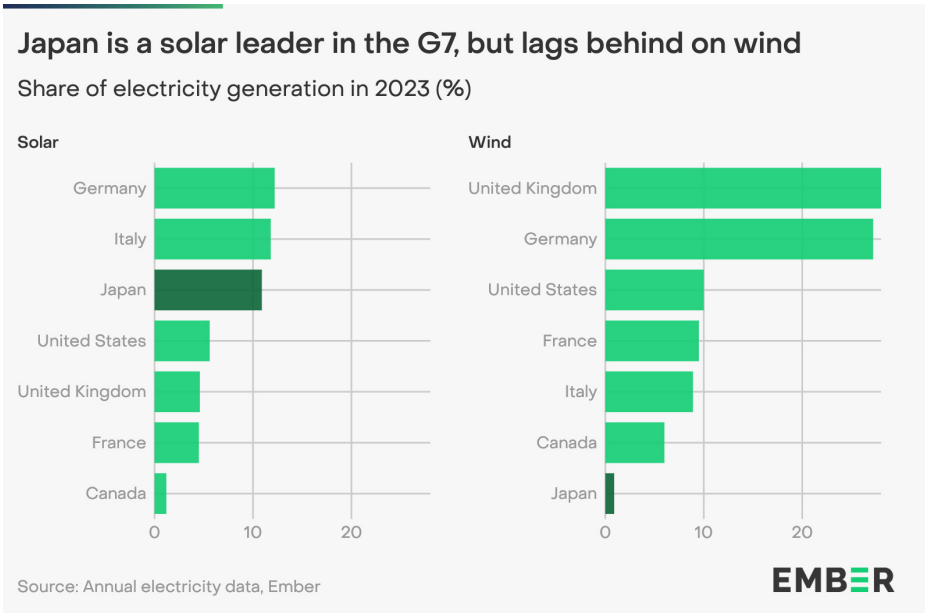
5.6 Japan

Key highlights

01 Solar generated 11% of Japan's electricity in 2023, twice the global average, but wind generation remained low at just 0.9% of the mix

02 Japan's power sector emissions fell by 7.3% in 2023, just below the G7 average of 7.6%

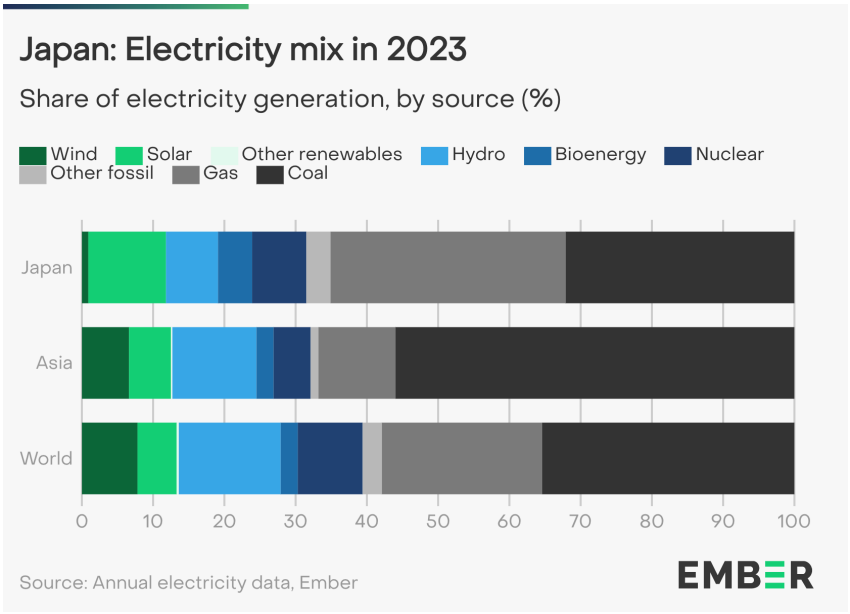
03 Japan's emissions intensity of electricity was 14% higher in 2023 than in 2000, whereas all other G7 countries saw declines



Japan: Current status

Solar made up 11% of Japan's electricity in 2023, twice the global average, but wind's share of the mix remained low at just 0.9%

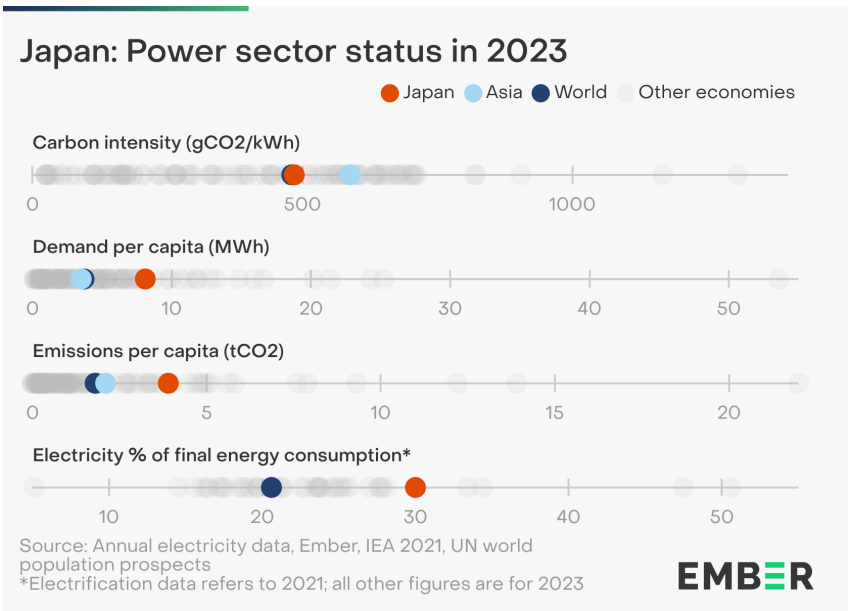
In 2023, Japan was the sixth largest power sector emitter globally, emitting 491 million tonnes of CO2 from electricity generation, behind China, the US, India, the EU and Russia. Japan's high emissions are mostly driven by its reliance on fossil fuels. It has the highest share of fossil power generation among G7 countries (69%). This is also eight percentage points higher than the global fossil share in electricity generation (61%). Coal (32%) and gas (33%) are both major sources of power generation in Japan.



Clean electricity made up less than a third of Japan's electricity mix (31%) in 2023, eight percentage points lower than the world's clean electricity share of 39% and below the average in Asia (32%).

Most of Japan's clean electricity growth came from solar in the last decade, which reached a record share of 11% in 2023, placing Japan ninth globally for solar share and twice the global average of 5.5%. Wind generation remained low at just 0.9% of the mix, despite significant potential. Nuclear generated 7.6% of Japan's electricity in 2023 and hydro generated 7.3%.

In 2023, the carbon intensity of Japan's power sector was 485 gCO2 per kWh, similar to the global average of 480 gCO2/kWh. However, per capita emissions (3.9 tCO2) were more than twice the world average (1.8 tCO2). This is because Japan's per capita demand for electricity was 8.1 MWh, more than twice the per capita demand across Asia and globally.

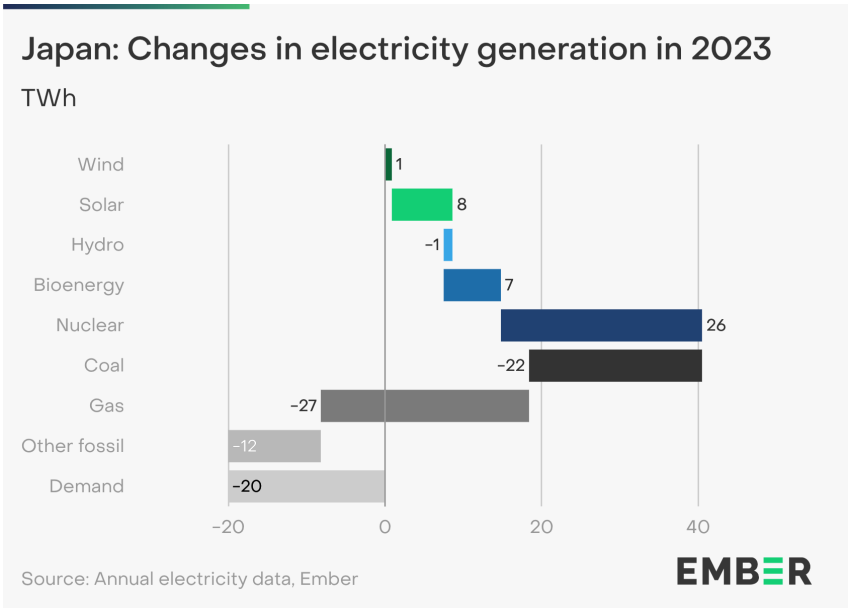


Electricity provided 30% of Japan's final energy consumption in 2021, significantly above the world average of 21%. This is expected to increase further as its economy electrifies.

Japan: Change in 2023

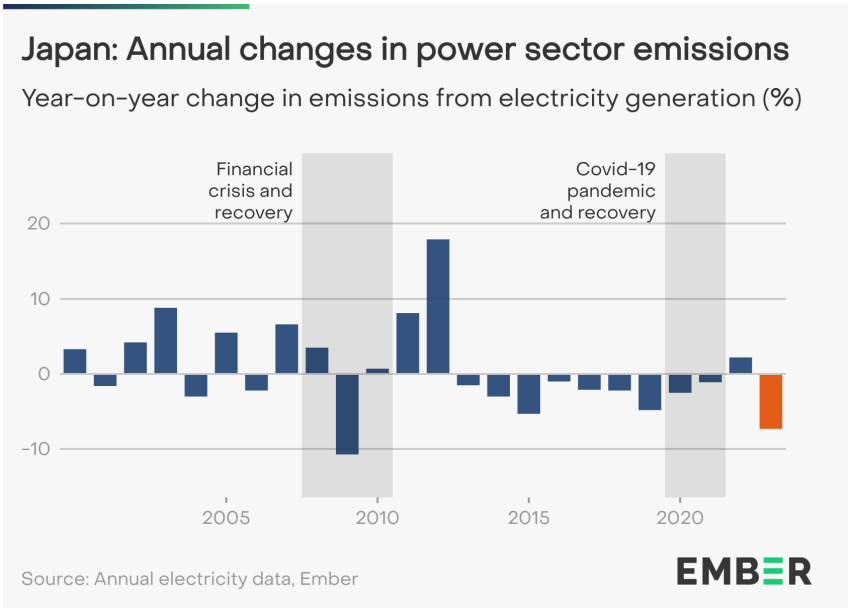
Japan's power sector emissions fell by 7.3% in 2023, just below the G7 average of 7.6%

In 2023, Japan's power demand decreased by 1.9% (−20 TWh) after it grew for two consecutive years in 2021 and 2022. The decrease in demand, together with a rise in clean power, led to falls in both gas (−27 TWh, −7.4%) and coal generation (−22 TWh, −6.3%). The fall in fossil fuel generation in 2023 (−61 TWh, −8%) was Japan's largest absolute drop since 2009.



In recent years, Japan's nuclear phase-out policy has been reversed by the 'Green Transformation' (GX) policy, which came into force in 2023. The GX policy seeks to increase the use of clean power, including the lifetime extension of nuclear power plants. As some of the oldest nuclear reactors restarted their operations in 2023, Japan's nuclear generation grew by 50% (+26 TWh). Nuclear power generated 7.6% of total electricity, up 2.6 percentage points from 2022.

Japan's power sector emissions in 2023 were 491 MtCO2, a decrease of 7.3% (−39 MtCO2) compared to 2022. The fall was a result of the drop in coal and gas use, as clean power generation increased and demand fell. In contrast, the world saw a rise in power sector emissions of 1%. In the G7, power sector emissions fell 7.6% in 2023.

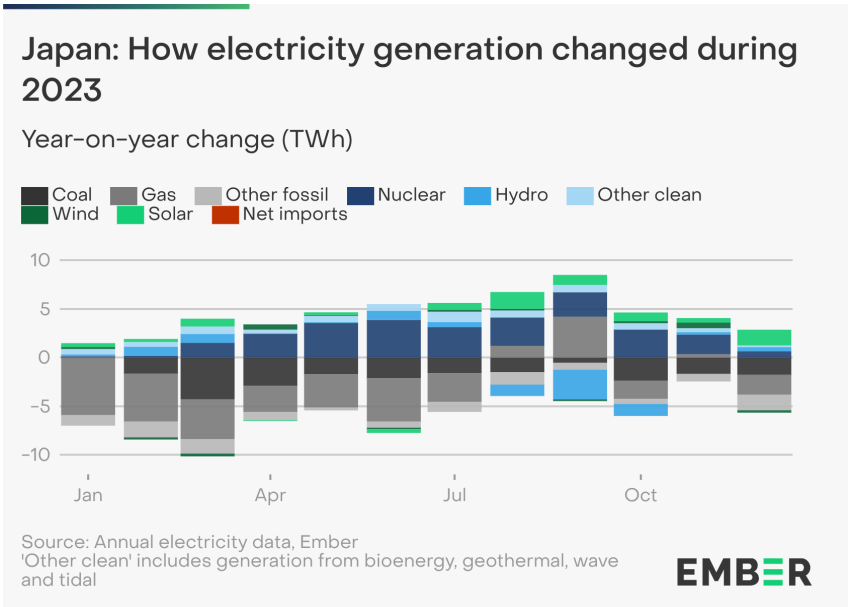


In 2023, Japan achieved the largest absolute and percentage reductions in emissions in the past decade. The year-on-year percentage fall in emissions (-7.3%) was significantly higher than the average annual emissions decrease over the last decade (-2.1%).

Japan's fossil generation saw the largest falls in the first half of the year. The fourth quarter saw smaller decreases in fossil generation compared to 2022.

Year-on-year, coal generation fell every month except January, while nuclear generation increased throughout the year due to higher reactor availability.

Solar generation increased the most from July to October, although overall gains were modest.

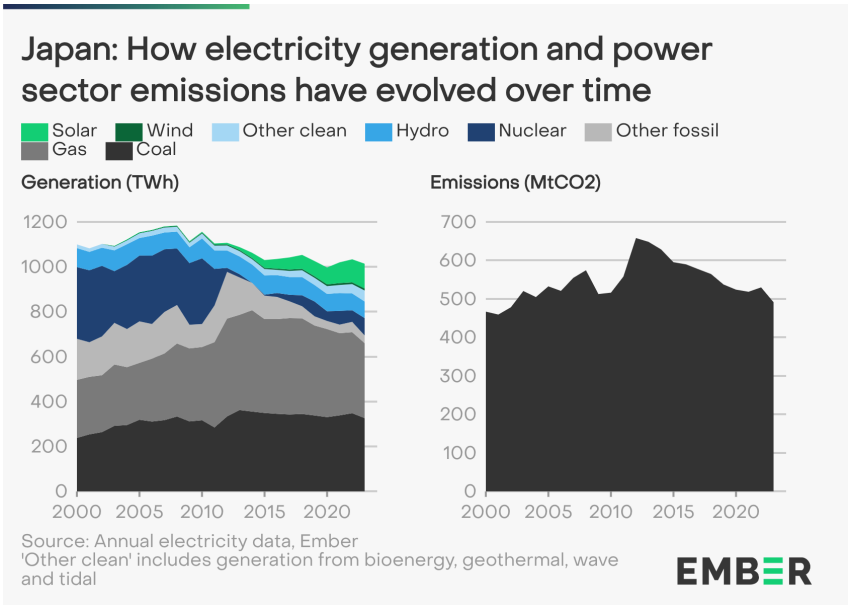


Japan: Long-term trend

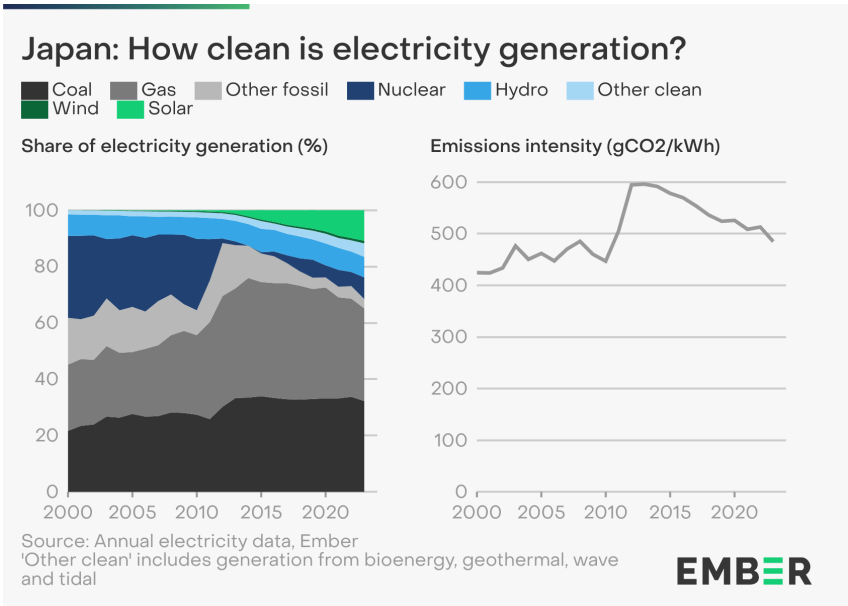
Japan's emissions intensity of electricity was 14% higher in 2023 than in 2000, whereas all other G7 countries saw declines

Japan's power sector emissions peaked in 2012. 2011 and 2012 had seen a rapid increase in emissions after the Fukushima nuclear disaster and the subsequent decision to shut down nuclear plants, causing a steep rise in fossil fuel generation to fill the power deficit. In recent years, nuclear generation has increased again.

The growth in solar in the 2010s replaced some of the fall in nuclear power. However, Japan has yet to tap into its wind power potential, with generation remaining stagnant at less than 1% over the past decade.



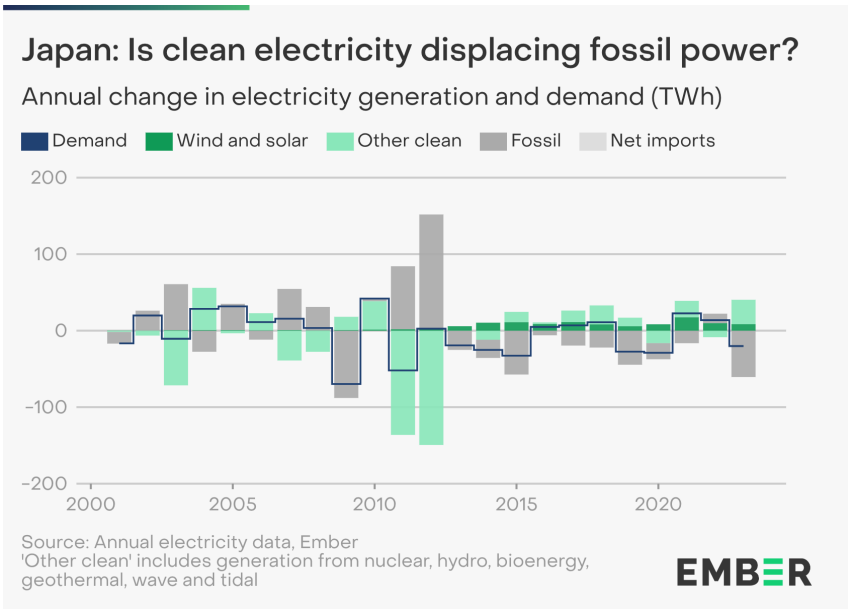
At the start of this century, Japan produced 38% of its electricity from clean power sources, mostly from nuclear (29%). Today, Japan's clean power accounts for 31% of total generation. The drop in clean power share was mostly driven by the halt in nuclear generation after Fukushima in 2011 and slow growth in renewables except for solar.



The fall in the share of clean power sources led to a sharp increase in the emissions intensity of Japan's power sector during 2011–2012. As Japan expanded solar and reintroduced nuclear power, the emissions intensity of electricity has been declining steadily since its peak in 2012. Nonetheless, it was 14% higher in 2023 than in 2000, whereas all other G7 countries saw emissions intensity decline during this period.

In 2023, the absolute increase in clean power (+40 TWh), together with the demand fall (–20 TWh), was large enough to drive a significant drop in fossil fuel generation (–61 TWh).

Solar has been rising fast in Japan, having grown at an average annual rate of 24% in the past 10 years. The high growth was driven by the strengthening of subsidies for solar (feed-in-tariff and feed-in-premiums) after Fukushima.



However, as Japan gradually phased out subsidies, the rate of solar growth has slowed in recent years, down to 7.6% in 2023. Meanwhile, wind has shown almost no growth.

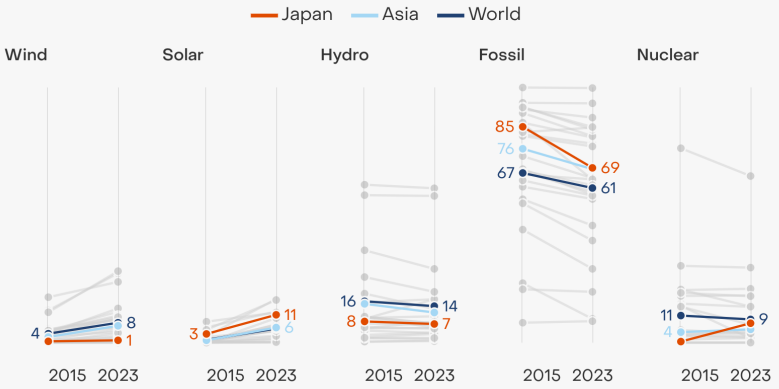
An acceleration of clean electricity growth is needed to further displace fossil generation from the electricity mix. Electrification of transport and industry is also expected to result in increased demand. This adds additional pressure to clean generation growth to meet and exceed new demand and drive down emissions.

Japan's power grid has become cleaner since the Paris Agreement in 2015. The fossil fuel share in electricity dropped by 16 percentage points, from 85% to 69%. This is faster than the percentage point reduction globally.

Solar and nuclear power showed the highest increase in share among individual generation sources. Solar grew from 3% in 2015 to 11% in 2023. As nuclear power stations resumed their operations, the share of nuclear power increased from just 0.4% in 2015 to 7.6% in 2023. The increase in the share of solar and nuclear power is faster than in Asia or the world. However, wind power has shown no growth while the world wind share increased from 3.5% in 2015 to 7.8% in 2023.

Japan: Electricity mix vs the rest of the world

Share of electricity generation (%)



Source: Annual electricity data, Ember
Graphic shows the 25 economies with the highest electricity demand

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Japan: Progress towards net zero

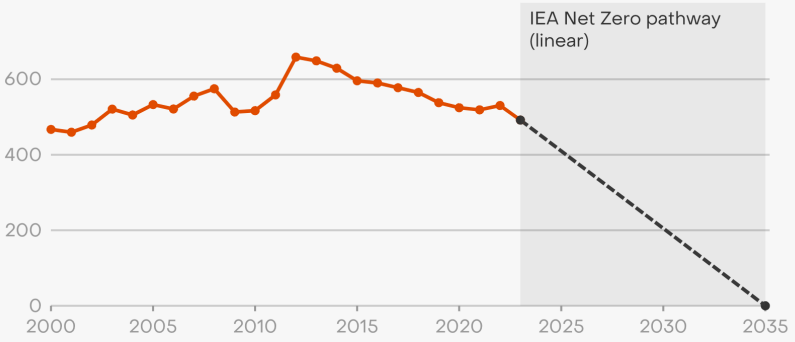
Annual emissions falls need to triple to achieve a clean power sector by 2035

Japan's power sector emissions would need to reach net zero by 2035 to align with the [IEA Net Zero Emissions scenario.]

After peaking in 2012, Japan's power sector emissions have declined by an average of 15 MtCO2 per year. To be on track with the IEA NZE scenario, annual emissions falls would have to triple (-41 MtCO2 per year) until 2035. Despite Japan recording its second-largest fall in power sector emissions in the last two decades in 2023, the decline of 39 MtCO2 was still below the levels needed to reach net zero.

Japan: Power sector emissions and the pathway to net zero

Emissions from electricity generation (MtCO2)



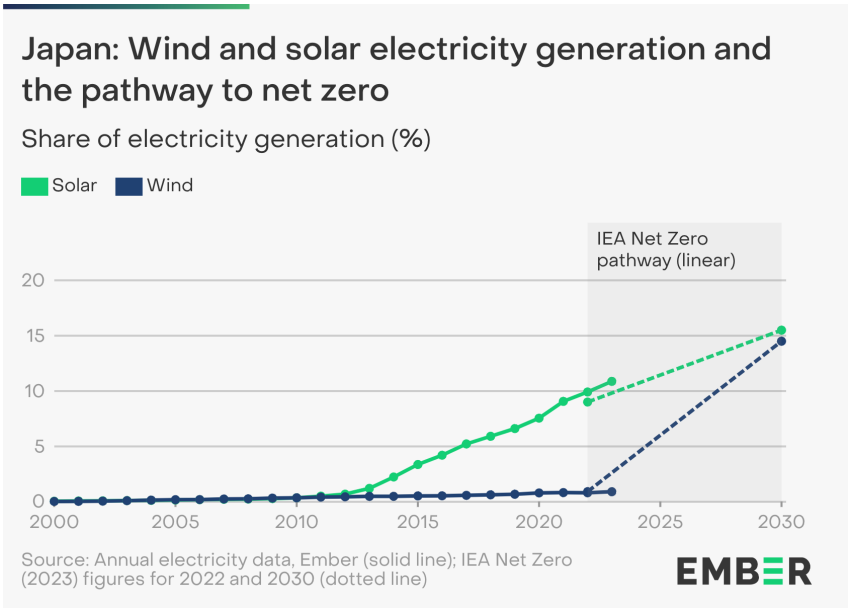
Source: Annual electricity data, Ember, IEA Net Zero (2023)

EMBER

Japan, along with the G7, committed to secure a predominantly clean power system by 2035, but has yet to map out a clear path for the goal.

Japan's wind and solar share needs to increase significantly if the country is to reach net zero emissions by 2035. In the IEA NZE scenario, Japan's share of solar generation is expected to grow to 16% by 2030, up from 11% in 2023. This would require solar growth to continue its current trend.

Wind generation would also see a more rapid transformation, with the share climbing to 15%, up from just 0.9% in 2023.



According to Ember's 2030 Global Renewable Target Tracker, Japan is only targeting a 21% solar and wind share of generation by 2030, which falls far short of the 30% in the IEA NZE scenario. A renewed nuclear programme presents a possible alternative path to clean power.

Conclusion

A clean energy future comes into view

2023 confirmed that the transition to clean electricity is irrevocable

As we have shown in this Global Electricity Review, the advance of renewable generation, spearheaded by wind and solar, has probably already caused fossil fuel use in the power sector to peak.

This is good news for the planet, as building a clean electricity system worldwide is an essential step towards mitigating the worst impacts of global heating. Combined with rapid electrification of transport, heating and industry, the world can move to a pathway aligned with the 1.5C climate target agreed by all governments at the 2015 Paris summit.

The continuing cost reductions for solar and wind power, battery storage, EVs and other key technologies show that a clean energy future is also a cheaper energy future. The supply and price shocks resulting from Russia's invasion of Ukraine, and the OPEC+ supply cuts that have kept international oil prices high, illustrate the wider risks of continued reliance on fossil fuels. A rapid transition to a world running on clean energy would bring added benefits in areas such as air quality, jobs and freedom from import dependency, while reducing the risk of stranded fossil fuel assets.

Government targets, industry forecasts and economic logic all indicate that the growth of wind and solar generation is likely to continue accelerating. G7 and IEA member governments have pledged to virtually decarbonise their electricity systems by 2035. The IEA forecasts that renewable energy will expand quickly enough in China to cut coal consumption by 3% in 2024. Delivering the pledge made at COP28 to triple renewables capacity by 2030 would mean renewables producing 60% of our electricity within seven years. The implications for fossil fuel use are stark, as this would eliminate more than one-third of their demand in the power sector by 2030, and make an impact beyond the power sector as well.

However, the speed of global progress on decarbonising the power system is not certain, and challenges remain. Nuclear and hydro generation are not growing at the rates envisaged in many 1.5C-compatible scenarios. The pace of energy efficiency improvements across the world needs to double by 2030, along the lines agreed at

COP28, to unlock the full fossil-fuel-shrinking potential of economy-wide electrification. Buildout of grid infrastructure and the system flexibility necessary to support high wind and solar capacities lags behind deployment of wind and solar, creating bottlenecks. Many developing countries face high financing costs for renewable electricity projects, and need financial support in order to take advantage of the opportunities that a faster rollout would bring.

Nevertheless, the big takeaway from 2023 is that solar and wind power are, right now, reshaping the global energy system, signalling the beginning of the end for the fossil fuel era.

From now on, increasing electricity demand will be met principally by the accelerating growth of wind and solar generation. The transition is at different stages in different countries, but it is happening in every region of the world. Societies will continue to develop on the back of increasing electricity use, but development will be powered by renewables instead, as the need for coal and gas eventually shrinks close to zero.

From 2023 onwards, thanks to the rise of wind and solar generation and clean electrification, the future of energy looks very different indeed. The year will likely go down in history as the pivot point in the world's shift from fossil fuels to clean electricity.

Supporting Materials: Methodology

Generation, imports and demand

Annual data from 2000 to 2022 is gross generation, taken primarily from the Energy Institute Statistical Review of World Energy, the Energy Information Administration (EIA), Eurostat and IRENA. 2023 data is an estimate of gross generation, based on generation gathered from monthly data. This estimate is calculated by applying absolute changes in monthly generation to the most recent annual baseline.

Net imports from 1990 to 2022 are taken from the EIA and Eurostat, with recent data estimated in the same manner as generation. Demand is calculated as the sum of generation and net imports, and where possible validated against published direct demand figures. Because it uses gross generation and does not include transmission and distribution losses, it will tend to be higher than end-user demand.

Monthly data is gathered for 80 countries from 70 sources, including national transmission system operators and statistical agencies, as well as data aggregators such as ENTSO-E. In some cases data is published on a monthly lag; here we have estimated recent months based on our generation model. These cases are flagged in the dataset.

Monthly published data is often reported provisionally, and is far from perfect. Every effort has been made to ensure accuracy, and where possible we compare multiple sources to confirm their agreement. A full detailed methodology can be found here.

Emissions

Ember's calculations for emissions are continually improving, but may be conservative or otherwise uncertain in ways we describe below. These figures aim to include full lifecycle emissions including upstream methane, supply chain and manufacturing emissions, and include all gases, converted into CO2 equivalent over a 100-year timescale.

Emissions can vary over time as power station efficiency changes, and as different fuel qualities are used. Therefore, we report emissions values by fuel type, and emissions intensity by country. These values are calculated by multiplying our generation numbers by emissions factors taken from a number of sources, detailed below. We aim where possible to capture variance between geographies and over time in emissions intensity from different fuels. We have recently updated this approach and are actively working to improve it. If you have any comments or suggestions for improvement, please email data@ember-climate.org.

Our sources and methodology for different fuels are described below. All factors we use are for net generation. Where we report gross generation, we adjust our factors by 6% for thermal fuel sources and 1% for others, following a standard conversion approach.

Coal

Data is taken from Gibon et al. 2022 (UNECE) and the Global Energy Monitor Coal Plant Tracker (GEM). UNECE provides lifecycle emissions factors for different fuel types for the year 2020 for each REMIND region. UNECE reports values for different technologies using bituminous coal. We derive factors for different coal grades based on IPCC 2005 direct combustion emissions factors. Using country-level annual technology and coal grade mixes from GEM capacity data, we estimate blended emissions factors per country per year for coal.

Gas

Country-level factors are taken from Jordaan et al. 2022, and are for generation for the year 2017. Two sets of factors are provided; we use the ones that attempt to account for combined heat and power. For smaller countries where no data is available, a world average number is used.

Nuclear and wind

We use region-level data from UNECE.

Bioenergy, hydro, solar, other renewables and other fossil fuels

We use data from the IPCC AR5 WG3 Annex III (2014). These are global estimates for the year 2020; we use midpoint lifecycle factors. These are:

- Bioenergy: 230 g/kWh
- Hydro: 24 g/kWh
- Solar: 48 g/kWh
- Other renewables: 38/kWh
- Other fossil: 700/kWh

Caveats

This approach attempts to account for some geographical and temporal variance in emissions factors. It is a work in progress, and figures may differ from reality for a number of reasons. Some of these are listed below:

- **Coal**: UNECE base factors are for coal plants in the year 2020. They do not capture operational efficiency losses associated with older plants or intra-technology efficiency differences. Finally, we make assumptions to derive factors for coal grades other than lignite, including identical combustion efficiencies and upstream emissions per MWh generated.

- **Gas**: Our gas factors are specific to the year 2017, so do not account for temporal variations in plant efficiencies or methane leakage rates. The methodology in Jordaan et al. 2022 also prefers to underestimate methane emissions where there is doubt. In general there is very significant uncertainty around methane emissions rates, even in countries that prioritise collecting this data. Some authors believe that emissions rates are significantly higher than assumed in our factors.

- **Time horizon**: Upstream methane emissions for gas and coal generation are calculated on a long-term basis assuming methane is 21 times as potent as CO2. However, the short-term impact of methane is actually four times higher, at 86 times the potency of CO2. See this page for more information.

- **Solar and wind**: Recent efficiency improvements have seen wind and solar emissions intensity drop, as energy output has increased relative to emissions from manufacturing. Our numbers may therefore be higher than reality. We also do not currently capture geographical variation in emissions intensity within REMIND regions; this can be significant, as countries with lower annual solar capacity factors will have proportionately higher lifecycle emissions.

- **Bioenergy**: Our value is very likely to be a significant underestimate of the actual emissions caused by bioenergy generation. The emissions intensity of bioenergy is highly dependent on the feedstock, how it was sourced, and what would have happened had the feedstock not been burnt for energy. The IPCC figure we use is for dedicated energy crops and crop residues, rather than the much more commonly used woody or forest biomass, which has been shown to carry a greater risk of high-carbon outcomes. In certain cases, bioenergy can have a carbon intensity significantly greater than coal. Bioenergy is also frequently cofired with fossil fuels. We have disaggregated these wherever possible, but in certain cases recorded bioenergy generation may include some co-firing. In these circumstances, actual emissions will be higher than we estimate.

- **Hydro and other renewables**: Hydropower emissions are generally very low, but can vary based on emissions during construction and biogenic emissions, and so in a small number of cases can be much higher than our value. Similarly, other renewable sources such as geothermal can in rare outlier cases have high emissions.

- **Gross and net generation**: In the EU, we report net generation for monthly data and gross generation for yearly data. For gross generation, we perform the conversion described above, which may introduce some error.

- **Combined heat and power (CHP)**: In many cases, thermal power plants produce both heat and electricity. Our coal factors are based on only the electricity produced by such plants, ignoring heat. It may not therefore be fair for our dataset to include all emissions attributed to co-firing plants, which actually have greater efficiency than reported when considering total useful energy output. Our gas factors account for CHP.

2024 generation and demand forecast

The 2024 demand and generation forecast is based on the following assumptions:

- Demand: 3.3% increase from 2023, based on IEA projections.

- Solar: BNEF regional 2024 capacity addition projections (mid-case scenario). Regional average load factors are used based on 5-year average of weather and timing of additions. Prediction range is based on Monte Carlo analysis varying capacity deployment and panel performance.
- Wind: Global capacity additions of 115 GW, from GWEC. Assumes 27% average global capacity factor.
- Hydropower: Assumes capacity factor recovers halfway towards pre-2021 global average.
- Nuclear: 2024 estimates calculated for the US based on EIA data, and for China based on capacity additions. Rest of world based on expected capacity additions.
- Other renewables: Follows historic trend.

Missing solar disaggregation

Missing solar is disaggregated as follows:

- National insolation and timing effects (i.e. the changes from a country having a less sunny year or unusually late installations) are estimated in individual countries where data is available, covering 75% of global capacity, and scaled up to a global figure. National insolation effects are recorded as "less sunny weather".
- Global insolation and timing effects (i.e. the changes caused by a global capacity shift towards countries which are less sunny or generally install later in the year) are calculated. Global insolation effects are recorded as "installations in less sunny countries".
- Global and national timing effects are combined as "late year additions".
- "Underreported solar generation" refers only to marginal underreporting – that is, it is an explanation of why 2023 departed from the historic trend rather than a comprehensive estimate of missing reporting. It is estimated from:
    - Solar generation in countries where we know a portion is not reported (e.g. in Spain)
    - Capacity installed in countries which do not report up-to-date generation (primarily in the Middle East and Asia).

Demand disaggregation

- Electricity demand from EVs is estimated based on the number of vehicles sold, multiplied by the annual average electricity consumption for key vehicle types: passenger cars, light commercial vehicles, trucks, buses, and two-wheelers, including battery-electric and plug-in hybrid vehicles. Key sources on EV sales: China (passenger cars, light commercial vehicles, trucks, buses, two-wheelers), India, EU, US, Japan, rest of the world.
- Electricity demand from heat pumps estimated based on the number of units sold, multiplied by annual average consumption. Key sources on heat pump sales: EHPA, AHRI, Rosenow et al, JRAIA, IEA.

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Authors and other contributors

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Annex - Country Snapshots

The separate Annex provides a summary analysis of the current electricity transition status in a further twenty-five countries and regions that are among the world biggest absolute CO2 emitters, alongside the top six set out in Chapter 5 – Major Countries and Regions.

Country and Region Snapshots – Annex

Analysis of the 25 largest power sector emitters in 2023

This Annex provides a summary analysis of the current electricity transition status in a further twenty-five countries and regions that are among the world biggest absolute CO2 emitters, alongside the top six set out in Chapter 5 – Major Countries and Regions.

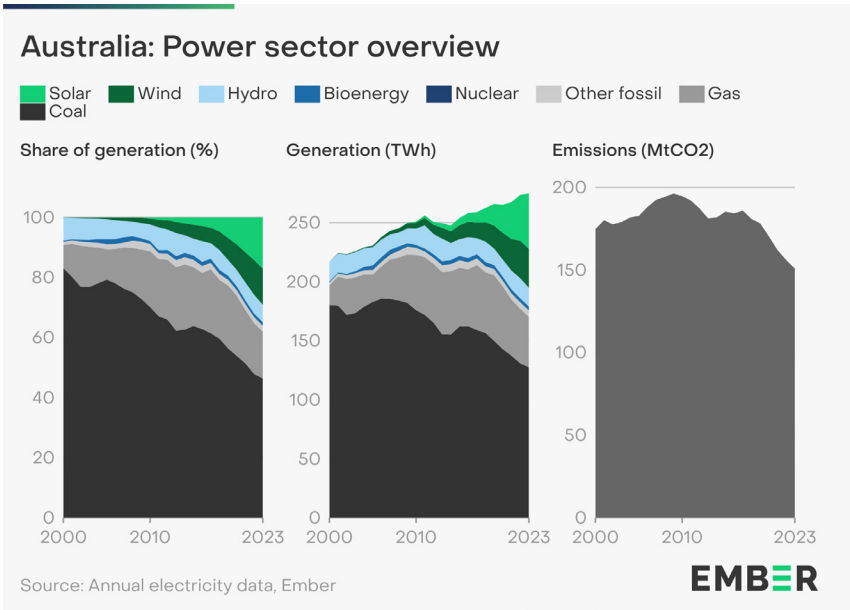
The countries are presented in alphabetical order, with their global ranking included, which is based on the amount of carbon dioxide emissions produced from the electricity sector of the given country or region in 2023, or the previous year if no data is available.

Australia

Australia's wind and solar increase has helped to drive down power sector emissions, but coal remains a major polluter

Australia relied on fossil fuels for 64% of its electricity in 2023, ranking as the G20's top coal emitter on a per capita basis.

Despite Australia's power sector emissions peaking in 2009, with its share of coal dropping from 73% to 46% and wind and solar growing from 3% to 29%, coal continues to dominate the electricity mix. Australian coal mines also emit massive amounts of the potent greenhouse gas methane.



Solar leads Australia's clean electricity at 17% of the mix, placing the country in 5th position globally for the largest share of solar. However, although its 29% share of wind and solar is well above the global average (13%), it lags behind major European economies such as Germany (39%) and the UK (33%).

Australia aims for 82% renewable electricity by 2030, while the IEA's Net Zero Emissions scenario sets out a global target of 60% renewable electricity by 2030.

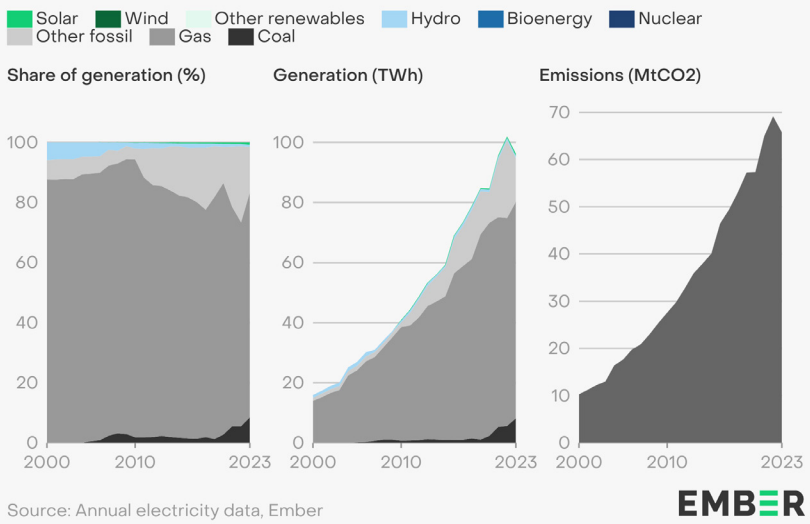
Bangladesh

Bangladesh has mostly met growing demand for electricity with fossil gas, but solar can help reduce reliance on costly imports

Bangladesh relied on fossil fuels for 98% of its electricity in 2023. However, its emissions per capita were below the global average due to low electricity demand.

Bangladesh generates less than 1% of its electricity from hydro and less than 1% from solar and wind – far below the global average (13%).

Bangladesh's power sector emissions grew over the last two decades as increased demand was met almost entirely by fossil fuels.



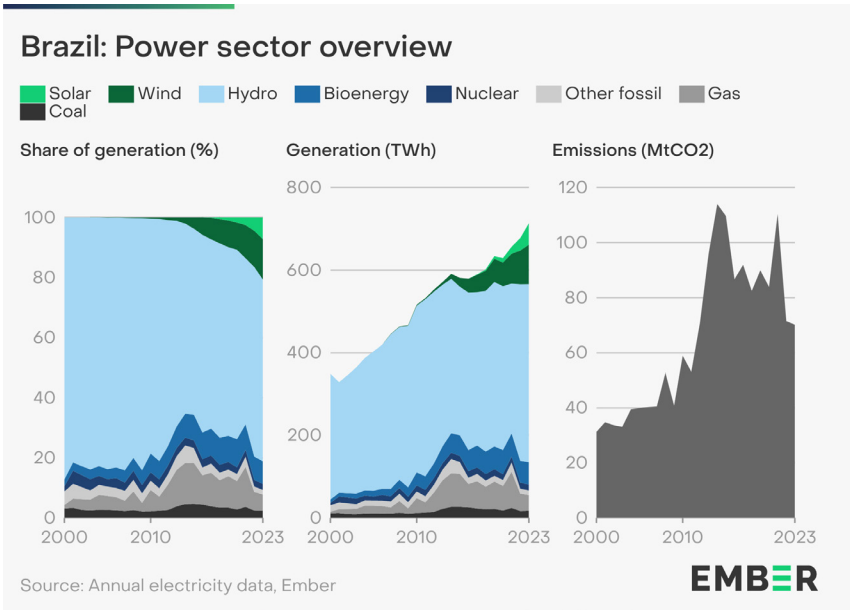
Bangladesh aims for 16% renewable generation by 2030, while the IEA's Net Zero Emissions scenario sets out a global target of 60% renewable electricity by 2030. Ember's analysis shows that an ambitious plan to build solar could help reduce fossil fuel import costs significantly.

Brazil

Wind and solar will help Brazil manage the impact of climate variability on hydro and rising demand

Brazil generated 91% of its electricity from clean sources in 2023, with hydro dominating the mix at 60%. Its share of wind and solar (21%) is above the global average (13%) and its neighbour Argentina (12%), but below Chile (32%).

Brazil relied on fossil fuels for just 9% of its electricity in 2023. Its per capita emissions were well below the global average. In 2023, it had the second lowest carbon intensity of electricity generation in the G20.



Brazil's power sector emissions have fluctuated significantly over the last two decades as weather conditions swung between rainfall and drought, affecting hydro output. A combination of rainy weather and strong growth in wind and solar delivered record-low fossil power in February of 2023.

Brazil has already surpassed its target of reaching 84% renewable electricity by 2030. The IEA's Net Zero Emissions scenario sets out a global target of 60% renewable electricity by 2030.

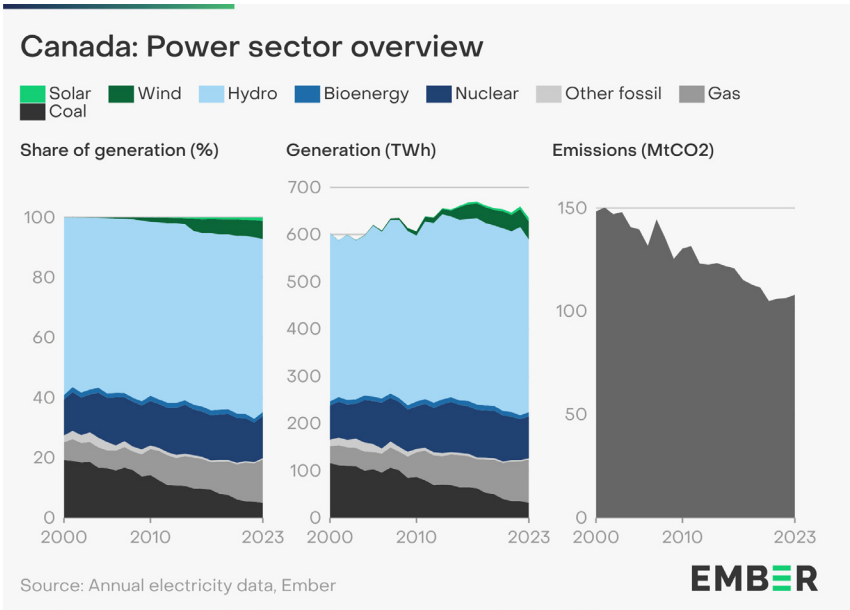
Canada

Hydro leads Canada's clean energy, with greater ambition for wind and solar needed to displace remaining fossil fuels

In 2023, Canada relied on fossil fuels for 20% of its electricity. Its emissions per capita were above the global average.

Hydro dominates Canada's electricity mix, making up 58% of generation in 2023. However, wind and solar lagged behind at 7%, below the global average (13%) and the United States (16%).

Canada's power sector emissions fell over the last two decades, having peaked in 2001, due to a steady fall in coal generation, which is now just 5% of the electricity mix.

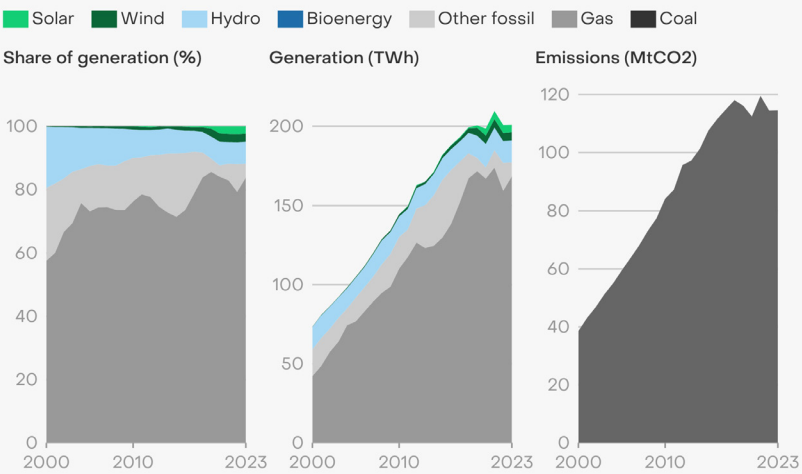


Canada aims for 72% renewable energy by 2030, while the IEA's Net Zero Emissions scenario sets out a global target of 60% renewable electricity by 2030.

Egypt

Egypt's vast untapped solar potential can help overcome its fossil gas dependency and cut its rising power sector emissions

Egypt relied on fossil fuels for 88% of its electricity in 2023. Its per capita emissions are lower than the global average.



Egypt's largest clean electricity source is hydro (7%). Wind and solar are starting to grow, comprising 5% of the country's electricity in 2023, up from just 1% in 2015. However, this figure is still below both the global average (13%) and the regional average for Africa (6%).

Egypt is Africa's largest fossil gas generating country, responsible for 45% of the continent's gas generation in 2022.

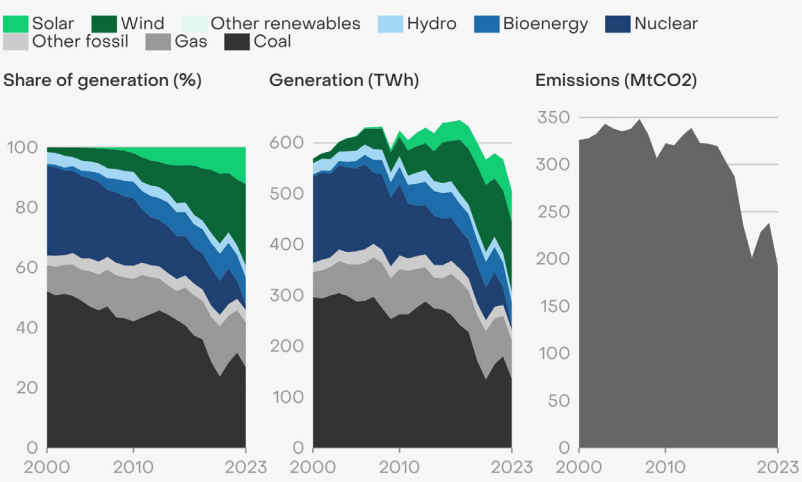
Over the last two decades, Egypt's electricity demand has more than doubled, and so have its power sector emissions. Rising demand was predominantly met by fossil gas generation which constitutes 84% of Egypt's electricity mix.

Egypt aims for 42% renewable electricity by 2030, while the IEA's Net Zero Emissions scenario sets out a global target of 60% renewable electricity by 2030.

Germany

Wind power overtook coal to become Germany's largest source of electricity in 2023

Germany relied on fossil fuels for 46% of its electricity in 2023. Its per capita emissions were above the global average.



Germany's largest source of electricity is wind (27.2%), which overtook coal (26.8%) in 2023. Its share of wind and solar (39%) is three times the global average (13%) and similar to Spain (40%) and the Netherlands (41%).

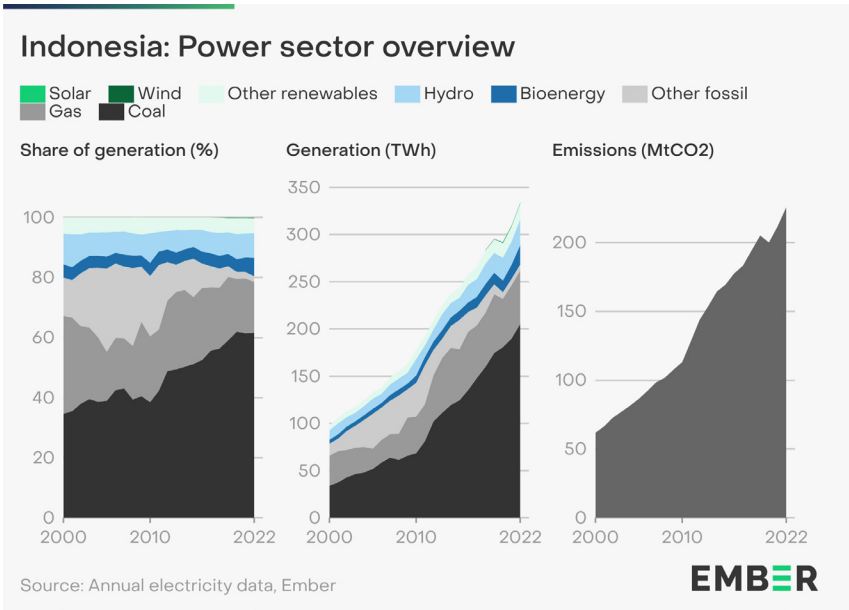
Germany's power sector emissions peaked in 2007 and have fallen significantly since then as coal-fired electricity generation more than halved. In 2000, coal generated 52% of the country's electricity, but by 2023 this had fallen to 26.8%.

Germany aims for 75% renewable electricity by 2030, while the IEA's Net Zero Emissions scenario sets out a global target of 60% renewable electricity by 2030.

Indonesia

Indonesia remains reliant on fossil fuels, while its neighbours have begun their transition to clean, cheap electricity

In 2022, Indonesia relied on fossil fuels for 80% of its electricity. Its emissions per capita were below the global average.



Indonesia's largest source of clean electricity is hydro (8%). Its share of wind and solar (0.2%) is below the global average (13%) and its neighbours the Philippines (4% in 2023) and Thailand (5% in 2023).

Indonesia's power sector emissions grew in the last two decades as electricity demand more than tripled and was met almost entirely with electricity generated by coal and gas.

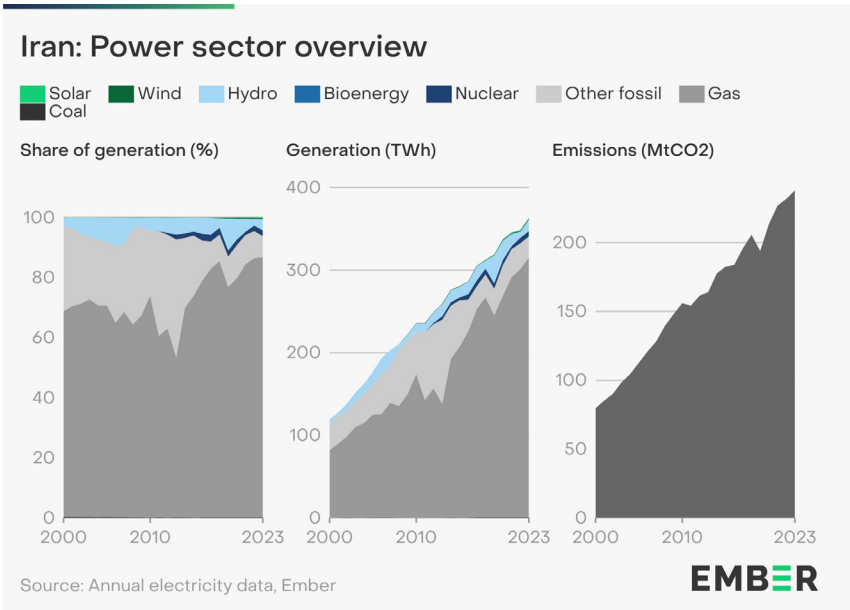
Indonesia's Just Energy Transition Partnership (JET-P) draft plan proposes it will reach at least 44% renewables in its power generation by 2030. This is below the global target of 60% renewable electricity set out in the IEA Net Zero Emissions scenario and overlooks the country's largely untapped renewables potential.

Iran (Islamic Republic of Iran)

Iran's vast untapped solar potential can help overcome its fossil gas dependency and slow its rising power sector emissions

In 2023, Iran relied on fossil fuels for 94% of its electricity generation. Its per capita emissions were above the global average.

Hydro is Iran's largest source of clean electricity at 4%. However, the share of wind and solar in total electricity generation is only 0.6%. The global average for wind and solar share is at 13% and its neighbour Türkiye at (16%).



Iran's power sector emissions have almost tripled in the last two decades, as rising demand for electricity was predominantly met by an increase in fossil gas. The country generated 87% of its electricity from fossil gas in 2023.

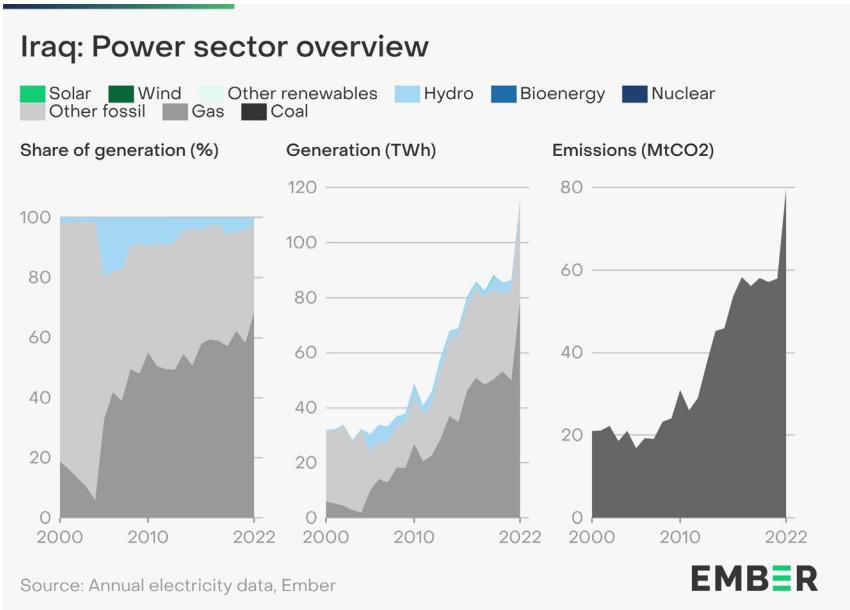
The Iranian government has plans to expand renewables capacity to take advantage of the country's huge untapped solar potential and reduce reliance on fossil gas in the power sector amid domestic gas shortages. The IEA's Net Zero Emissions scenario sets out a global target of 60% renewable electricity by 2030.

Iraq

Iraq's power sector emissions have nearly quadrupled over the last two decades as gas grew to meet rising demand

In 2022, Iraq relied on fossil fuels for 98% of its electricity generation. Its emissions per capita were slightly above the global average. Gas generation increased 105% year-on-year, as a new gas power plant came online.

Iraq generates less than 3% of its electricity from hydro, and less than 1% from solar and wind. Its share of wind and solar is far below the global average (13% in 2023) and its neighbour Türkiye (16% in 2023).



Iraq's power sector emissions nearly quadrupled over the last two decades, as increased demand for electricity was met almost entirely by gas. The share of hydro generation has also decreased since 2020, when it was 5%, with droughts leading to lower hydro output which was replaced by fossil generation.

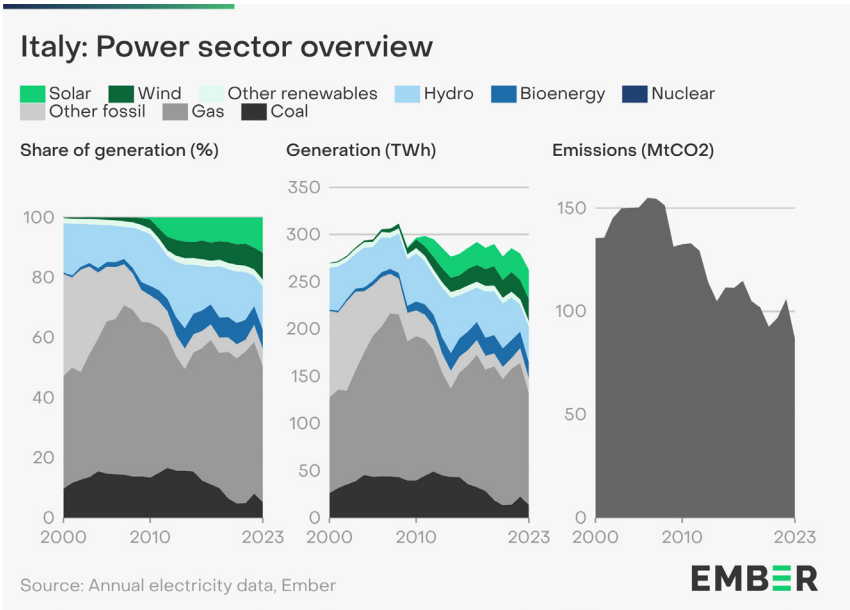
Iraq has not yet set an official renewables target, while the IEA's Net Zero Emissions scenario sets out a global target of 60% renewable electricity by 2030.

Italy

Italy is falling behind its European peers in harnessing cheap, clean solar and wind energy

Italy relied on fossil fuels for 56% of its electricity in 2023. Its per capita emissions were below the global average.

Italy's largest source of clean electricity is hydro (14%). While its share of wind and solar (21%) is above the global average (13%), it is almost half that of its southern European peers Spain (40%) and Portugal (40%).



Italy's power sector emissions have fallen over the last two decades, predominantly due to a decline in electricity generation from oil and coal, which were in part replaced by an increase in wind and solar.

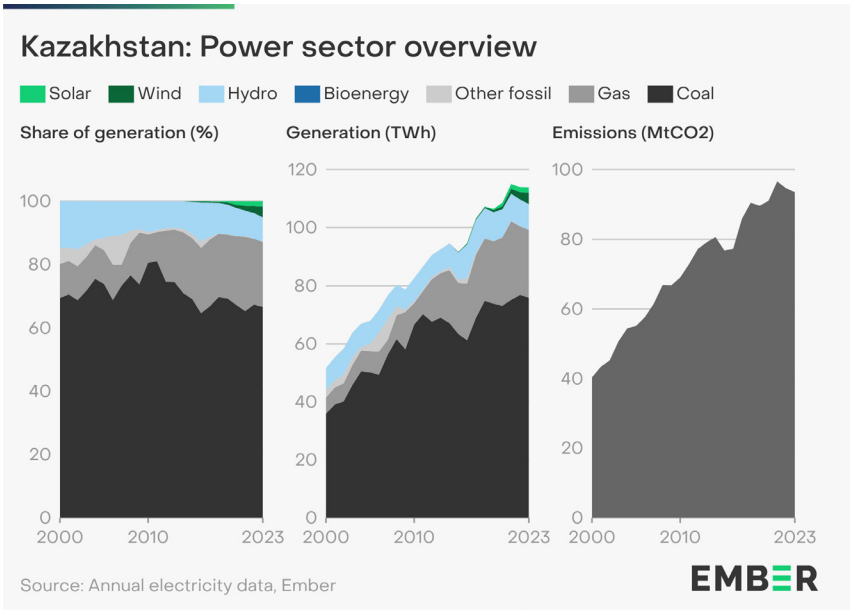
Italy aims for 72% renewable electricity by 2030, while the IEA's Net Zero Emissions scenario sets out a global target of 60% renewable electricity by 2030.

Kazakhstan

Kazakhstan's untapped renewables potential can help it transition away from fossil fuels whilst meeting demand

Kazakhstan relied on fossil fuels for 87% of its electricity in 2023, falling only slightly from 90% in 2015. Its per capita emissions were more than two and a half times higher than the global average.

Kazakhstan's largest clean electricity source is hydro (8%). Wind and solar are starting to play a role, reaching 5% of Kazakhstan's electricity in 2023 – a significant increase from their near-zero share in 2015. However, this is still far below the global average (13%) and regional average for Asia (13%).

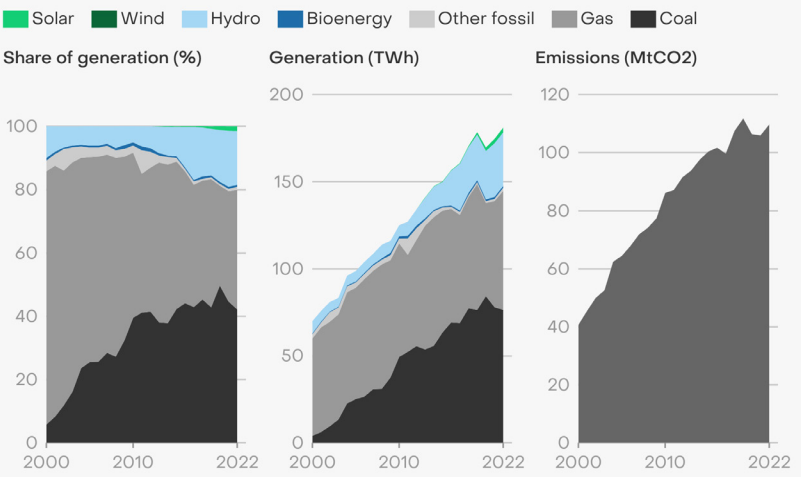


Over the last two decades, Kazakhstan's electricity demand has more than doubled and so have its power sector emissions. The country continues to rely heavily on coal and gas to meet a large portion of this demand.

Malaysia

Malaysia boasts a largely untapped solar potential that can help it overcome fossil fuel reliance to meet growing power demand

Malaysia relied on fossil fuels for 81% of its electricity in 2022. Its per capita power sector emissions are below the global average.



Malaysia generates 19% of its electricity from clean sources, with hydropower providing the majority (17%). However, its share of solar and wind (1.5%) is far below the global average (13%) and less than half the ASEAN average (4.4% in 2023).

Malaysia's increasing power demand is instead being met by rising coal generation, which has doubled in the last two decades, overlooking its vast solar power potential. Consequently, its power sector emissions have also doubled during the same period.

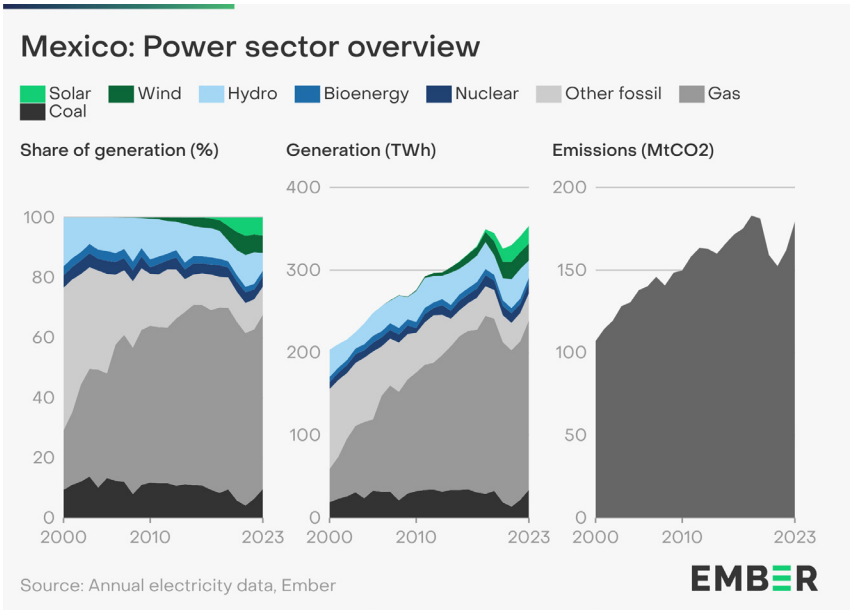
Malaysia aims for 29% renewable electricity by 2030, while the IEA's Net Zero Emissions scenario sets out a global target of 60% renewable electricity by 2030.

Mexico

Mexico is yet to harness its high potential for cheap, clean solar and wind energy

In 2023, Mexico relied on fossil fuels for 77% of its electricity generation, with gas remaining the single largest source at 58%. Its per capita emissions are below the global average.

Mexico's largest source of clean electricity is solar (6%). Despite high potential for wind and solar, their combined share in the electricity mix (12%) is below the global average (13%) and its neighbour the United States (16%).



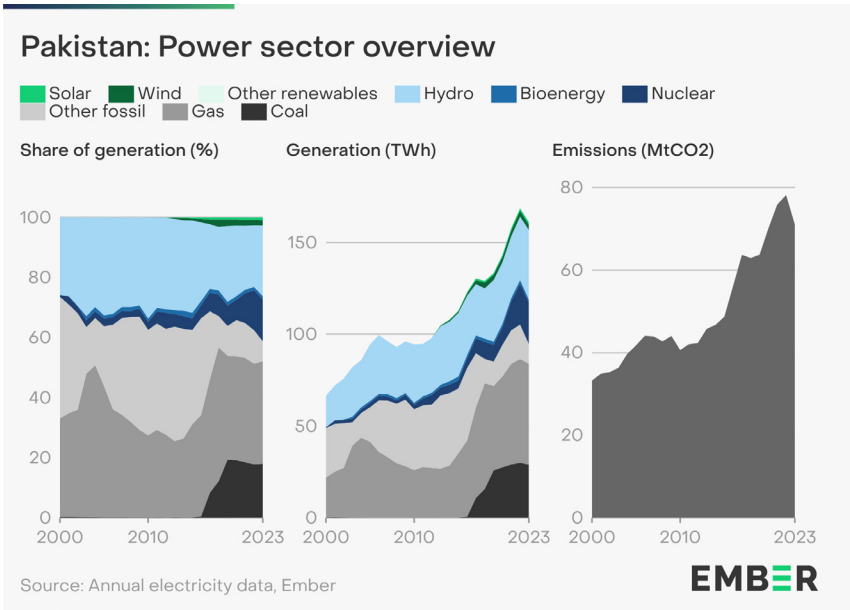
Despite being the second country in the world to introduce a legally binding emissions reduction target in 2012, Mexico has not meaningfully increased ambition on emissions reduction in recent years. Mexico aims for 33% renewable electricity by 2030, while the IEA's Net Zero Emissions scenario sets out a global target of 60% renewable electricity by 2030.

Pakistan

Pakistan's vast solar and wind potential can help tackle its ongoing energy crisis

Pakistan relied on fossil fuels for 59% of its electricity in 2023. However, its emissions per capita remain below the global average.

Hydro dominates Pakistan's low-carbon electricity at 24% while its share of wind and solar (2.7%) is far below the global average (13%) and its neighbours India (10%) and Afghanistan (13%).



As Pakistan's electricity demand more than doubled in the last two decades, so have its power sector emissions. This rising electricity demand was predominantly met by fossil fuels, with coal seeing a huge jump from less than 1% in 2016 to almost 18% in 2023. However, high oil-and-gas-powered plant running costs have led to the government imposing energy conservation measures, artificially suppressing demand, which fell 7.5% year-on-year. Increasing wind and solar would help Pakistan to meet demand more cost-effectively and resolve its ongoing energy crisis.

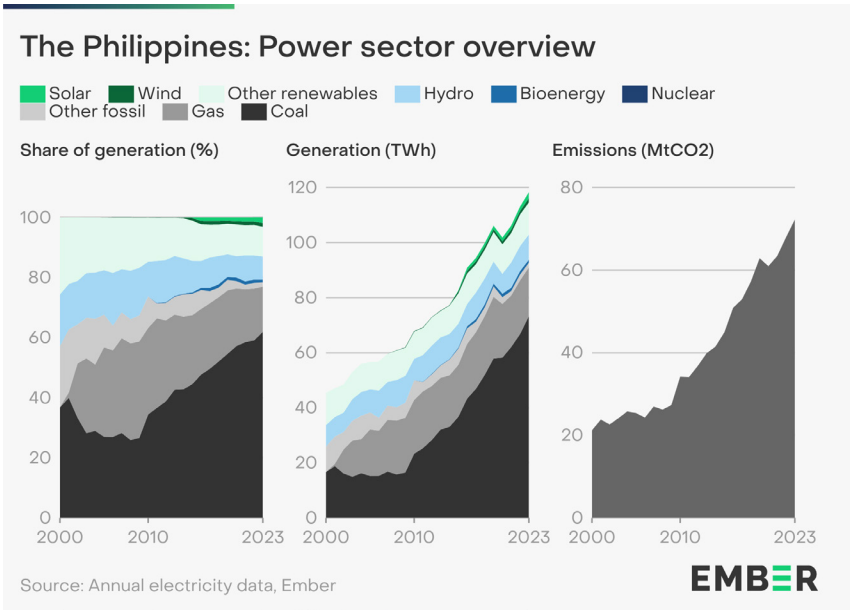
While Pakistan has committed to increasing its renewable electricity share to 60% by 2030, it also has plans to quadruple its coal-fired capacity. The IEA's Net Zero Emissions scenario sets out a global target of 60% renewable electricity by 2030.

The Philippines

The Philippines can harness its wind and solar potential to reduce its reliance on coal

In 2023, the Philippines relied on fossil fuels for 78% of its electricity. Its per capita power sector emissions were below the global average.

Low-carbon sources provide more than a fifth of the Philippines' electricity, with the majority from hydropower and geothermal. Solar and wind shares make up just 2.5%, which is below the global average (13%) and the average among ASEAN countries (4.4%).



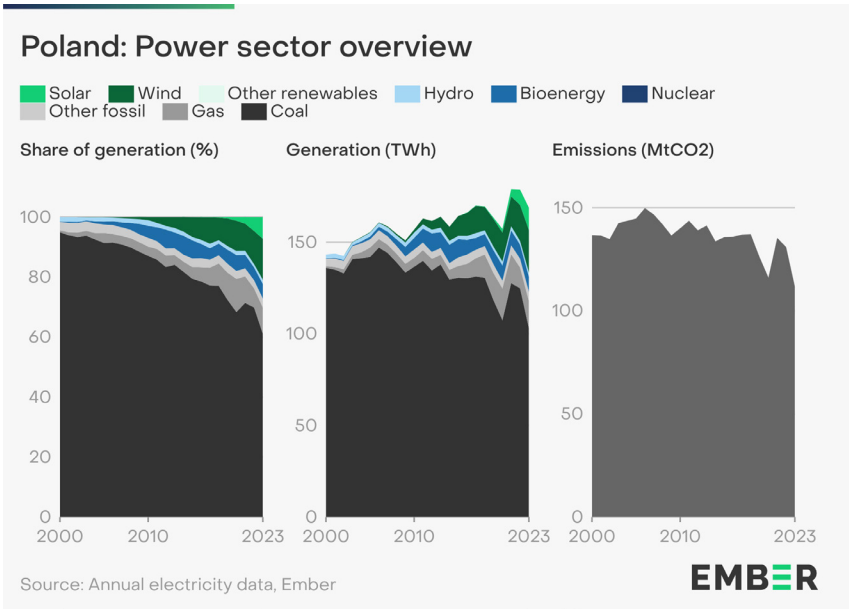
The Philippines saw its power sector emissions nearly double in the last ten years as rising demand was met with a more than doubling of coal power generation.

The Philippines aims for 35% renewable electricity by 2030, while the IEA's Net Zero Emissions scenario sets out a global target of 60% renewable electricity by 2030.

Poland

Poland has increased its share of wind and solar but still lags behind EU peers

In 2023, Poland generated nearly three-quarters (73%) of its electricity from fossil fuels, falling from 79% in 2022, with 61% of its electricity generated by coal. Its per capita power sector emissions were above the global average.



Wind and solar produced a record 21% of the Polish electricity mix in 2023 and in June they covered 66% of domestic power demand in certain peak hours.

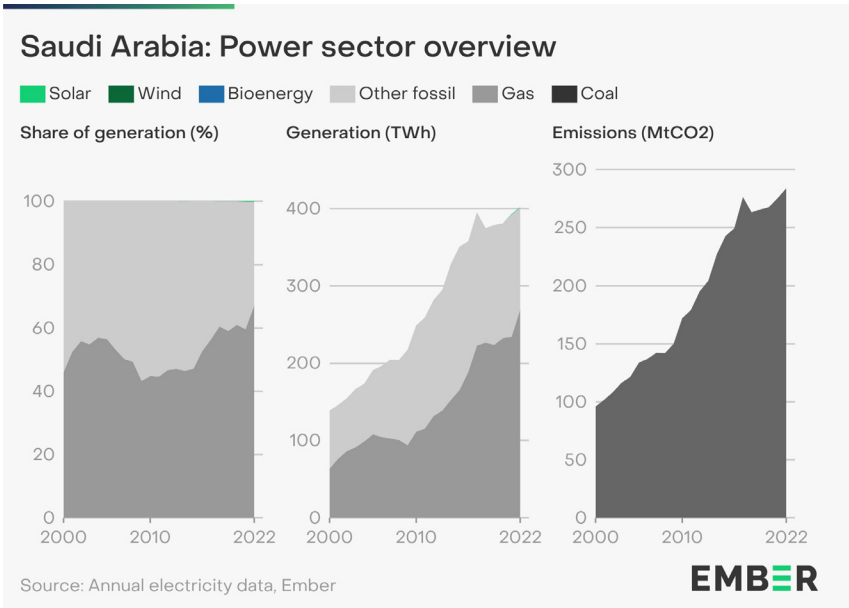
Poland aims for 53% renewable electricity by 2030. However, Ember's analysis found 60-70% is feasible in the same timeline, while the IEA's Net Zero Emissions scenario sets out a global target of 60% renewable electricity by 2030.

Saudi Arabia

Saudi Arabia needs to rapidly increase its renewables share from near-zero today to meet its ambitious 2030 targets

Saudi Arabia relied almost entirely on fossil fuels (99.8%) for its electricity generation in 2022, with per capita emissions four times higher than the global average.

While solar provided only 0.2% of Saudi Arabia's electricity generation, the country did not generate any electricity from nuclear or renewable sources such as hydro and wind. Whereas, in 2022 its neighbour the United Arab Emirates generated 17% of its electricity from clean energy sources.



Saudi Arabia's power sector emissions more than doubled in the last two decades, with the increase in electricity demand predominantly met by fossil gas. The country generated 67% of its electricity from fossil gas and 33% from oil.

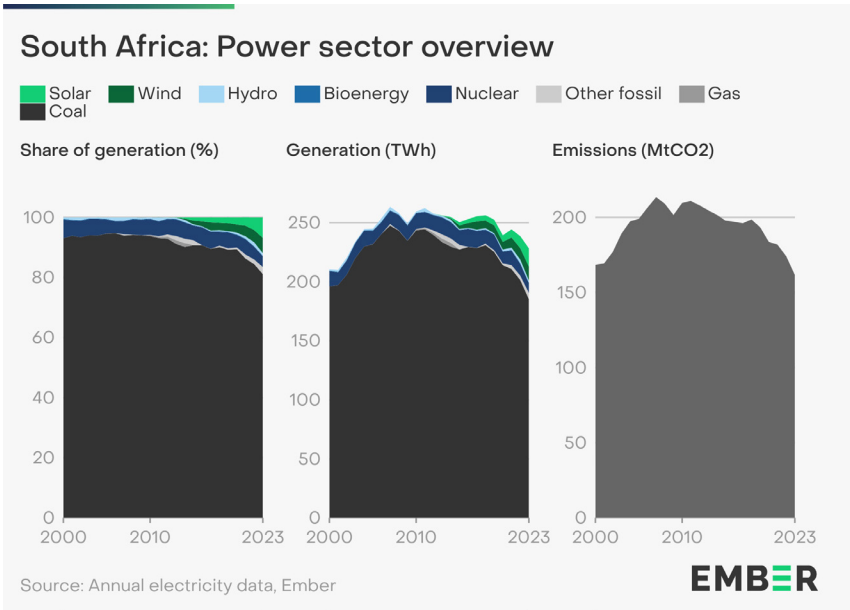
Saudi Arabia is targeting 50% renewable electricity by 2030, while the IEA's Net Zero Emissions scenario sets out a global target of 60% renewable electricity by 2030. However, while it is planning one of the most rapid scale-ups of renewables globally, the path to implementation remains unclear.

South Africa

South Africa's vast renewables potential can safeguard it from its looming electricity demand growth and over-reliance on coal

In 2023, South Africa relied on fossil fuels for 83% of its electricity generation. Its emissions per capita are 1.5 times the global average, while its coal emissions per capita are the highest in the G20.

South Africa is by far Africa's largest generator of coal-fired electricity, responsible for 83% of Africa's coal generation in 2023. Wind and solar produced 12% of electricity in 2023, up from just 2% in 2015. This is below the global average (13%), but above Africa's average (6%).



Power sector emissions have seemingly declined since 2007. However, the ongoing energy crisis is suppressing demand growth and South Africa risks seeing emissions rebound if future demand growth is met by coal instead of clean sources.

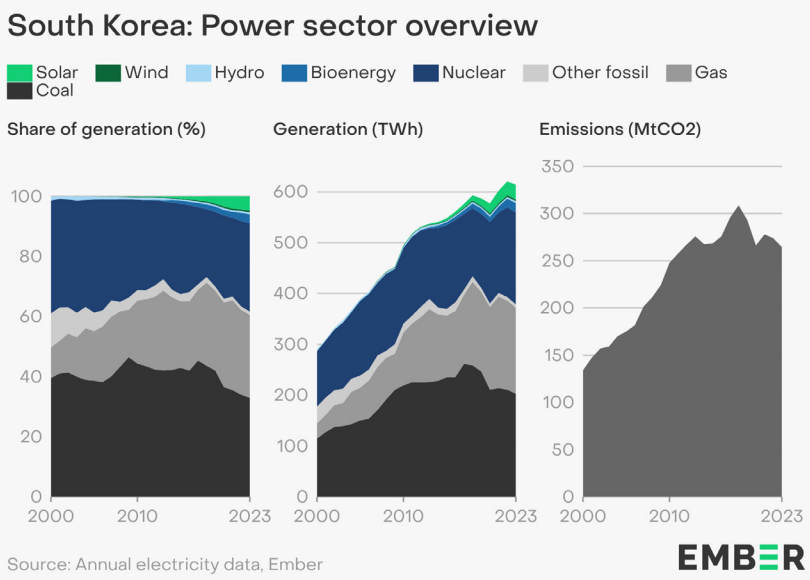
South Africa aims for 33% renewable electricity by 2030, while the IEA's Net Zero Emissions scenario sets out a global target of 60% renewable electricity by 2030.

South Korea

South Korea's solar and nuclear generation have helped drive a decline in power sector emissions in recent years

In 2023, South Korea relied on fossil fuels for 62% of its electricity in 2023, ranking as the G20's second-highest emitter per capita.

South Korea's largest single source of low-carbon electricity is nuclear (29%), but its combined share of wind and solar (5%) lags behind the global average (13%) and its neighbours Japan (12%) and China (16%). Despite this, solar has already saved the country billions in fossil fuel costs.



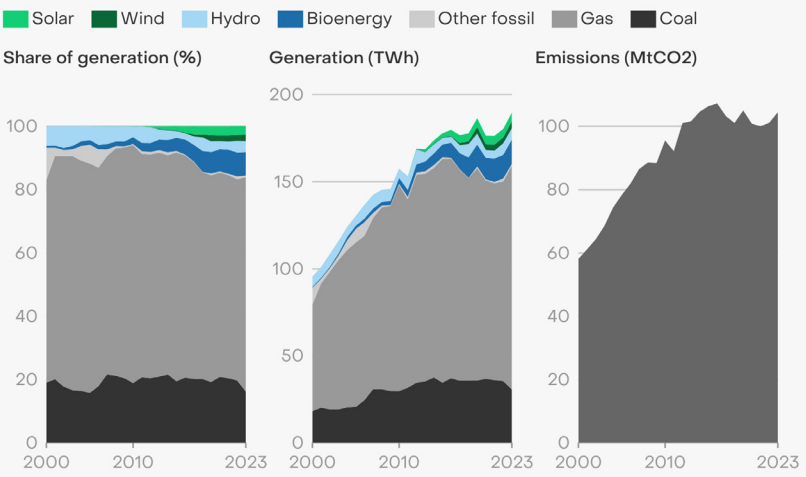
South Korea's power sector emissions grew in the last two decades as increasing demand for electricity was met predominantly by coal and gas, but emissions reached their peak in 2018 as solar and nuclear power increased and replaced coal.

South Korea aims for 20% renewable electricity by 2030, while the IEA's Net Zero Emissions scenario sets out a global target of 60% renewable electricity by 2030.

Thailand

Thailand can harness its solar and wind power potential and overcome its historic reliance on fossil gas

In 2023, Thailand relied on fossil fuels for 84% of its electricity, primarily gas (68%). Its per capita power sector emissions are below the global average.



About one-sixth of Thailand's electricity generation comes from renewables, mostly bioenergy and hydropower. Solar and wind accounted for only 4.7% of Thailand's electricity, which is less than the global average (13%) and behind Viet Nam (13%).

Thailand has a high per capita power demand that is almost double the regional average. To meet that demand, fossil gas has powered around two-thirds of Thailand's electricity since 2000, overlooking the country's largely untapped solar and wind potential.

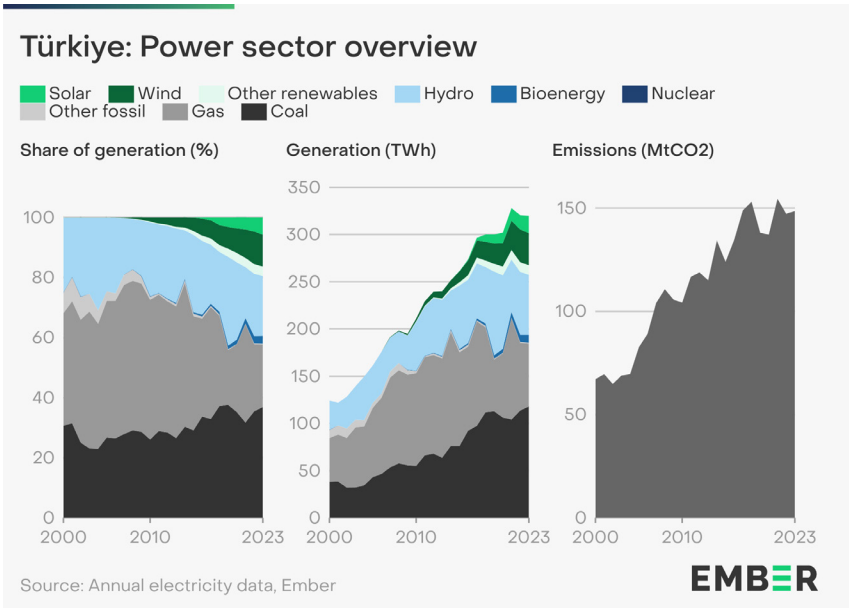
Thailand has a target to reach 37% renewable electricity by 2037, while the IEA's Net Zero Emissions scenario sets out a global target of 60% renewable electricity by 2030.

Türkiye

Türkiye can harness its huge renewables potential to reduce its reliance on fossil fuel imports and avoid being left behind

Türkiye became the second largest coal-fired power generator in Europe in 2023, with coal accounting for over a third of its total power generation.

In 2023, fossil fuels generated 58% of the country's electricity. Its per capita emissions were similar to the global average.



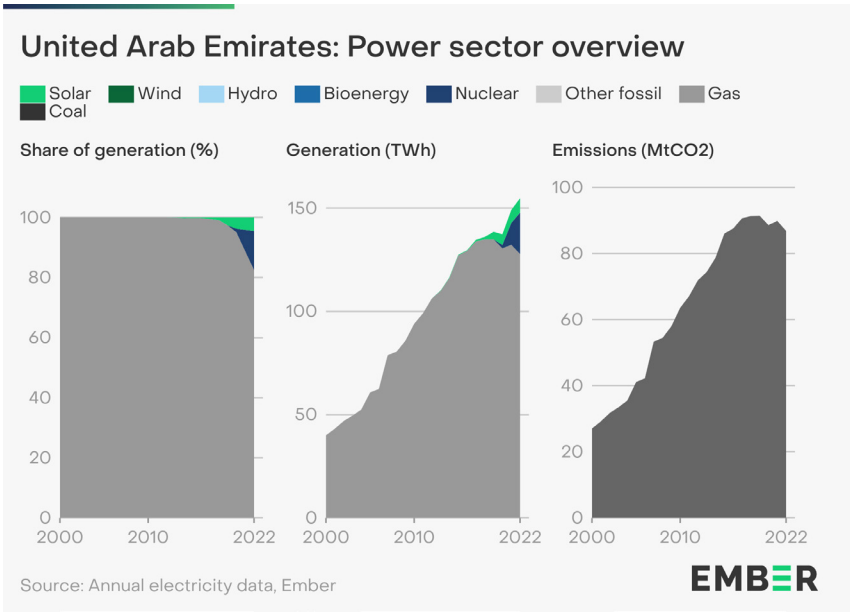
Despite enormous potential, Türkiye produced only 16% of its electricity from wind and solar in 2023. With solar accounting for just 6% of its power generation, the country lags behind nations with similar solar potential, such as Greece (19%) and even those with lower solar potential, such as Poland (7%).

Türkiye aims for 47% renewable electricity by 2030, while the IEA's Net Zero Emissions scenario sets out a global target of 60% renewable electricity by 2030.

United Arab Emirates

UAE can harness its untapped solar potential to decrease its reliance on fossil gas

In 2023, the United Arab Emirates (UAE) relied on fossil fuels for 83% of its electricity. Its per capita emissions were five times higher than the global average.



The UAE's largest source of clean electricity is nuclear which provides 13% of its total electricity mix. Its share of wind and solar (4.5%) is below the global average (13%), but higher than that of its neighbour Saudi Arabia (0.2%).

The UAE's electricity demand has more than tripled in the last two decades and so have its power sector emissions. The increase in demand has largely been met by fossil gas, with increased contributions from nuclear and solar since 2019.

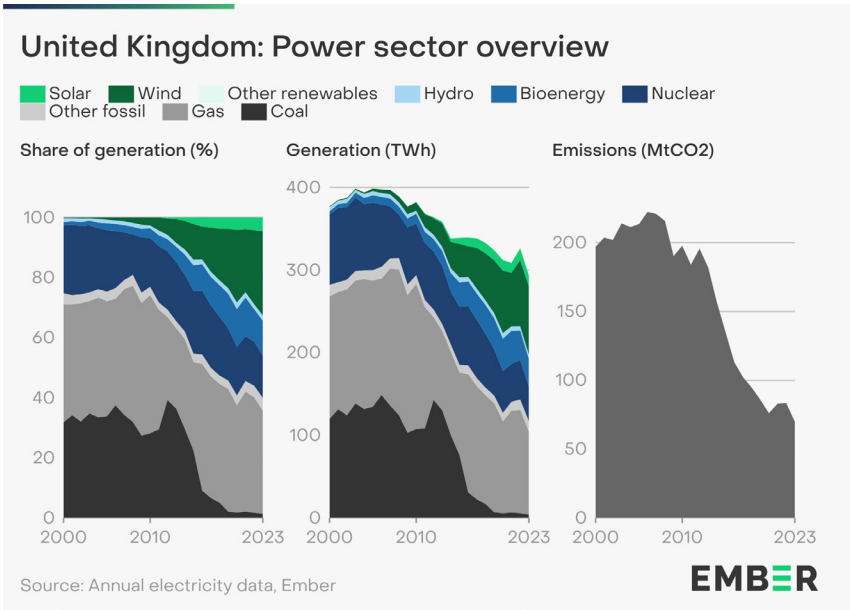
The UAE aims for 32% renewable electricity by 2030, while the IEA's Net Zero Emissions scenario sets out a global target of 60% renewable electricity by 2030.

United Kingdom

Wind power has displaced coal and the UK is now targeting a fully decarbonised electricity system

The United Kingdom relied on fossil fuels for 40% of its electricity in 2023. Its per capita emissions were below the global average, and three times lower than in 2010.

The country still relies on gas for 34% of its electricity production, but its coal phase-out is almost complete with the last remaining coal plant set to close by October 2024. In 2023, coal generation was about 30 times lower than in 2013, at just 1.4% of the UK's electricity mix.



The expansion of renewable energy has been the driver of this collapse in coal generation. The UK's largest source of clean electricity in 2023 was wind (28%), up from 8% in 2013. Wind and solar combined accounted for 33% of total electricity generation, which is above the global average (13%) and just behind its neighbour Ireland (37%).

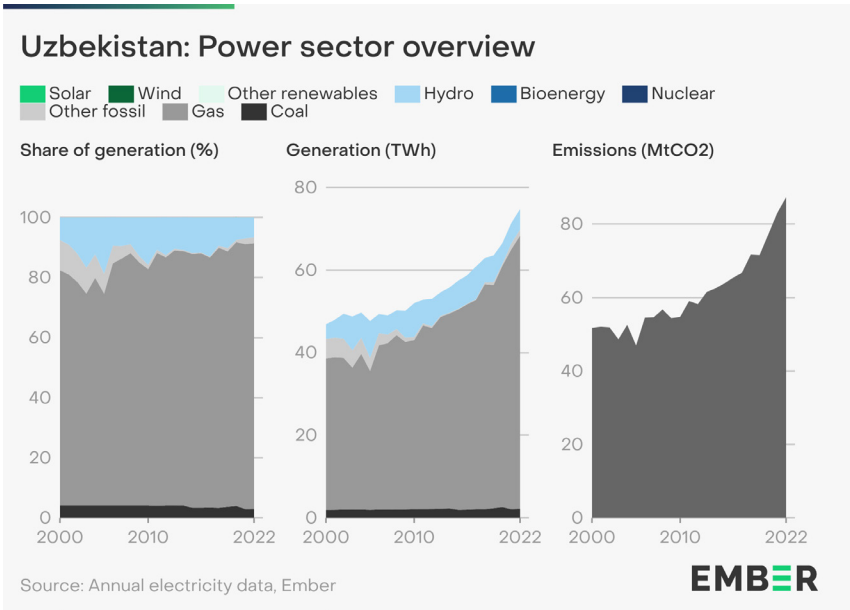
Britain aims for 87% renewable electricity by 2030, while the IEA's Net Zero Emissions scenario sets out a global target of 60% renewable electricity by 2030.

Uzbekistan

Wind and solar could help Uzbekistan overcome hydro deficits and meet increasing demand

Uzbekistan relied on fossil fuels for 93% of its electricity in 2022. Its emissions per capita were above the global average.

Uzbekistan's largest source of clean electricity is hydro (6%). Its share of wind and solar is less than 1% and is below the global average (13%) as well as its neighbour Kazakhstan (5% in 2023).



Uzbekistan's power sector emissions grew over the last two decades as increased demand was met almost entirely by fossil generation. Hydro generation has been falling since 2017 due to droughts in the region, leading to an increase in fossil generation. Uzbekistan plans to bring new hydropower online in 2024.

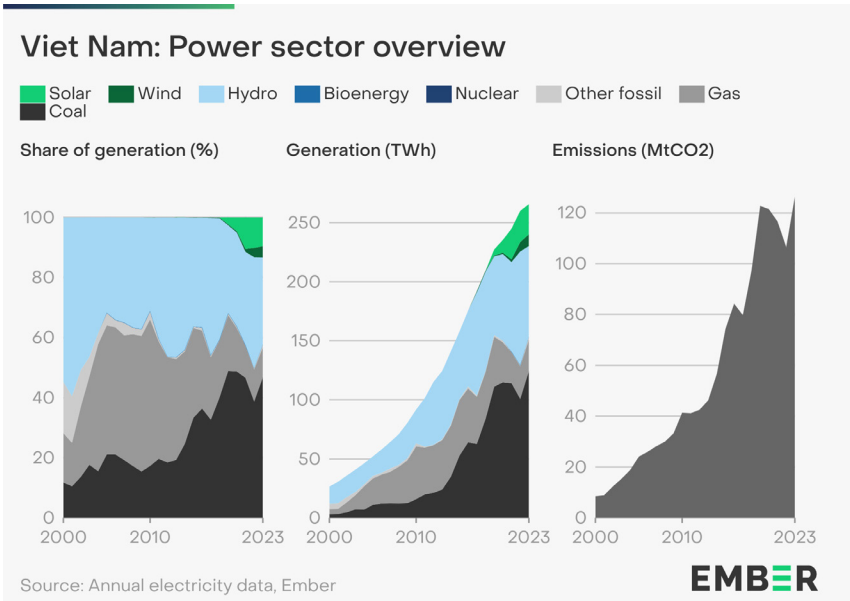
Uzbekistan aims for 27% renewable electricity by 2030, while the IEA's Net Zero Emissions scenario sets out a global target of 60% renewable electricity by 2030.

Viet Nam

As Southeast Asia's renewable powerhouse, Viet Nam can quickly decarbonise its power sector by integrating untapped solar and wind potential

In 2023, Viet Nam relied on fossil fuels for 58% of its electricity. Its per capita emissions are below the global average.

Viet Nam leads Southeast Asia in share of low-carbon generation (42%), primarily from hydro (29%). From 2015 to 2023, solar and wind grew tenfold to 13% of electricity generation, on a par with the global average and exceeding peers like Thailand (4.7%) and the Philippines (3.2%).



However, as electricity demand more than doubled over the past decade, Viet Nam met this with a doubling of coal generation, which led to a tripling of emissions. Its latest plans will more than double fossil capacity by 2030. The IEA's Net Zero Emissions scenario sets out a global target of 60% renewable electricity by 2030.

With its vast solar and wind potential, Viet Nam can ramp up renewables and ensure their integration into the electricity system. This will reduce reliance on fossil fuels to meet rising demand.

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