



# European Electricity Review

# 2024

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Europe's electricity transition  
takes crucial strides forward



**EMBER**



## About

The European Electricity Review analyses full-year electricity generation and demand data for 2023 in all EU-27 countries to understand the region's progress in transitioning from fossil fuels to clean electricity. It is the eighth annual report on the EU power sector published by Ember (previously as Sandbag). Our data is free and easily downloadable, and is available at annual and monthly granularity. We hope others also find the data useful for their own analysis.

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# Highlights

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**-19%**

Record fall in both fossil generation and CO2 emissions

**44%**

Record share of renewables in the EU electricity mix, over 40% for the first time

**55 TWh**

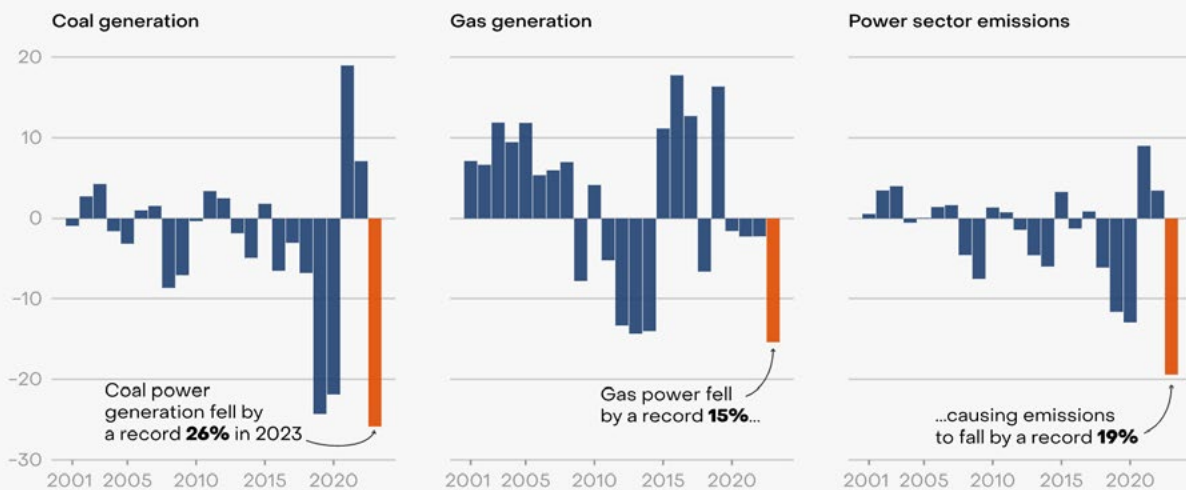
Record annual growth in wind generation pushes it above gas for the first time

# Europe's electricity transition takes crucial strides forward

A record fall in coal, gas and CO2 emissions in 2023 left the EU with a cleaner electricity mix than ever, as renewables took major steps forward. The EU's electricity transition is in full swing.

## 2023: Record falls in EU coal and gas electricity generation push power sector emissions down 19%

Annual change (%)

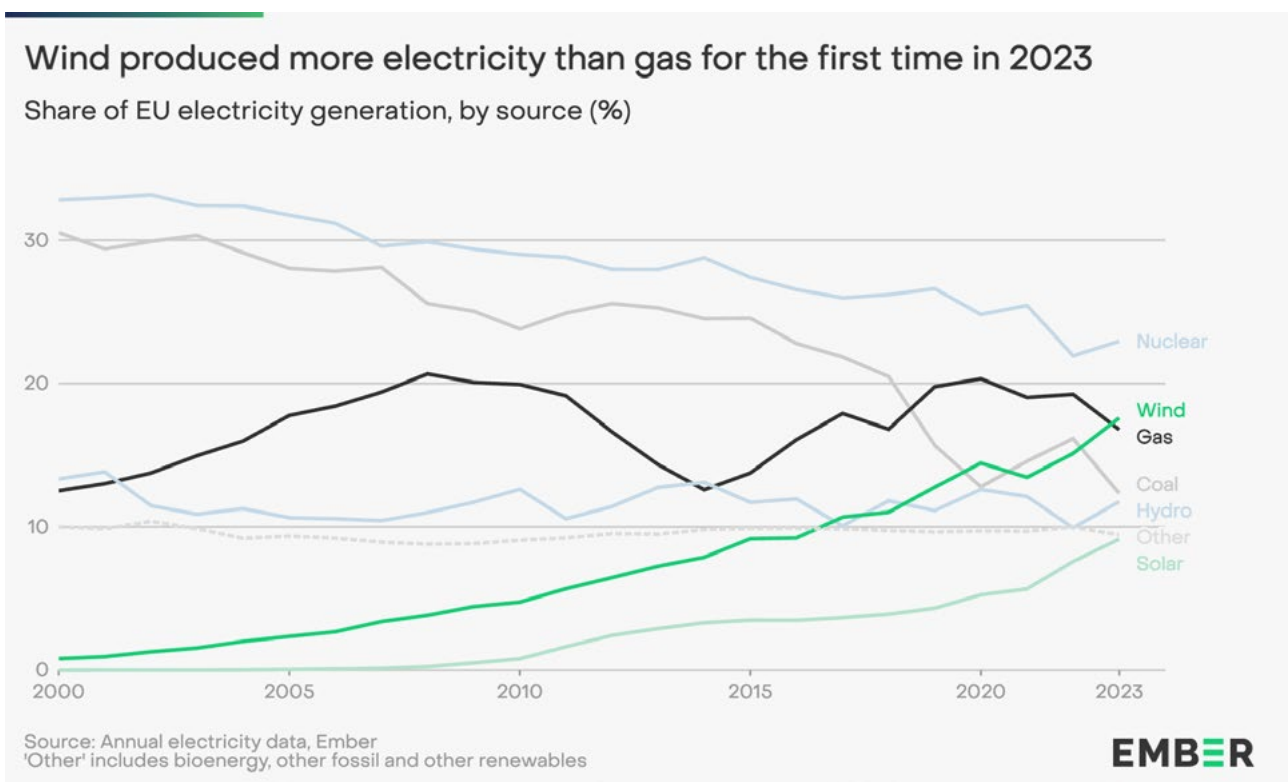


Source: Annual electricity data, Ember

The EU accelerated its shift away from fossil fuels in 2023, with record falls in coal, gas and emissions. Fossil fuels dropped by a record 19% to their lowest ever level at less than one third of the EU's electricity generation. Renewables rose to a record 44% share, surpassing 40% for the first time. Wind and solar continued to be the drivers of this renewables growth, producing a record 27% of EU electricity in 2023 and achieving their largest ever annual capacity additions. Furthermore, wind generation reached a major milestone, surpassing gas for the first time.

Clean generation reached more than two-thirds of EU electricity, double fossil's share, as hydro rebounded and nuclear partially recovered from last year's lows alongside the increase in wind and solar.

Coal was already in long-term decline, and that trend resumed in 2023. The temporary slowdown in coal plant closures during the energy crisis did not prevent a huge fall in coal generation this year, with a wave of plant closures imminent in 2024. Gas generation fell for the fourth consecutive year, and as coal nears phase-out in many countries, gas will be next to enter terminal decline.



In addition to clean growth, falling electricity demand also contributed to the drop in fossil fuel generation. Demand fell by 3.4% (-94 TWh) in 2023 compared to 2022, and was 6.4% (-186 TWh) lower than 2021 levels when the energy crisis began. This trajectory is unlikely to continue. With increased electrification, this rate of demand fall is not expected to be repeated in the coming years. To reduce fossil fuels at the speed required to hit EU climate goals, renewables will need to keep pace as demand increases.

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The EU is firmly on its way to transition from a fossil-based system to one where wind and solar are the backbone. In 2023, 24% of hours saw less than a quarter of electricity coming from fossil fuels, a major step up from just 4% of hours in 2022. As this shift becomes even more evident, so does the importance of enablers of a clean power system. Alongside wind and solar growth, grids, storage and demand side response will determine the power system of the future.

## 01

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### **Unprecedented collapse in coal and gas generation**

Fossil generation plummeted by a record 19% (-209 TWh) in 2023, to account for less than a third of the EU's electricity mix for the first time. Coal generation fell by 26% (-116 TWh) to its lowest level ever (333 TWh), making up just 12% of the EU electricity mix in 2023. Coal generation halved from 2016 to 2023 (-327 TWh) due to a similar rise in wind and solar generation (+354 TWh). Coal plant closures slowed during the energy crisis, but coal's structural decline continues as a fifth of the EU's coal fleet will shut down in 2024 and 2025. The collapse in coal did not result in a rise in gas. Gas generation fell by 15% (-82 TWh) to 452 TWh, the largest annual reduction since at least 1990. This was the fourth consecutive year of gas generation decline, with gas accounting for 17% of total EU generation in 2023.

## 02

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### **Record fall in EU power sector emissions**

EU power sector emissions fell a record 19% (-157 million tonnes of carbon dioxide equivalent) in 2023. This eclipsed the previous highest annual drop of 13% in 2020, when the Covid-19 pandemic struck. Power sector emissions have now almost been cut in half (-46%) since their peak in 2007. Eleven countries achieved their largest emissions falls ever. Wind and solar growth was responsible for much of the decline, with electricity demand also playing a significant role. Electricity demand dropped by 3.4% in 2023. This meant demand was 6.4% lower in 2023 than it was in 2021 when the energy crisis began – just over a third (38%) of the fall in that period can be attributed to a reduction in industrial electricity consumption

## 03

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### **Wind power exceeds gas for the first time**

Wind power saw record annual generation growth in 2023 of 55 TWh (+13%). This resulted in generation from wind surpassing gas for the first time. Electricity produced from wind was 475 TWh, equivalent to France's total electricity demand, compared to 452 TWh from gas. This was the only year that wind generation exceeded that of coal (333 TWh) aside from 2020 amid Covid-19 impacts. 17 GW of wind power was installed in 2023 compared to 16 GW in 2022, marginally achieving the highest ever annual capacity increase. However, this deployment rate needs to almost double to over 30 GW per year to 2030 if the EU is to achieve its targets.

## 04

**Wind and solar drive record share of renewables**

For the first time, more than a quarter of EU electricity (27%) was provided by wind and solar in 2023, up from 23% in 2022. This drove renewable electricity to a record high of 44%, passing the 40% mark for the first year in the EU's history. Combined wind and solar generation increased by a record 90 TWh and installed capacity by 73 GW. Solar continued its strong growth with 56 GW of additional capacity in 2023, compared to 41 GW in 2022 (+37%). But solar failed to match its 2022 year-on-year generation growth (+36 TWh in 2023 versus +48 TWh in 2022). The EU's electricity system continued its shift towards one powered by wind and solar as 24% of hours saw less than a quarter of electricity coming from fossil fuels, up from just 4% of hours in 2022. Grids, storage and other enablers of system flexibility will be increasingly critical as wind and solar's share continues to grow.

The EU's power sector is in the middle of a monumental shift. Fossil fuels are playing a smaller role than ever as a system with wind and solar as its backbone comes into view. The energy crisis and Russia's invasion of Ukraine did not lead to coal and gas resurgence — far from it. Coal is nearing phase-out, and as wind and solar grow, gas will be next to enter terminal decline. However it is not time to get complacent. The EU needs a laser focus on rapidly deploying wind, solar and flexibility to create a system free of fossil fuels.

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**Sarah Brown**

Europe Programme Director, Ember





# Encouraging progress in difficult times

**Europe's power sector transition made crucial progress in 2023 as the energy system emerged from a period characterised by high prices and political intervention. While the EU strengthened renewables ambition in response, Member States are not yet aiming high enough for common EU goals, and delivery remains too slow.**

The gas crisis of 2022 exposed the many costs of fossil fuel dependency. It cost governments billions of euros in energy subsidies, plunged millions of Europeans into energy poverty, put global energy security at risk and drove inflation to the highest levels in decades.

While consumers and businesses still struggle with the economic fallout, the climate crisis continues to intensify, with 2023 the [second hottest](#) year on record in Europe. Against this backdrop, it is clear that the transition to affordable renewable power will help on multiple fronts. There are encouraging signs that Europe is bolstering its ambition and picking up the pace, but delivery is still not fast enough for the EU's energy goals or international climate obligations.

As wind and solar power reach new highs across Europe, targets set by the EU and its Member States have begun to shift to reflect a future energy system dominated by renewable power. The [REPowerEU plan](#) foresees 72% of power generation coming from renewables by 2030, up from 44% in 2023. This is driven by wind and solar, which will double from 27% in 2023 to 55% in 2030.

EU Member States have started to realign their National Energy and Climate Plans (NECPs) with this future, increasing their 2030 wind and solar targets by 45% and 70% respectively, compared to just four years ago. While [not yet sufficient](#) to deliver on EU goals, the latest plans put wind and solar on track to produce the majority of EU power by 2030, with wind as the single largest source.

Europe's direction of travel towards clean power was entrenched further by key political statements in 2023. Seven interconnected Member States [pledged to decarbonise their power systems by 2035](#), meaning 10 Member States have now formally aligned with this critical milestone for net zero.

Furthermore, Czechia, Europe's third largest coal power producer, joined the Powering Past Coal Alliance. The year concluded with the call from COP28 to transition away from fossil fuels, including the EU advocating for the tripling of renewables and doubling of the rate of energy efficiency improvements globally by 2030. This can be seen as a global recognition of these key tools for climate action, and places even more emphasis on the EU to deliver.

Heightened ambitions mean nothing without delivery. Despite breaking records in 2023, wind power continued to struggle against economic headwinds. Deployment must be accelerated if EU goals are to be achieved. The roll-out of solar power is a more positive story, with strong capacity growth maintained in 2023, but now is not the time for complacency. The challenges facing the power sector transition are complex but increasingly well understood: from slow permitting to outdated grid infrastructure and vulnerability to global supply chains. These complex challenges require dedicated action, guided by a clear and united vision for a clean power system.

The power sector transition must remain a political focus in 2024 in order to consolidate and build on the progress made last year. A highly electrified energy system based on cheap, domestic renewables can power Europe's economy while slashing carbon emissions. Rapid progress is essential in order to seize the commercial advantages, uphold international climate commitments, and expedite the benefits of cheap renewables across Europe.

# The Big Picture

The biggest stories of 2023: Fossil power collapsed as wind and solar hit new records and demand slumped. Flexibility emerged as key to stepping up this power system shift.

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Insight 1:

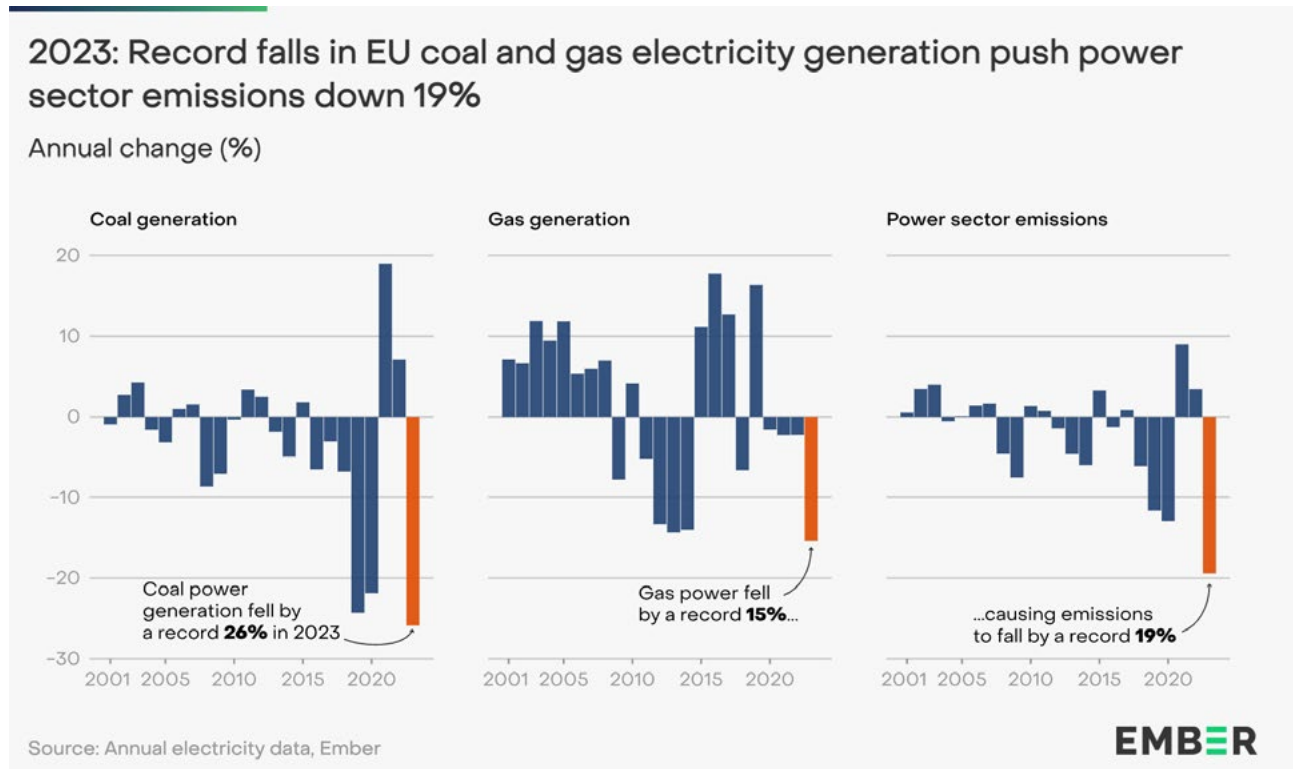
# Record fossil collapse shows the shift to clean power in action

2023 followed an extremely turbulent year for EU electricity. In 2022, hydro generation hit a record low due to extreme droughts, and nuclear generation dropped to the lowest output in 30 years due to unexpected outages at French nuclear plants. Combined, these left a gap of 7% of the EU's overall generation, pushing fossil generation up by 2% in 2022. Going into 2023, the expectation was that fossil fuel generation would rapidly fall to correct for these. 2023 did not disappoint.

A record fall in coal, gas and CO2 emissions in 2023 left the EU with a cleaner electricity mix than ever, amid a progressing energy transition and a sustained response to turbulent conditions. The temporary slowdown in coal plant closures during the energy crisis did not prevent a huge fall in coal generation this year, and gas generation fell for the fourth consecutive year.

## Record falls in coal and gas as fossil fuels drop below a third of EU power

Both coal and gas generation had a record percentage fall in 2023, leading to a record drop in power sector CO<sub>2</sub> emissions as well. Fossil generation fell to less than a third of the EU's electricity (33%) for the first time ever.



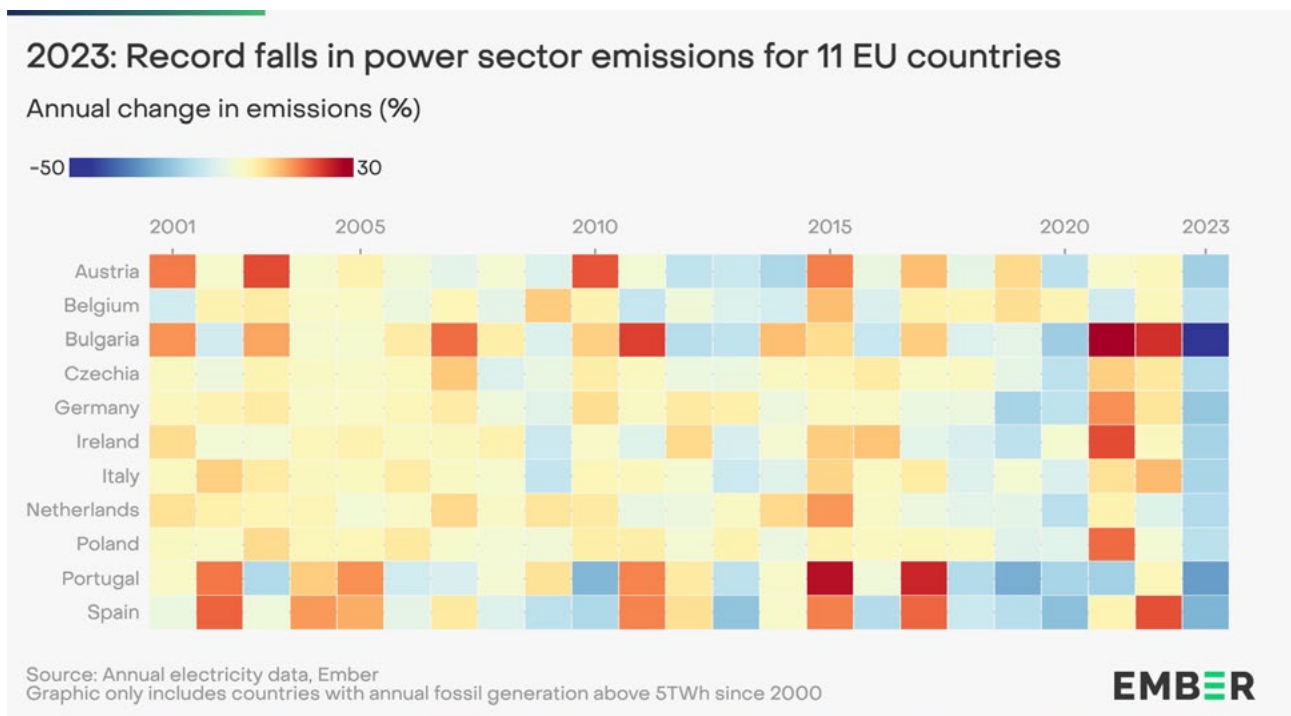
Coal generation fell by 26% (-116 TWh) to 333 TWh, the largest annual percentage reduction since at least 1990. As a result, coal dropped to the lowest level ever, below the previous record low in 2020 (352 TWh), more than erasing the upticks during the last two years (+96 TWh). Coal made up just 12% of the EU's electricity in 2023.

Gas generation fell by 15% to 452 TWh. This is the biggest annual reduction since at least 1990 and the fourth year in a row that it has declined. In 2023, gas generation was 20% below the pre-Covid level in 2019 (569 TWh), but it was still above the lowest year on record. At 17% of the EU's electricity mix, gas generated more power than coal (12%) in 2023.

### Record fall in power sector emissions

Power sector emissions fell by 19% (-157 million tonnes CO<sub>2</sub> (MtCO<sub>2</sub>)), also a record annual decline and the largest drop since at least 1990. It is unusual that large reductions in coal and gas generation happen simultaneously, since falls often occur due to switching from one fuel to another. As a result, 2023's emissions fall eclipsed the previous record 13% drop in 2020 amid impacts from Covid-19. Power sector emissions in 2023 are now almost half (-46%) their peak, which occurred in 2007.

Eleven EU countries set records for their biggest annual percentage falls in power sector CO<sub>2</sub> emissions. Of these, Bulgaria recorded the largest fall in 2023 at 44%, primarily because it exported less coal power. Spain's emissions fell by 25%, due equally to a rise in solar and a fall in electricity demand. Germany's emissions fell by 21%, much of which was due to a rise in wind and solar replacing coal generation (whilst increased electricity imports met the fall in nuclear generation as Germany closed its final reactors). The Netherlands' emissions fell by 16% as wind significantly increased. Czechia's emissions fell by 16% as it was unable to export as much costly coal generation. Poland's fell by 15% as coal generation was replaced by a combination of more wind, solar and gas, more electricity imports and lower demand.



## Fossil fell due to a mix of factors

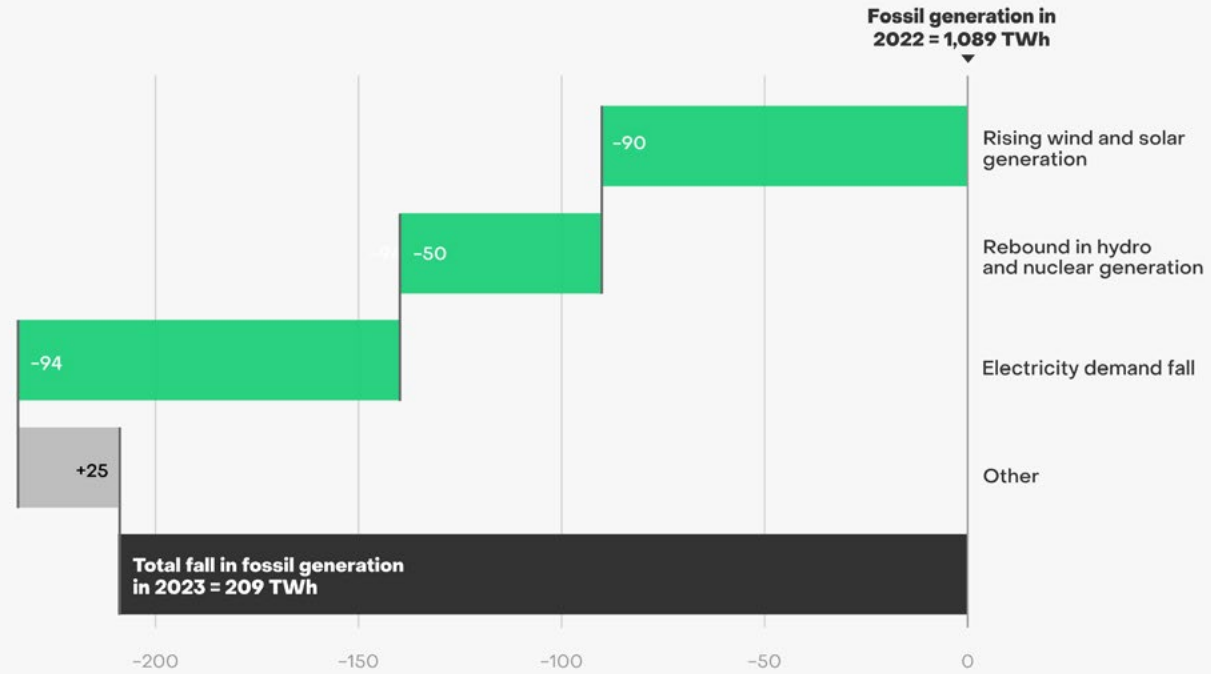
Fossil fuel generation fell by a record 209 TWh (-19%) in 2023. Rising wind and solar generation contributed to 43% (90 TWh) of the fall in fossil fuel generation. Declines in electricity demand accounted for 45% of the drop.

In addition, hydro generation rebounded significantly in 2023 (+15%) after a 1-in-500 year drought hit mainland Europe in 2022. French nuclear generation also recovered after huge falls in 2022 due to extended plant outages, which meant EU nuclear generation was up 1.5%.

The substantial fall in fossil generation was anticipated. Last year, Ember predicted a [20% \(211 TWh\) drop in fossil generation](#) for 2023, compared to an actual 19% (209 TWh) decline.

## What drove the record fall in EU fossil fuel electricity generation in 2023?

Change in electricity generation or demand (TWh)



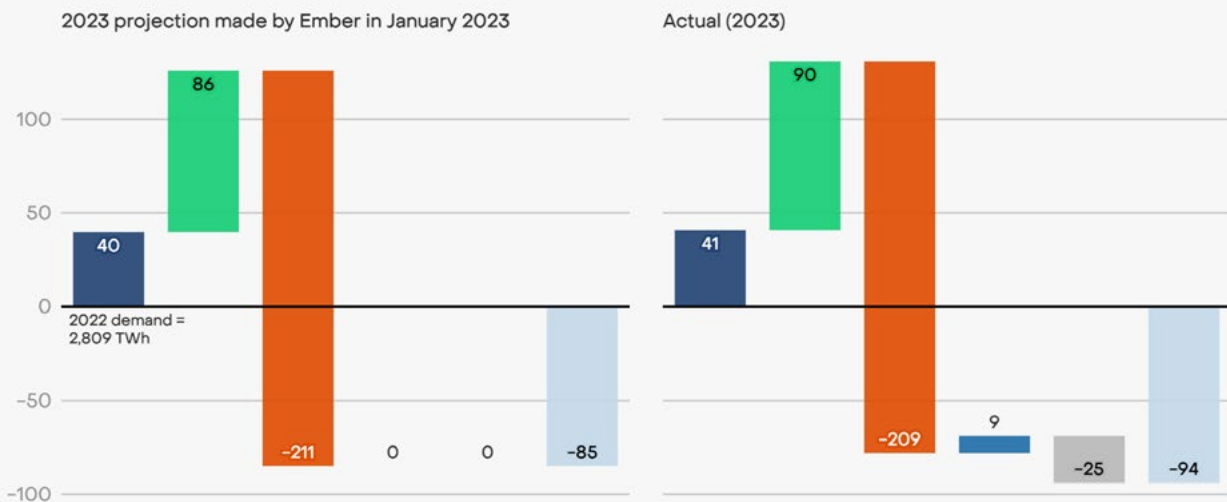
Source: Annual electricity data, Ember



## A big fall in fossil generation was predicted for 2023

Year-on-year change in electricity generation, TWh

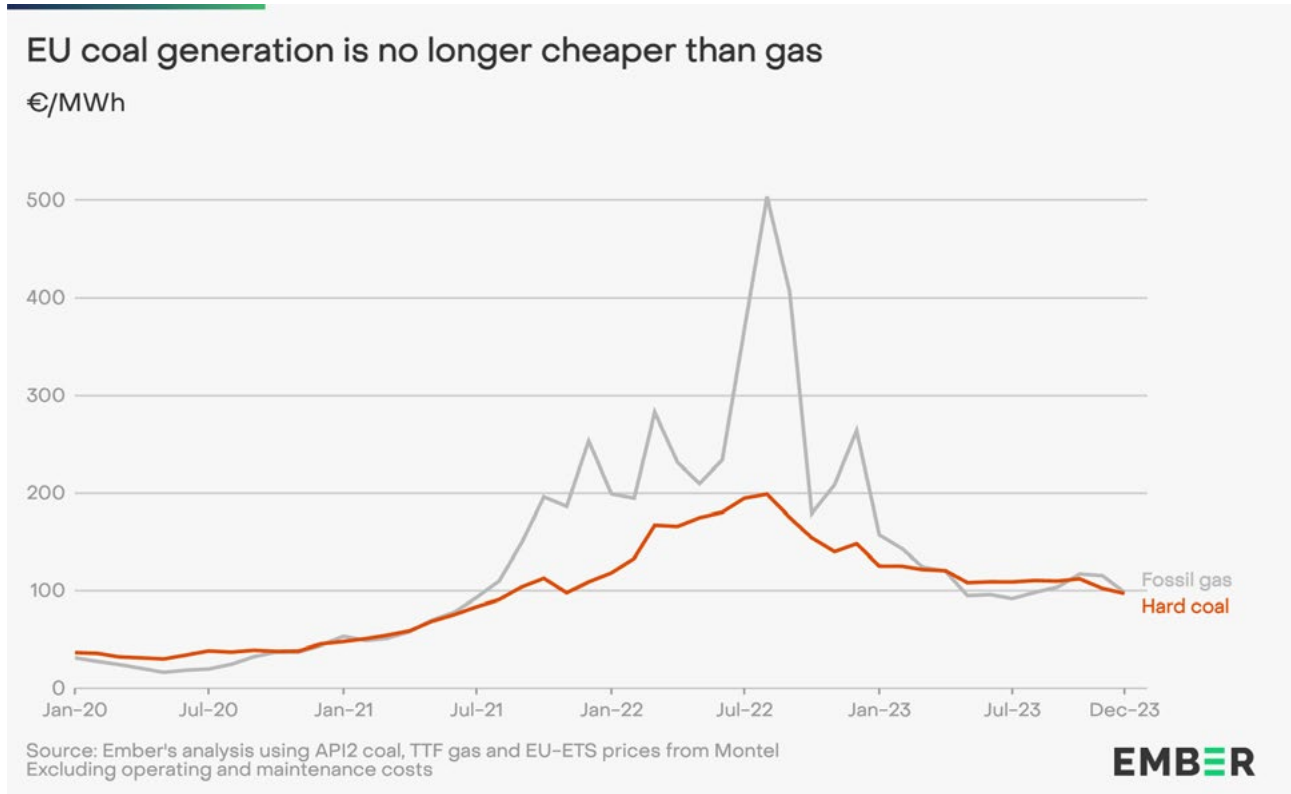
■ Hydro ■ Wind and solar ■ Fossil ■ Nuclear ■ Other\* ■ Demand



Source: Annual electricity data, Ember; Ember calculations  
 \*Other includes bioenergy, other renewables, other fossil fuels and net imports



What Ember's analysis did not anticipate was that the majority of the fall in fossil fuel use would be from coal generation. Out of the 209 TWh drop, over half (56%, 116 TWh) was coal. Gas generation was far more expensive than coal throughout 2022, but this did not persist for long into 2023, as gas generation costs returned to similar levels as coal.



## Europe's coal phase-out gathers pace

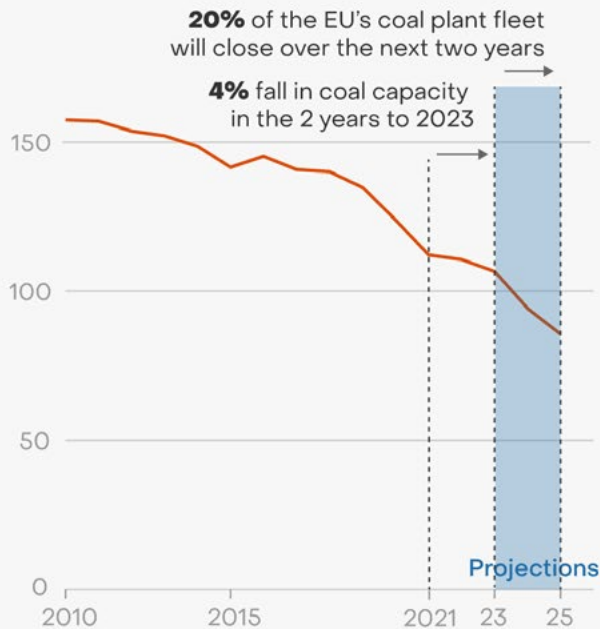
Coal generation fell by a record 26% in 2023. However, amidst the energy crisis, only 4% of the EU's coal fleet (4 GW) closed from 2021 to 2023. The closures of some coal power plants were postponed and a small proportion of units came back into operation as part of emergency reserves.

This is about to change. A fifth (21 GW) of the EU's coal fleet will close in 2024 and 2025. This includes 10 GW of coal power plants in Germany, most of which are scheduled to shut down in April 2024. In 2025, a large number of coal plants will close in Italy, Poland and Greece. Spain will close its remaining coal power plants in 2025.



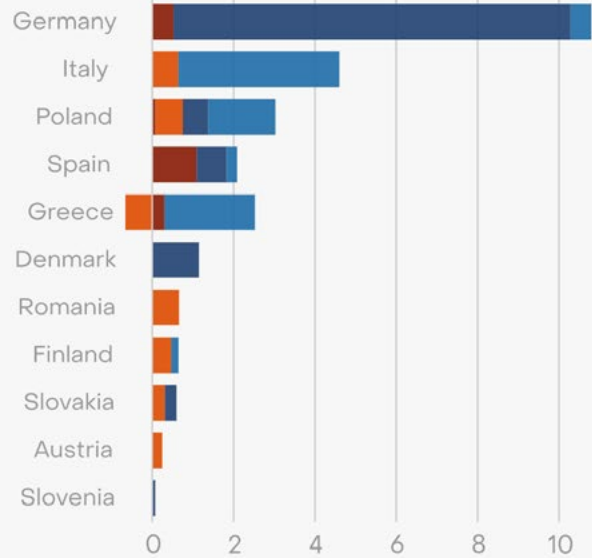
## A fifth of the EU's coal plant fleet will close in the next two years

### EU coal capacity (GW)



### EU coal capacity closures (GW)

2022 2023 2024 2025



Source: Beyond Fossil Fuels: European Coal Plant Database, Ember calculations

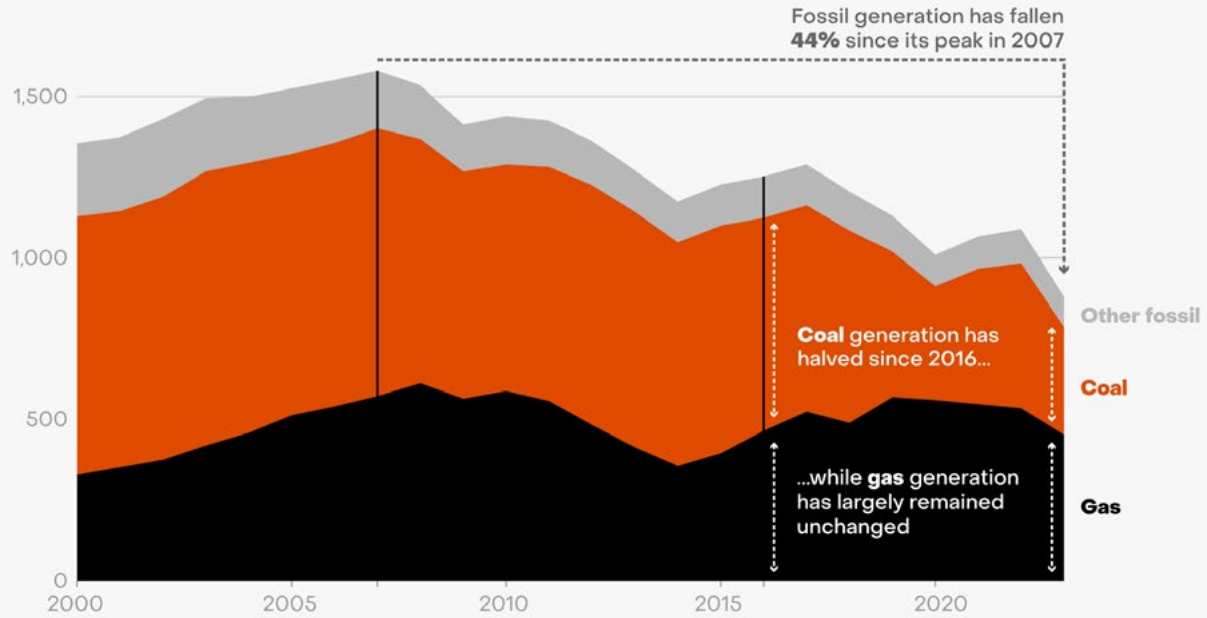
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These closures continue a pattern of structural decline for coal in the EU, alongside a shift to renewables. EU coal generation has halved since 2016 (-49.5%). Coal generation fell by 327 TWh from 2016 to 2023, compared to a rise in wind and solar generation of 354 TWh. The halving of coal can be completely attributed to the rise in wind and solar generation. Coal's decline did not lead to higher gas generation: even as coal generation halved, gas generation showed a slight fall (-3%) since 2016.

As coal nears its end date across the EU, the next big shift will be away from gas. In many countries, coal has been almost phased out, so as the build-out of wind and solar accelerates gas generation will also begin to fall. This is especially true in the key gas burning countries of Italy, Spain and the Netherlands, which accounted for half (51%) of the EU's gas generation in 2023. Across 2023, the share of coal in these countries had fallen to 5%, 1.5% and 7% respectively; in multiple hours there was no coal generation running.

## Coal power generation has halved since 2016

Electricity generation (TWh)



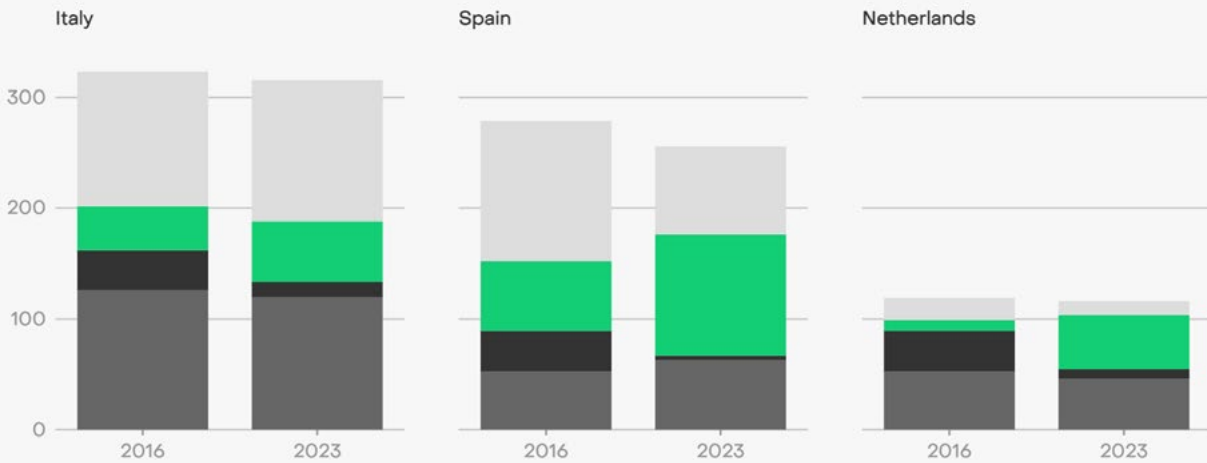
Source: Annual electricity data, Ember

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## Wind and solar have pushed out coal in Italy, Spain and the Netherlands. Gas will be next

TWh

Gas Coal Wind and solar Other



Source: Annual electricity data, Ember

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The EU has made huge strides in its electricity transition in 2023, with fossil fuels now making up less than a third of the EU's electricity. The slowdown of coal plant closures during the energy crisis did not prevent a substantial fall in coal generation this year and the coal phase-out continues. Gas generation has fallen for the last four consecutive years and its decline looks set to gather pace. As fossil fuels get pushed further out of the electricity mix, emissions will fall at a faster pace towards the EU's 2030 reduction targets.

## Insight 2:

# Wind and solar are driving renewables growth towards REPowerEU targets

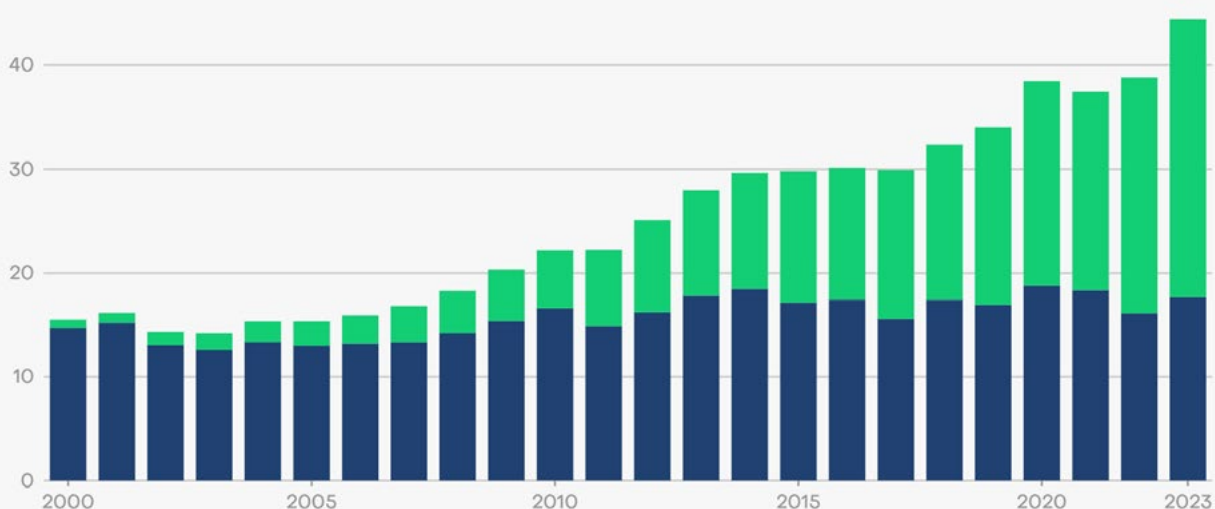


For the first time, more than a quarter of EU electricity (27%) came from wind and solar in 2023, with 10 countries above this level. Wind and solar drove renewable electricity past the 40% mark for the first year in EU's history as well, reaching 44% of EU electricity generation in 2023.

### Wind and solar power drove EU renewable electricity past 40% for the first time in 2023

Share of EU electricity generation (%)

Wind and solar Other renewables

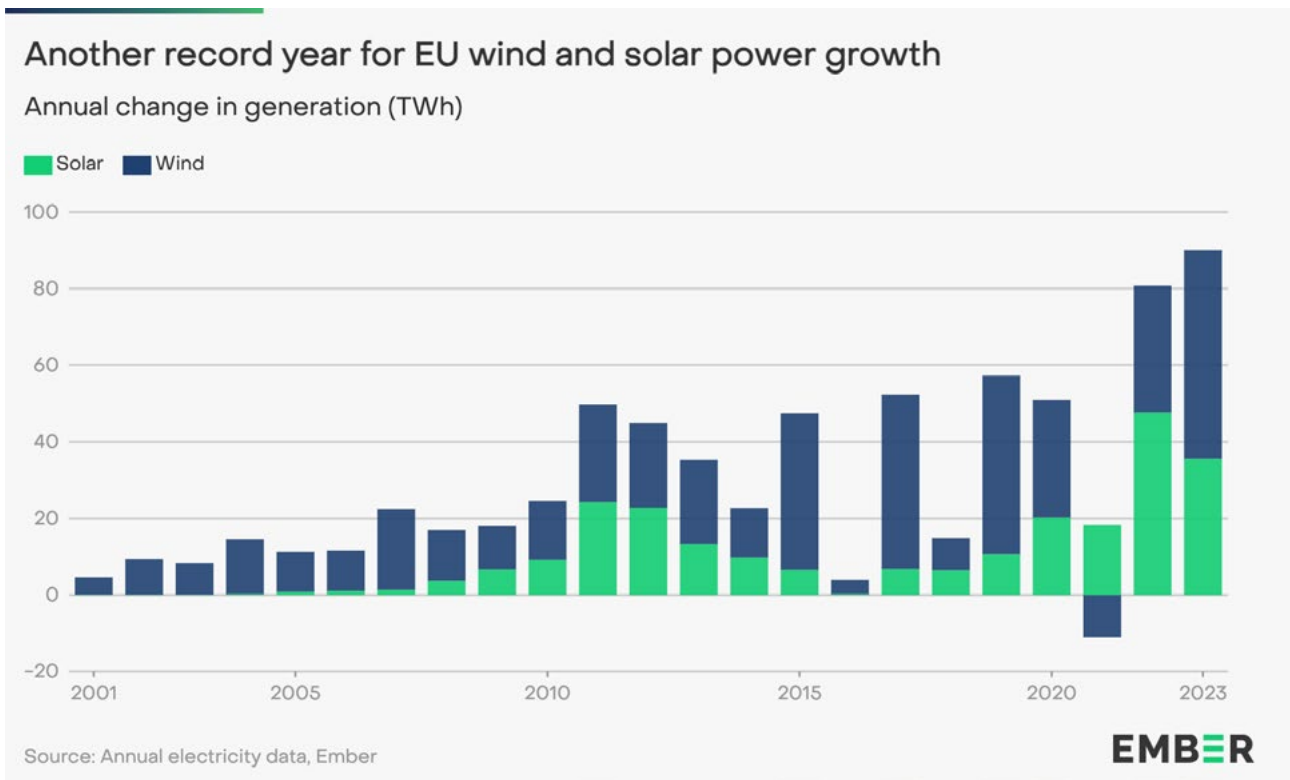


Source: Annual electricity data, Ember  
Other renewables include bioenergy and hydro

The share of renewable electricity increased by 14 percentage points in the last seven years, but this pace needs to almost double over the next seven to reach the 72% of generation target [proposed in REPowerEU](#). The renewables growth since 2017 has come from increased wind and solar generation, with bioenergy stagnant and hydro declining over the same period.

## Wind and solar are growing, but pace must increase

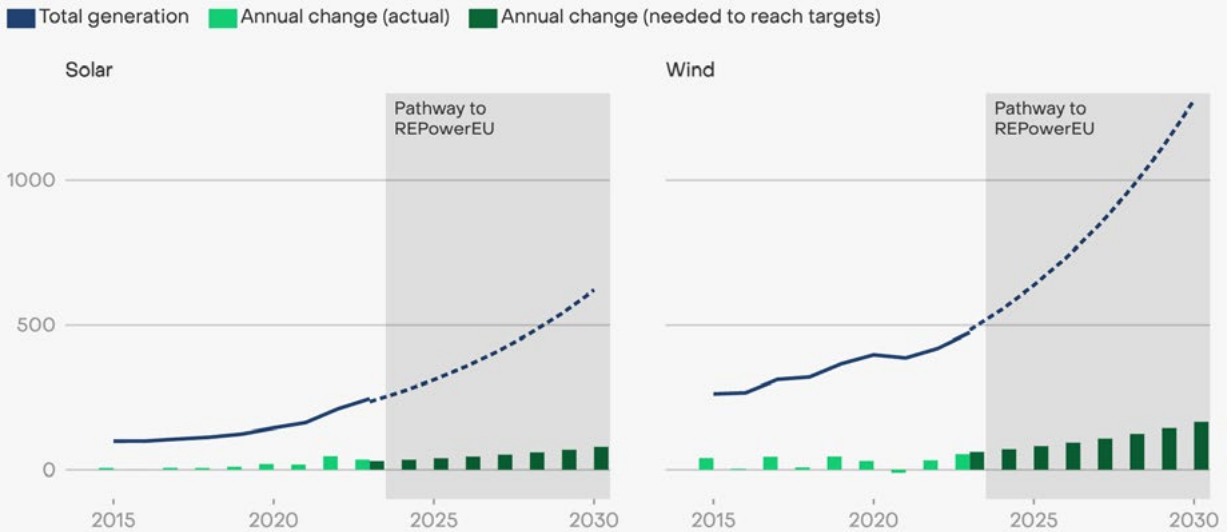
In 2023, wind generation grew by 55 TWh (+13%) and solar by 36 TWh (+17%) compared to 2022. Combined, wind and solar achieved their highest year-on-year increase on record. And wind exceeded its previous peak annual growth of 45 TWh (+17%) in 2017 by 8 TWh.



However, after an exceptional year in 2022, solar generation growth was lower in 2023 by 25%, dropping from 48 TWh to 36 TWh. And while wind generation growth was strong in 2023, it has been inconsistent over the past decade. This is concerning, because to reach the EU's 2030 climate targets and stay on track for 1.5C, the pace of wind and solar deployment [needs to be accelerating](#).

## Wind and solar growth needs to accelerate to reach EU renewables targets

EU electricity generation from wind and solar against targets (TWh)



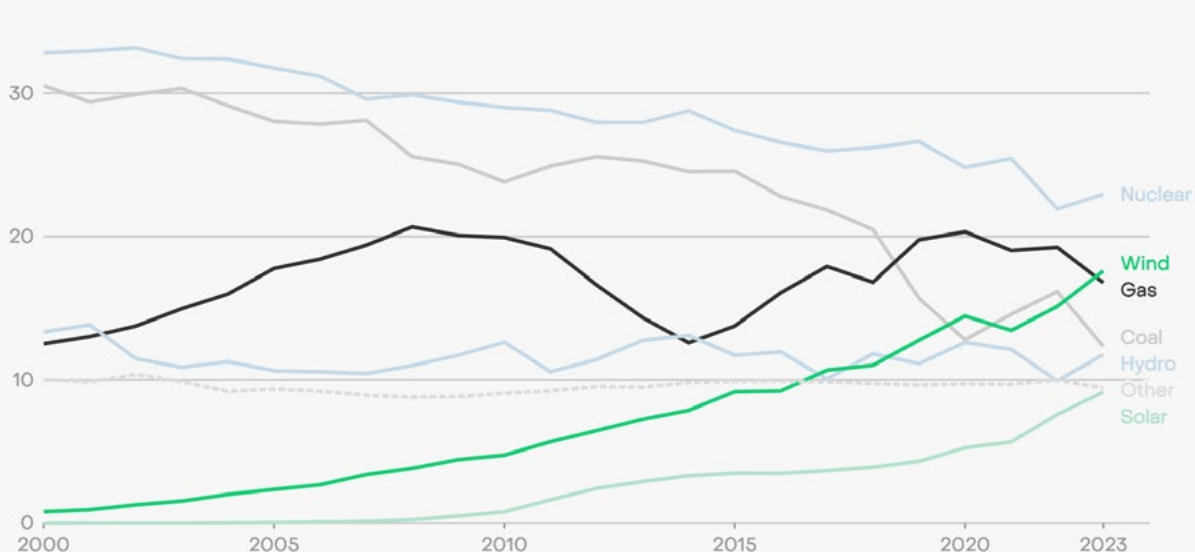
Source: Annual electricity data, Ember, European Commission REPowerEU modelling  
A fixed percentage growth pathway for wind and solar is assumed, starting from 2022 and reaching 2030 generation values from European Commission modelling



Wind’s strong performance in 2023 led to an important milestone: wind alone surpassed EU gas power for the first time, reaching 18% of electricity generation (475 TWh compared to 452 TWh for gas). 2023 was also the first year (other than Covid-19-impacted 2020) when wind electricity exceeded coal (333 TWh). The EU’s total installed wind capacity grew by 17 GW (+8%) in 2023 up to 219 GW.

## Wind produced more electricity than gas for the first time in 2023

Share of EU electricity generation, by source (%)



Source: Annual electricity data, Ember  
'Other' includes bioenergy, other fossil and other renewables



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Still, even wind's 13% rate of generation growth is not enough to meet the REPowerEU targets that would require [at least 15% yearly increases in wind electricity generation](#), consistently until 2030.

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## Wind's future is still to be determined

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Several risk factors have historically negatively impacted wind power deployment, and could again. The factor mentioned most often is long permitting times [exceeding four years](#) in almost all EU countries for onshore wind, and [twice that or more for offshore wind](#). Meanwhile, the industry has been flagging a rise in costs across the [supply chain](#) and there have also been reported technical [issues with some wind turbines](#).

However, there were some positive indications for wind in 2023. The first offshore wind auction was resolved in [Lithuania](#), Latvia announced a potential increase in its [first offshore wind farm capacity ELWIND](#) and [German auctions awarded 7 GW of offshore wind projects](#). Also positively, in a long-awaited move, the [Polish government changed](#) the very restrictive [onshore wind distancing law](#) and the [Hungarian government is sending positive signals](#) about a similar legislative change as well.

2024 will be a defining year for offshore wind, with a record [50 GW](#) of offshore wind due to be auctioned. The results of these auctions will indicate just how important, or not, offshore wind will be to Europe's energy future.

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## Despite fears, solar is going strong

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Recent concerns for solar deployment have included curtailment, panel stockpiling and grid connection queues, [but data from 2023](#) shows that solar power is hitting capacity records. An additional 56 GW of solar capacity was installed in 2023, which is a significant increase compared to the 41 GW added in 2022. Cumulatively, solar capacity now stands at 263 GW. The installed capacity growth this year puts the EU in line with SolarPower Europe's most likely scenario, which estimated 54 GW additions for 2023, and on track to surpass the REPowerEU capacity goal of 380 GW by 2025.

Solar electricity generation grew by 36 TWh in 2023, reaching 9% of the EU's total electricity generation. However, the growth in generation did not match the record high capacity additions. In fact, the yearly generation increase was lower than in 2022. A drop in capacity factors (how much electricity is produced compared with a plant's maximum potential output) can be attributed to lower irradiation in key solar energy producing countries, such as Germany and Italy. Looking at the [Global Horizontal Irradiation](#) (GHI) values weighted by capacity, on average [solar irradiation](#) across EU countries was 3.4% below 2022 levels.

Additionally, it is apparent from Ember's analysis that system operators in many countries are struggling to measure behind-the-meter solar accurately as capacity rapidly increases. Taking this and weather adjustments into account, we estimate that solar generation probably grew by at least 47 TWh in 2023 rather than 36 TWh. However, the annual growth would still be marginally below that seen in 2022 (48 TWh). This structural under-reporting of solar generation also makes it appear that electricity demand is falling faster than it actually is.

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## More and more power systems are running with very high renewables shares

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Many examples show renewables-based power systems working reliably with up to 100% renewable electricity shares. Greece ran on [100% renewables](#) for 5 hours in October 2022 and in July 2023 hit [87 consecutive hours without lignite](#) and with renewables shares up to 84%. Portugal ran entirely on renewables for [6 consecutive days](#) in November 2023. In Poland, a country historically almost fully dependent on coal, renewables covered [67% of domestic power demand](#) in peak moments in June 2023 – a number significantly exceeding the often repeated threshold of 50%. In the Netherlands, there were approximately [140 hours](#) in June in which electricity production from solar and wind exceeded the total electricity demand. And generation data reveals that Germany saw six days in December when all of its demand was covered by renewables.

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## Wind and solar leaders and laggards

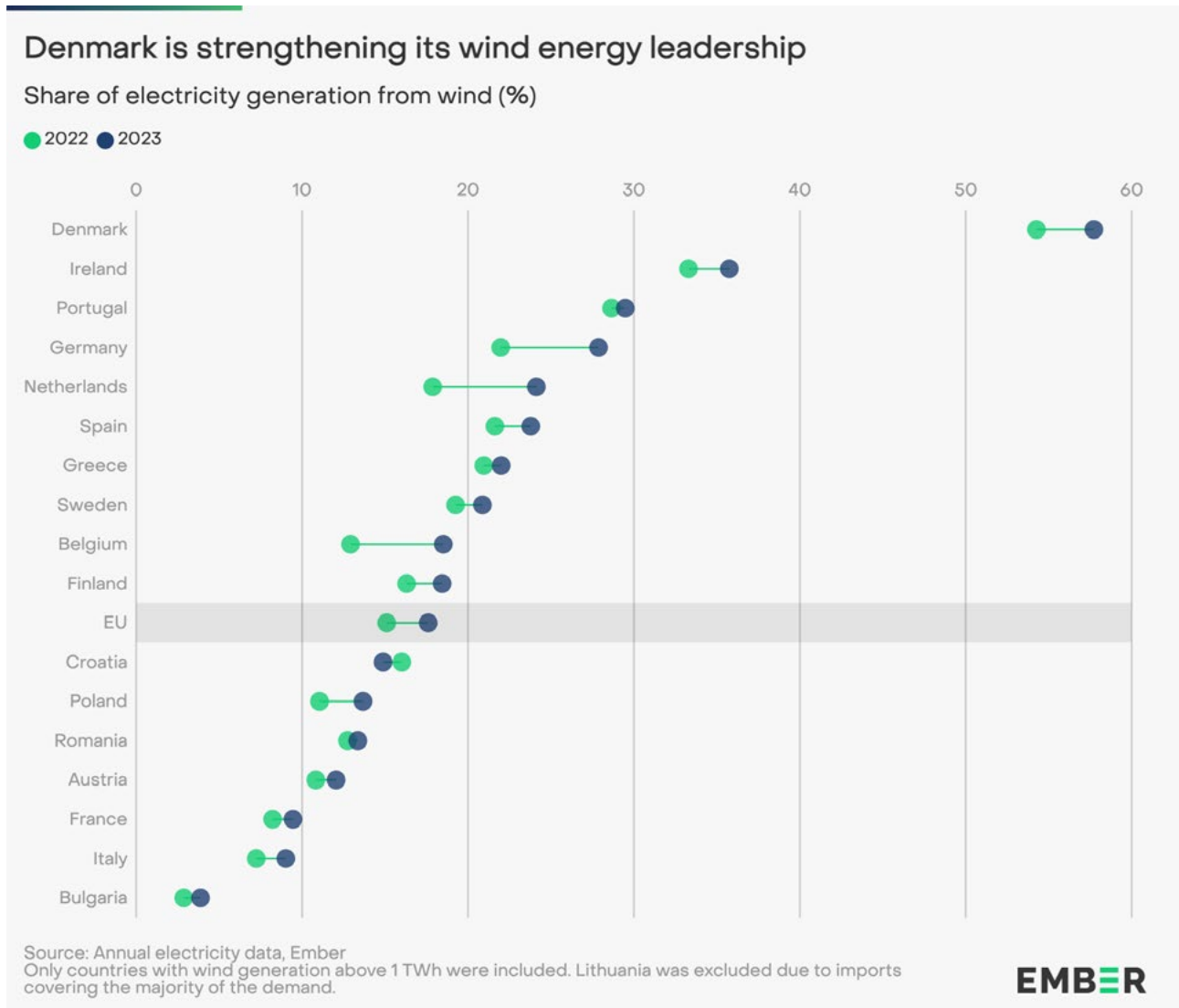
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In terms of wind energy, Denmark is strengthening its leadership position, producing 58% of the country's electricity from wind, up from 54% in 2022. Second place goes to Lithuania with a 46% share of wind in the electricity mix, although it is important to note that the country covered only 44% of its power demand with domestic generation. Third place is occupied by Ireland, having increased the wind share from 33% to 36% in 2023. Overall, 21 countries achieved their highest ever share of wind in the electricity mix in 2023, with the largest year-on-year percentage point increases seen in Lithuania, the Netherlands, Germany and Belgium.

Germany achieved the highest absolute increase in wind generation (+16 TWh), followed by France (+10 TWh, five times the 2022 annual increase of 2 TWh) and the Netherlands (+8 TWh, double the 2022 value of 3.5 TWh). The Netherlands was also among the countries achieving the highest percentage increases in wind electricity generation (+36%), only outperformed by smaller Lithuania (+59%), Luxembourg (+58%) and Latvia (+37%) that are benefitting from relatively large wind capacity additions, and followed by France (+26%), Belgium (+25%) and Finland (+25%).



If the high wind growth in Germany and the Netherlands is sustained, both countries might surpass Portugal in terms of wind share in the power mix next year. In fact, despite being one of Europe's clean energy champions, Portugal has still not moved past a peak in wind generation achieved in 2019 (14 TWh), even though the updated [National Energy and Climate Plan](#) assumes a swift doubling of the current wind capacity, from 5 GW in 2022 to 12 GW by 2030. Wind deployment in Portugal should be accelerated by the upcoming [3.5 GW](#) offshore wind auction scheduled for early 2024, although it is becoming late to secure project delivery by 2030.



The list of solar leaders saw a significant shift this year, with Greece emerging as the new leader, generating 19% of electricity from solar, followed by Hungary (18%) and Spain (17%).

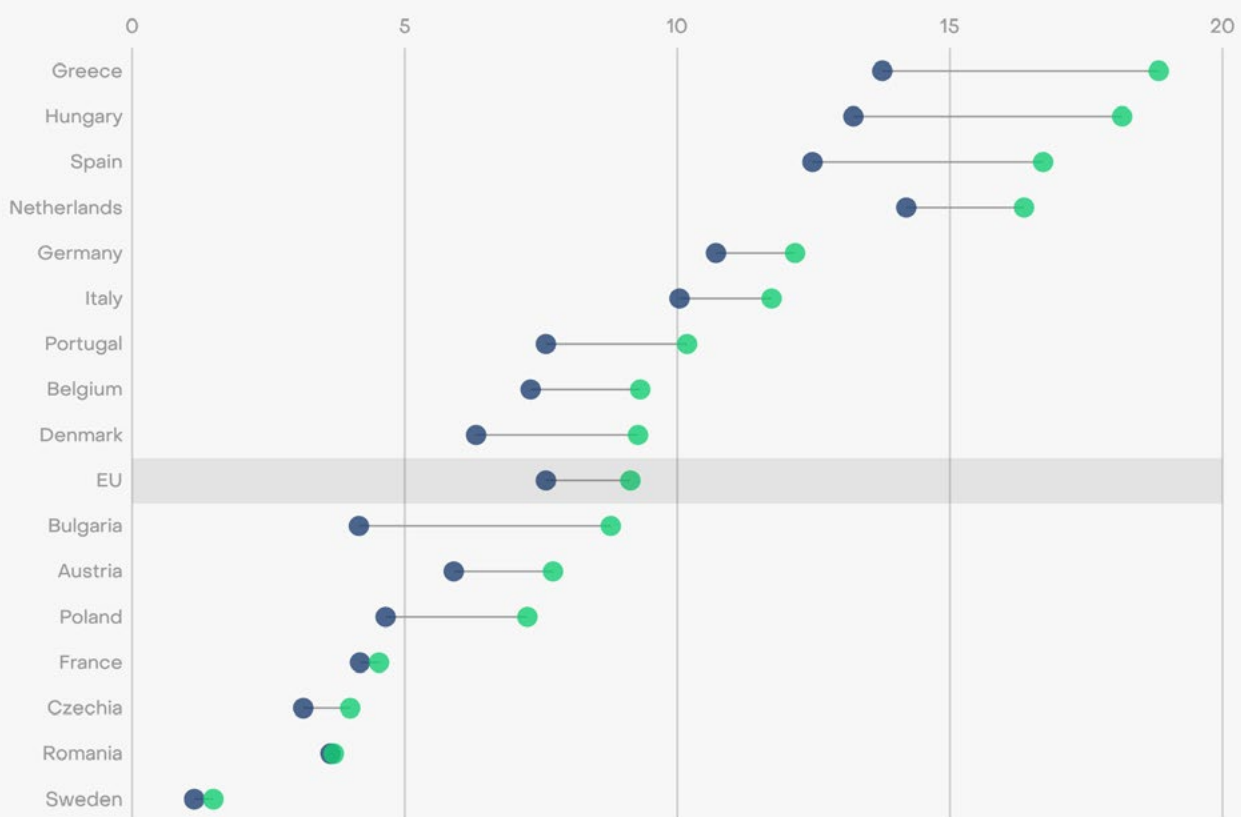
Greece's success can be attributed to the accelerating capacity growth since 2019 ([1.4 GW added in 2022 and 1.7 GW in 2023](#)), made possible due to the feed-in premium for small ground-mounted PV (until the end of 2022), permitting procedures simplified in 2022 and strengthened Power Purchase Agreement (PPA) support.

The Netherlands – the former solar champion – dropped into fourth place (16%), a significant change from the five percentage point jump in 2022. This was predominantly caused by grid congestion, a lack of available space for ground-mounted PV systems and the anticipated phase out of the net-metering scheme. The Netherlands is also the only country not to increase its 2030 solar capacity target in its draft National Energy and Climate Plan.

## The EU solar race is increasingly intense, with Greece emerging as a new leader in 2023

Share of electricity generation from solar (%)

● 2022 ● 2023



Source: Annual electricity data, Ember  
Countries with solar generation below 1 TWh were excluded from this graphic

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Overall, 24 countries achieved a record share of solar in their electricity mix in 2023, with Latvia, Slovakia and Slovenia as the only EU exceptions.

In absolute generation, Spain had the largest increase of 9.4 TWh (+26%). This is more than double the next highest, Poland, with a 3.9 TWh (+47%) increase, which however did not match 2022 growth (+4.4 TWh). Next were France at 3.6 TWh (+18%), Netherlands and Italy (+2.8 TWh, +16% and +10%, respectively). The year-on-year solar generation growth in the Netherlands was below 2022 values (+5.8 TWh, +51%).

[25 countries](#) installed more capacity in 2023 than in 2022, setting the stage for a record solar performance in 2024. Germany became the first Member State to add more than 10 GW of solar capacity in a year – 14 GW – bringing its total to 82 GW. Germany also has one of the most substantial 2030 solar target increases in its NECP, adding a huge 93 GW (+76%) to the previous target and aiming for 215 GW of solar in total by 2030. Yet, Germany is also among the countries that saw almost no solar generation growth in 2023 (+0.8 TWh).

It is important to note that within Germany's generation data, Ember's analysis has identified an unusual trend of declining solar irradiance-adjusted performance over the past several years. We do not yet have a definitive explanation for why this is, but it could be related to challenges in measuring behind-the-meter solar generation, exacerbated recently by [high levels of residential battery storage](#). Regardless of the cause, it is possible that there is under-reporting of German solar generation.

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## Multiple countries have increased their ambition

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At the time of publication, 23 countries have [submitted updated draft NECPs](#). Nine of these have increased renewables targets for 2030, with Czechia having the largest jump from 15% to 41% renewable electricity share. This has been bolstered by plans for 10 GW of solar by 2030 up from 4 GW previously. Lithuania (100%), Denmark (99%) and Portugal (92%) lead the way on targets for share of renewable electricity. Lithuania is aiming for 5.1 GW of solar compared to 0.9 GW stated in its previous NECP. Italy is also stepping up, with plans to triple its current solar capacity to 80 GW by 2030.

Overall, 17 out of the 20 EU countries that specified wind and solar targets in their updated NECPs have raised wind capacity goals, while 18 countries have raised solar ambition.

The [Solar Energy Strategy](#) – introduced as part of the REPowerEU package in May 2022 – and the [Wind Power package](#) – announced in October 2023 – contain tools to facilitate implementation of regulation and targets by Member States. These plans are vital steps to ensuring countries achieve their and the EU's wind and solar ambitions.

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## Wind and solar remain cheaper than fossil fuel generation

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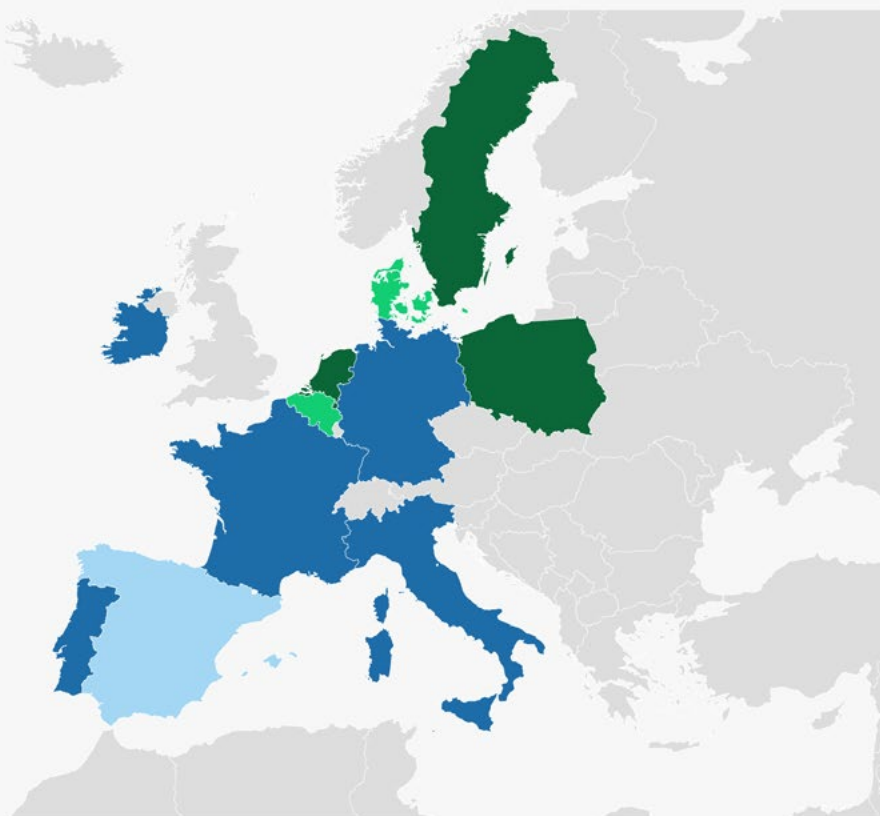
There was much attention drawn to increased costs for renewables projects in both 2022 and 2023. Global inflation pushed up prices for supply chain materials and significantly raised the cost of capital, as the era of extremely low interest rates came to an end. Solar fared better than wind, with solar panel prices in Europe [falling to a record low](#) in 2023.

However, even despite some increased costs, the levelised costs of electricity for coal and gas have remained much more expensive than wind and solar. This is partially due to the fact that high inflation rates also affect fossil fuel assets, but it is also a result of coal and gas prices. While prices were lower in 2023 than the unprecedented highs of 2022, they remained higher than pre-energy crisis levels. Looking at 2023, analysis for the first half of the year confirms that new build wind and solar projects remained cheaper than new build coal and gas in the EU.

## EU wind and solar projects are still cheaper than coal and gas

Cheapest new-build technology by country (January–June 2023)

■ Onshore wind
 ■ Offshore wind
 ■ Fixed-axis PV
 ■ Tracking PV



Source: BloombergNEF

Technology with the lowest LCOE or auction price for new-build plants. LCOEs exclude subsidies, tax credits and grid connection costs but include carbon costs. Kosovo: This designation is without prejudice to positions on status, and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo declaration of independence.

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As cheaper wind and solar provide an ever increasing share of the EU's electricity, replacing more expensive fossil fuels, this will reduce wholesale electricity prices.

These wholesale prices may only account for a proportion of the prices paid by consumers but they are the largest single contributor. [Ember analysis of the UK market](#) has revealed that deploying renewables at speed will not only lower wholesale power prices, but also cut bills for households, even accounting for additional costs such as grid expansion or Contracts for Difference schemes (CfDs).

There has been some encouraging news for wind and solar in 2023, achieving both installed capacity and generation records. This has driven the share of renewables in the EU electricity mix to its highest level ever, with wind overtaking gas for the first time. However, the pace of growth is still not fast enough, in particular for wind. And there is still much work to be done to remove implementation barriers and bottlenecks and achieve the ambitious EU 2030 targets.

## Insight 3:

# After disruption to demand, an increase is on the horizon

In 2023, EU electricity demand fell by 3.4% to its lowest level since 2001 (2,696 TWh). This follows a large fall in 2022, putting EU electricity demand 6.4% lower in 2023 than it was in 2021. Multiple factors contributed to the drop amid a turbulent few years for Europe's power sector. However, this looks set to change as energy prices stabilise and a new, rapidly-electrifying system emerges.

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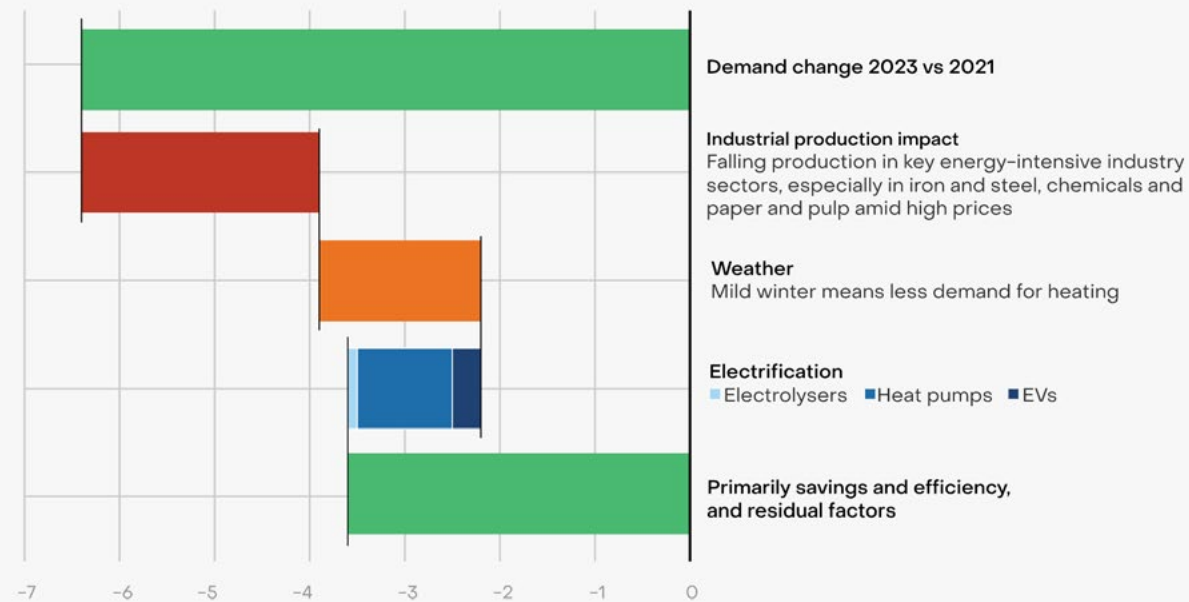
## Multiple factors drove down electricity demand, with industry accounting for just over one third of the drop

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Amid the energy crisis, EU electricity demand fell by 6.4% (-186 TWh) from 2021 to 2023, with just over a third (38%) caused by a drop in industrial electricity consumption. Mild weather and energy savings and efficiency also contributed, as electrification created more demand.

## The EU's fall in electricity demand can be attributed to industrial production, weather and savings and efficiency

Attribution of the demand fall from 2021 to 2023 (%)



Source: Ember analysis based on Ember data (electricity demand), Eurostat (industrial production, electricity final consumption in industry), European Alternative Fuels Observatory, UBS (EV sales), European Heat Pump Market and Statistics Report 2023 (heat pump sales), IEA Global Hydrogen Review (electrolyser capacity), ERA5 Reanalysis extracted via <https://tealtool.earth/> (weather)

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Overall EU industrial production was actually 1% higher in 2023 than in 2021. However, energy-intensive industries saw steeper declines in their output during this period. As any fall in production from those industries has a much greater impact on total industrial electricity consumption, we have accounted for each sector's share in final industrial electricity demand. When that electricity-weighting is taken into account, calculations show a 70 TWh decline in total industrial electricity consumption from 2021 to 2023. Of this fall, 80% came from three key sectors: chemicals and petrochemicals, iron and steel, and paper and pulp.

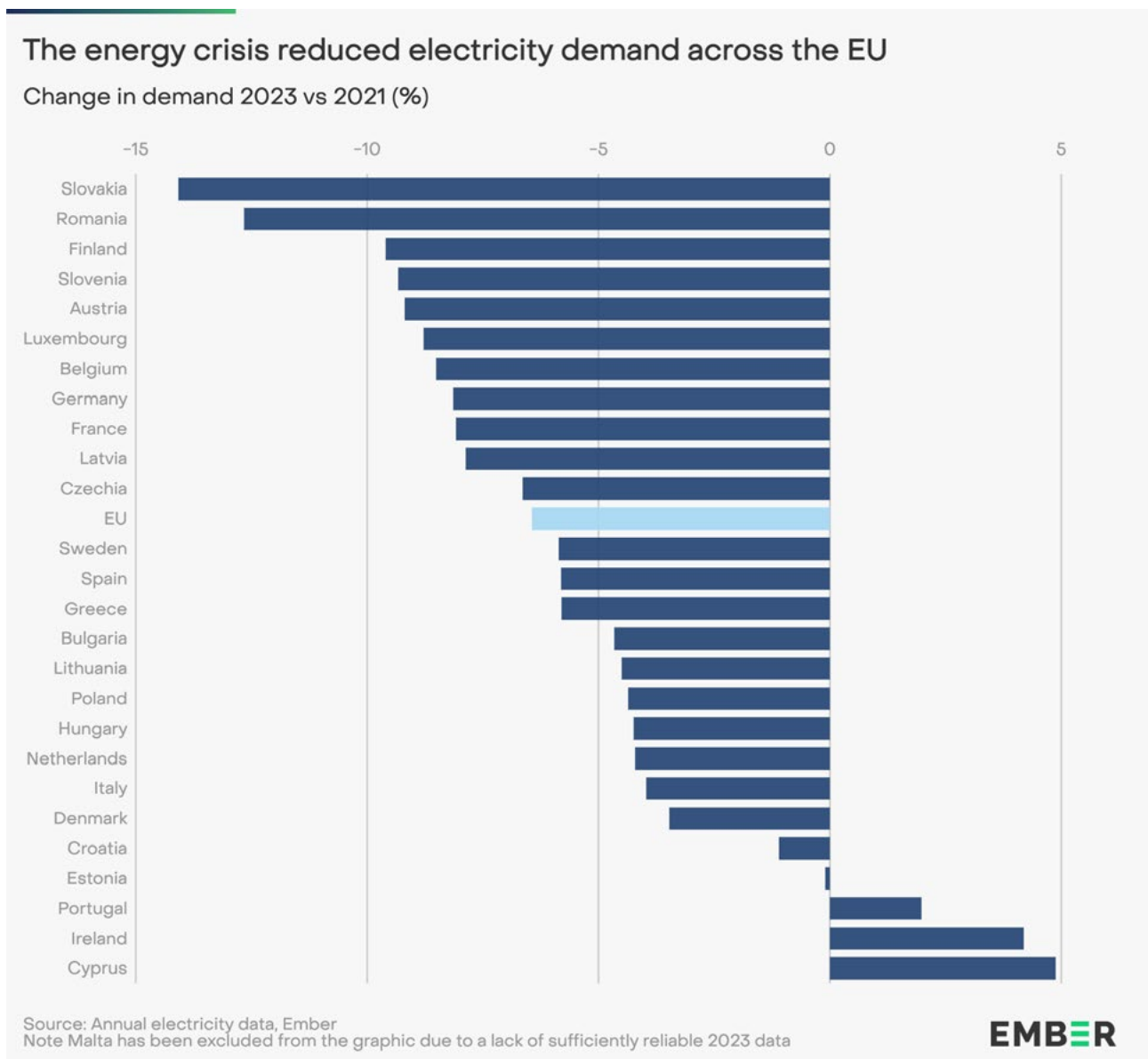
These sectors are heavy gas consumers, so it is possible that the falls in production were more a consequence of higher gas prices than of higher electricity prices. The overall fall in EU gas demand was three times that of electricity demand. It fell by 21% from 2021 to 2023.

Weather was also a significant factor in reducing EU electricity demand, accounting for 27% of the fall in demand from 2021 to 2023. 2023 was the [second-warmest year on record for Europe](#), at 1C above the 1991–2020 average. And, due to the fact that EU consumption currently peaks in winter due to heating, our weather adjustment shows that the warm temperatures in 2023 resulted in 1.7% lower electricity demand compared to 2021. Consequently, electricity demand would have fallen 4.7% – rather than 6.4% – if 2023 weather had been in line with the 1991–2020 average.

In contrast, electrification led to more demand for electricity. Since the energy crisis began, three million heat pumps and three million electric cars have been sold in the EU, and approximately 500 MW of electrolysers. This added an estimated 1.3% to the EU's overall electricity demand from 2021 to 2023.

56% of the fall in demand in the same period remains after accounting for the fall in industrial demand and weather impacts, this can be attributed to energy savings and efficiency at least in part.

The energy crisis reduced electricity demand in almost every country. Slovakia and Romania saw the biggest falls, of over 10%. Ireland, Cyprus and Portugal were the only countries to record rises. In Ireland, much of the rise was from [data centres](#), which consumed 18% of Ireland's electricity in 2022, a four-fold rise from 2015.





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## Impact from energy efficiency continues

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The fall in demand between 2021 and 2023 can be partially attributed to energy savings and efficiency. Of the 6.4% demand drop in that period, slightly over half (3.6%) is unaccounted for after factoring in impacts from industrial production and weather.

As discussed previously in this report, we know a small proportion of this is from behind-the-meter solar generation, which is not reported and therefore not captured in Ember's dataset. There are also a growing number of small behind-the-meter oil and gas generators. However, energy savings and efficiency are likely to be a more significant factor.

The energy crisis led to the European Commission introducing [emergency measures](#) to decrease both gas and electricity demand. There were voluntary electricity demand reduction targets introduced from November 2022 to March 2023. The majority of Member States [reduced their monthly electricity consumption](#) but only three reached the 10% target.

Most national governments introduced [energy saving measures](#), including consumer incentives and support for efficiency improvements, but the sky-high energy prices meant that consumers also voluntarily took action. Energy efficiency improvements were implemented, such as building insulation and efforts to reduce thermostat levels and lighting. In some cases, households were financially incentivised by suppliers to lower consumption during periods of peak electricity demand.

Whether or not these reductions in demand related to energy efficiency and savings are sustainable outside of an energy crisis remains to be seen.

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## A new era of rising electricity demand

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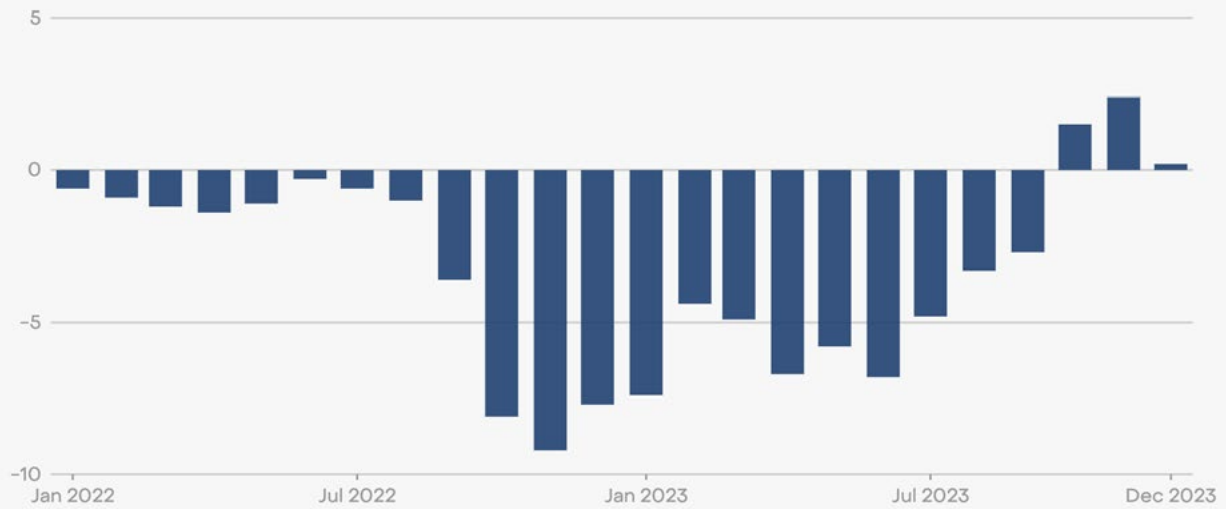
The latest monthly data indicates that the decline in electricity demand has now stabilised. After 21 months of consecutive declines, the falls stopped in October 2023 and turned to small rises. The latest [industrial production data](#) confirms year-on-year rises in the chemicals and petrochemicals sector (+1% in November 2023) and iron and steel (+3% in November 2023).

The unprecedentedly high electricity prices during the energy crisis will have been a factor in the reduction in industrial demand. The current electricity prices for the year ahead are at the lowest level since August 2021, when gas prices first began to surge.

Ember estimates that 2024 could see an electricity demand rise of around 2–3% compared to 2023 due to easing price levels; increasing economic growth and lower inflation; a colder start to the year; and accelerating electrification.

## EU electricity demand has now stabilised, following large falls during the energy crisis

Year-on-year change in electricity demand (%)

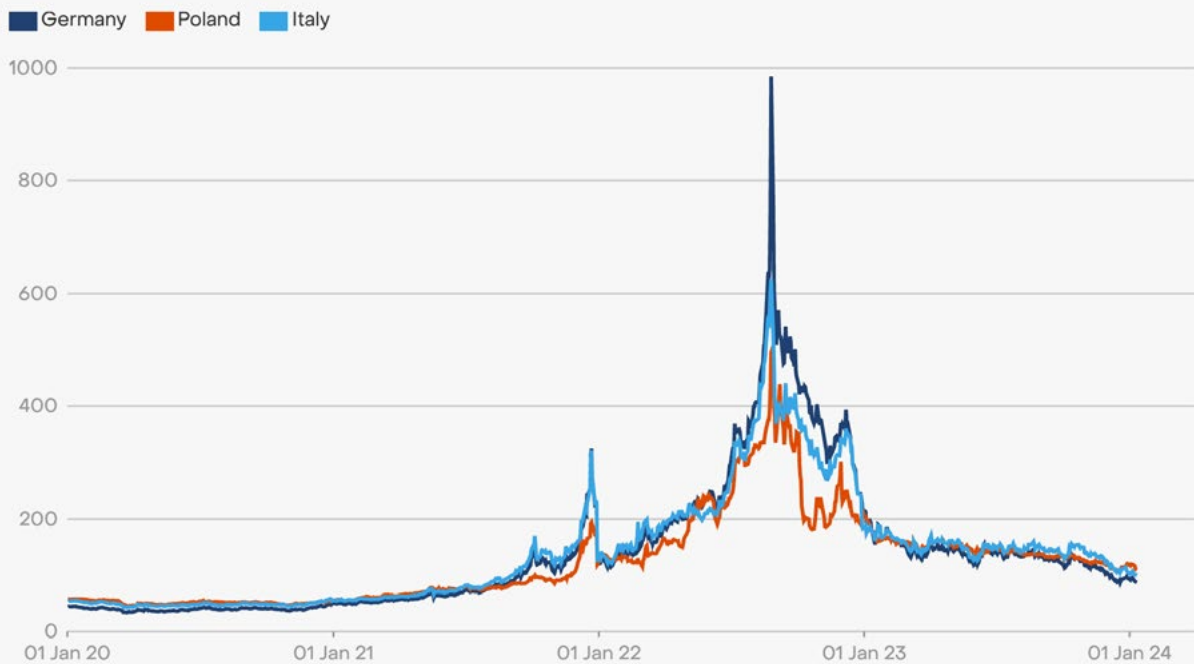


Source: Monthly electricity data, Ember

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## European electricity prices are returning to pre-gas crisis levels

Year-ahead electricity price, €/MWh



Source: Front calendar year electricity prices, Montel

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We can expect to see electricity demand continue to rise this decade as electrification picks up. Of the seven [National Energy and Climate Plans](#) that provided electricity demand forecasts for 2030, all show consumption increasing from 2020 levels, including increases of 13% for Italy and 17% for Spain.

The demand falls have most likely stopped, and we are about to enter a new era of rising electricity demand for the first time since the 2000s. Renewables will need to keep pace as demand increases, or the reduction in fossil fuels will fall short of what is required to hit EU climate goals.

## Insight 4:

# The EU moves towards a new mode of system flexibility



Multiple big shifts are coming for the EU's power system. By 2030, the EU will be well on its way to a decarbonised power system. Alongside the benefits to cost, climate and security, this will also come with new challenges as the system adapts to support high shares of variable sources. Consumption will also increase and become more variable as clean electrification takes off, a process that could see [EU electricity consumption increase by 60% by 2030](#).

It was evident in 2023 that these shifts are already in progress. As fossil fuel generation and emissions tumbled to record lows and the share of wind and solar in the electricity mix reached new highs, the challenges, solutions and opportunities of integrating ever-increasing levels of wind and solar rose to the top of the agenda.

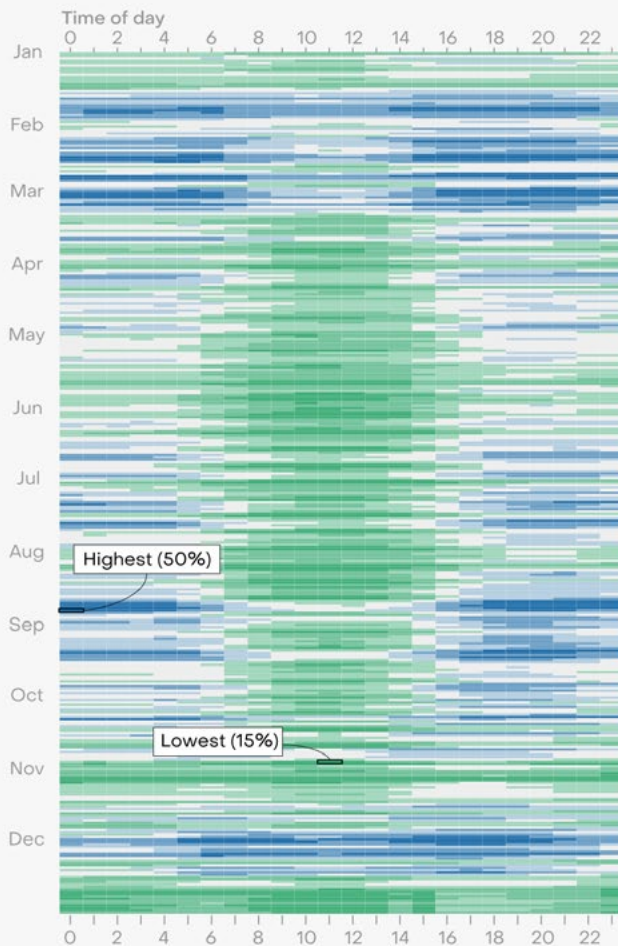
System infrastructure and flexibility mechanisms need to be enhanced and implemented to manage the unique needs of the future power system. In 2023, attention was turned towards the key enablers of that power system flexibility – including grids, storage and demand side response – to take the transition to the next level.

# The shift has already started towards a wind and solar backed system

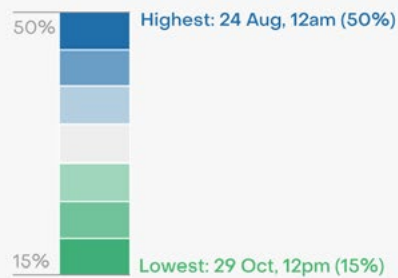
The EU power system has already started to move away from reliance on fossil fuel plants to provide flexibility. In 2023, 24% of hours saw less than a quarter of electricity coming from fossil fuels. This is an enormous change from just 4% of hours in 2022. EU fossil generation fell to its lowest hourly level ever at 12pm on 29th October 2023 to just 15% of the EU electricity mix. Fossil generation could have fallen even more throughout the year if the full availability of wind and solar generation had been harnessed rather than curtailed.

## How much fossil fuel generation is left in every hour?

Share of electricity from fossil generation in 2023 (%)

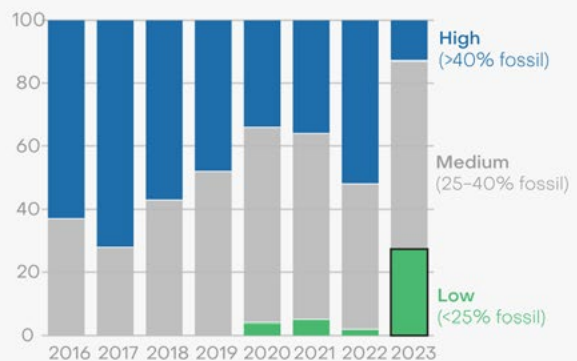


Share of EU electricity from fossil generation in every hour in 2023 (%)



### 2023 saw - for the first time - many hours with low levels of fossil fuel generation

The percentage of hours with high, medium or low fossil fuel share in EU electricity generation (%)



Source: Ember calculations based on ENTSO-E, Eurostat, E-Control GmbH, Cyprus Transmission System Operator, Energy-Charts, Agora Energiewende, Energy Institute, Terna, Statistics Netherlands, NetAnders, Solcast, Open-Meteo, ARE via Instrat, Red Eléctrica, and Elstatistik. Ireland and Malta excluded due to data quality issues.

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Available data suggests that the scale of the wind and solar curtailment problem in the EU is not currently that large, but that it is rising. Curtailment is when network system operators or electricity producers limit the output of certain generators to avoid overloading the grid.

In the [Netherlands](#), there were 3,476 residential solar curtailment events in the first half of 2023 compared with 1,074 over the same period in 2022. This could be a contributing factor in our findings earlier in this report that solar generation in the Netherlands has slowed down. Installing more battery storage alongside residential solar could solve this issue.

The latest [IEA Renewables report](#) suggests that Spain's curtailment rate increased from around 0.3% in 2021 to 1.7% in 2022. In April 2023, the Czech Transmission System Operator (ČEPS) turned off around [400 MW](#) of solar capacity, or about one-sixth of the country's total PV capacity. Moving against the tide, the IEA reports that Italy's curtailment rate has actually fallen from around 4% in 2020 to 1.6% in 2022, despite wind and solar's generation share marginally increasing over this period.

The scaling up of alternative flexibility mechanisms is a solution to these emerging challenges. There are multiple, connected components to the provision of the required system flexibility, the demand for which is expected to double by 2030. 2023 saw attention shift towards how these elements can be optimised to best support the power sector transition.

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## Grids are critical for wind and solar integration

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Grids consist of [interconnectors](#), transmission grids and distribution networks. Adequate grid infrastructure will be crucial to ensure ever-increasing amounts of wind and solar can be integrated into the power system and transported to where it is needed the most, minimising output fluctuations and curtailment. The significance of grids has been recognised in the European Commission's [Grids Action Plan](#), which was launched in November.

Reforms to grid planning will go some way to ensuring adequate supportive infrastructure. [Ember submitted recommendations](#) to the European Commission, many of which have been incorporated into this Grids Action Plan. One particularly important requirement is for national grid development plans and incentives to be aligned with the EU's clean power targets. This has become even more imperative since [seven Member States committed to decarbonising their power sectors by 2035](#).

Investment is also a priority. The European Commission estimates that a €584 billion investment in grids is required by 2030. Industry estimates that [€375-425 billion of this needs to be in the distribution network](#). Investments in cross-border interconnectors and storage need to be €6 billion per annum. To address this, the Grids Action Plan seeks to identify reasons behind current grid underinvestment and improve access to finance.

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While this level of investment is certainly substantial, the benefits of system enhancements outweigh the costs and the price of inaction is far higher. Cross-border projects can decrease generation costs by €9 billion annually until 2040 according to the European Commission. A recent report by Bruegel found the added value of interconnection means that [upfront investment costs are soon recuperated](#). Ember's [analysis focused on Central and Eastern Europe](#) demonstrates that greater cross-country collaboration and interconnection is critical to unlock the region's over 100 GW of offshore wind potential, reduce its electricity costs and enhance its energy security.

Grid connection queues are another current challenge, also addressed in the Grids Action Plan. Currently, network reinforcement projects take five to ten years to complete. And offshore wind farms have to wait around a decade to secure grid connection. According to analysis by [BloombergNEF](#), Spain and Italy have almost 200 GW of wind and solar projects waiting to connect to the grid and France has nearly 50 GW. The situation is similar in Eastern Europe, with over 50 GW currently unable to connect in both Poland and Romania.

The EU could learn lessons from the UK, where the energy regulator Ofgem recently announced [new rules to speed up electricity grid connections](#) for viable projects and remove more speculative and unfeasible ones from the queue. There are currently 400 GW of projects waiting for connection in the existing 'first come, first-served system'.

There is also the issue of ageing infrastructure. About a third of Europe's low voltage grid is over [40 years old](#), by 2030 this will be up to 55%. In Central and Eastern European countries, there are sections of the network that have been in service for over 50 years. This demonstrates that much of the EU network needs to be upgraded or replaced even without growth in renewable generation.

However, building new poles and wires is not the only solution. There are complementary alternatives, including additional flexibility mechanisms such as storage and demand side response, which must also be planned and prioritised. The Grids Action Plan incentivises increased efficiency of the existing networks as well as prioritising investment in storage and demand flexibility. The [Electricity Market Design](#) reforms also include provisions for system operators to consider local flexibility solutions.

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## Storage relieves price cannibalisation, negative prices and curtailment

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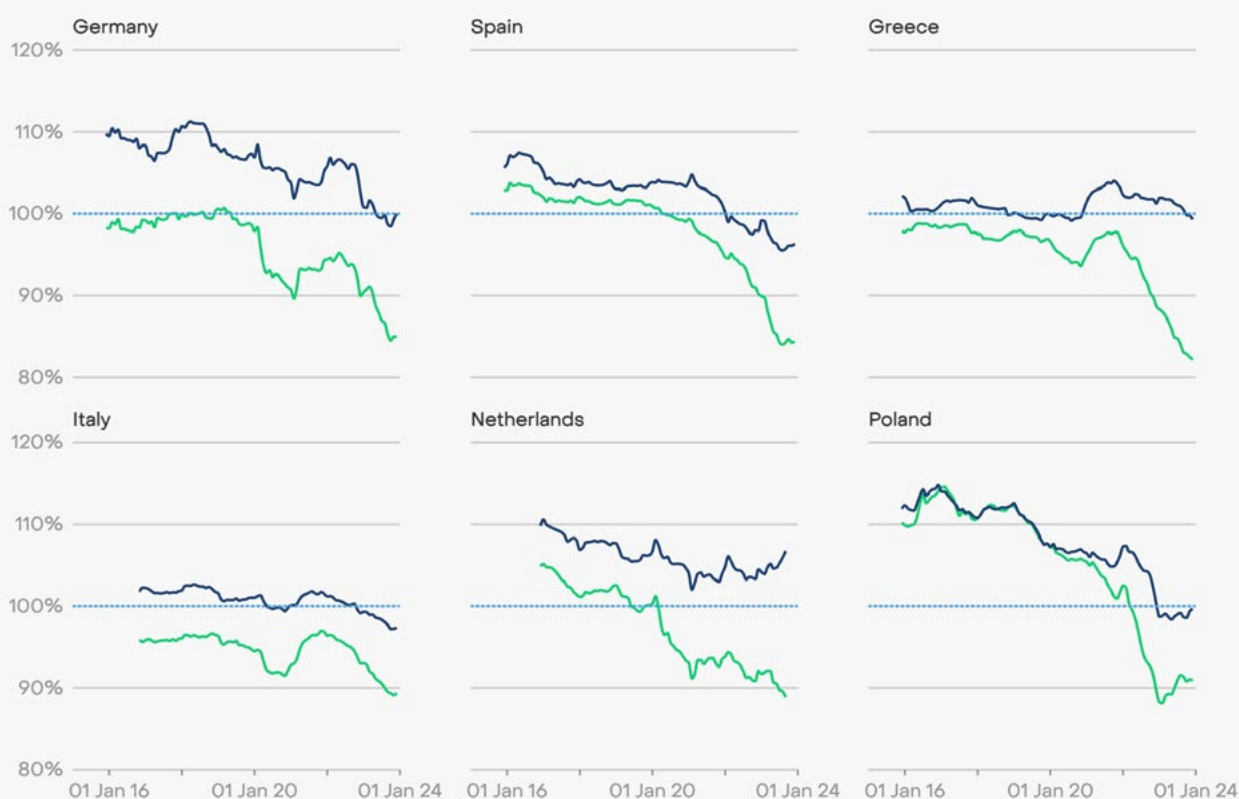
Analysis has estimated that the [EU needs 200 GW of storage by 2030](#) to enable efficient integration of renewables into the electricity grid. Storage can accumulate the electricity produced by solar at times of low demand and shift it to other times of the day when it is needed most. The enhanced flexibility that storage provides is one of the ways to reduce incidents of price cannibalisation, negative prices and curtailment.

Price cannibalisation and negative prices can occur when electricity prices are depressed during periods of high supply from variable renewable generation. This adversely impacts the generators' capture rates – the price received for their electricity in those time periods compared to the baseload price over the whole day. However, storage solutions are readily available to alleviate these instances of price falls and low capture rates.

## Battery storage makes solar electricity more valuable

Market value of solar as a % of the base price of electricity (1 year rolling mean)

Real values Modelled unit with battery storage



Sources: ENTSO-E, Agora Energiewende, Energy-Charts, Terna, CBS, Solcast, ARE, Infracore, OpenMeteo  
Battery model is for a 100 MW solar array with a 60 MW 2 hour battery. It is for a marginal unit and assumes that electricity prices are not affected by the existence of the battery. It therefore does not reflect what value factors would be captured if a large amount of such units were added. Discharge is not optimised, so is an underestimate of true value. For full details, see Ember's European Electricity Review 2024.

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Two-sided [Contracts for Difference](#) (CfDs) and Power Purchase Agreements will also remove some of these issues by delivering guaranteed prices for wind and solar generation. CfDs provide both investor confidence, due to the protection they provide against low prices, and shield consumers against price surges.

Increased system flexibility combined with grid enhancements can alleviate curtailment. Analysis by Energy Systems Catapult has found that long-duration battery storage (4 to 12 hours) could [reduce the curtailment of wind power in the UK by up to 65%](#).



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## Storage reduces bills and increases consumer control

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Storage is not only utility scale. With rooftop solar accounting for two-thirds of total installed solar capacity in the EU in 2023, residential storage co-located with rooftop solar will play a significant role going forward. Residential storage is a valuable tool for reducing energy bills and increasing consumer control over consumption. By storing excess energy generated by their solar panels, households can use it to power their homes when electricity prices are high.

### Case study – Germany is leading the way in residential battery storage

Alongside the boom in rooftop solar has come a surge in residential battery storage installations. And according to the [Joint Research Centre](#), Germany accounts for two-thirds of the EU market. Over 80% of new German home solar installations have battery storage systems. Almost [500,000 home batteries have been installed in Germany in 2023](#), more than double the 212,000 in 2022. Total German battery storage capacity now stands at 7 GW, equivalent to the 6.8 GW of pumped hydro. Residential storage accounts for 80% (5.6 GW) of Germany's total battery storage, with large scale and industrial batteries trailing behind at a combined 1.4 GW.

Storage can also benefit consumers by reducing wholesale electricity prices, which ultimately feed into residential tariffs, by delivering power to the system at times when, currently, more expensive technologies are supplying the electricity at higher prices.

On the 4th of April 2023, the Day Ahead wholesale market in France cleared at €2,712/MWh at 7am and €2,987/MWh an hour later. More than 15 GWh of electricity was transacted at these prices. According to analysis by [Fluence](#), 350 MW of operating battery assets would have substantially reduced market prices and saved French consumers around €75 million.

2024 could be the year of the battery. A step-up in manufacturing capacity would be enough to significantly push down battery prices even as demand surges – similar to what has happened to solar panel manufacturing in 2023. The IEA [forecasts that Europe may install 70 GW of stationary batteries](#) from 2023 to 2028. This is higher than the 50 GW of total storage currently forecast in the National Energy and Climate Plans by 2030.

## The need for seasonal storage may be exaggerated

The weather-dependency and variability associated with wind and solar power generation requires hourly and daily balancing through storage or peaking power plants. However, persistent claims about wind and solar creating a need for seasonal storage might be highly exaggerated.

According to monthly data, wind and solar have been working in tandem, complementing each other to provide stable output across all months of 2023. Across different months in 2023, the combined wind and solar generation in terawatt hours only varied within the range of -13% to +10% from the yearly average, with October, November and January (critical months due to the heating season) all delivering above average. Due to the higher electricity demand in winter months, the share of electricity generation from wind and solar in winter was slightly lower, but even in the month with the lowest performance (February) it only dropped to 23% from the 26% yearly total.

### Wind and solar provide stable electricity generation across all seasons

Share of EU monthly generation (%)

■ Solar ■ Wind



Source: Monthly electricity data, Ember

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## Demand side flexibility delivers stability and savings

Another important tool for increasing system resilience is demand side flexibility. While storage enables supply to be transferred to periods of higher demand, demand side management allows non-critical consumption to be shifted in times of grid constraint. Just as significantly, this gives consumers much greater control over their energy consumption and costs.

The UK is demonstrating how beneficial demand side flexibility can be. The [Centre for Net Zero](#) estimates that the UK needs to increase demand flexibility from 6 GW today to 20–30 GW by 2030. National Grid ESO ran its [Demand Flexibility Service](#) from November 2022 to March 2023. It specified hours during which electricity suppliers should ask their customers to reduce their consumption. Households were paid between £2/kWh and £4/kWh, five to ten times the unit price of electricity.

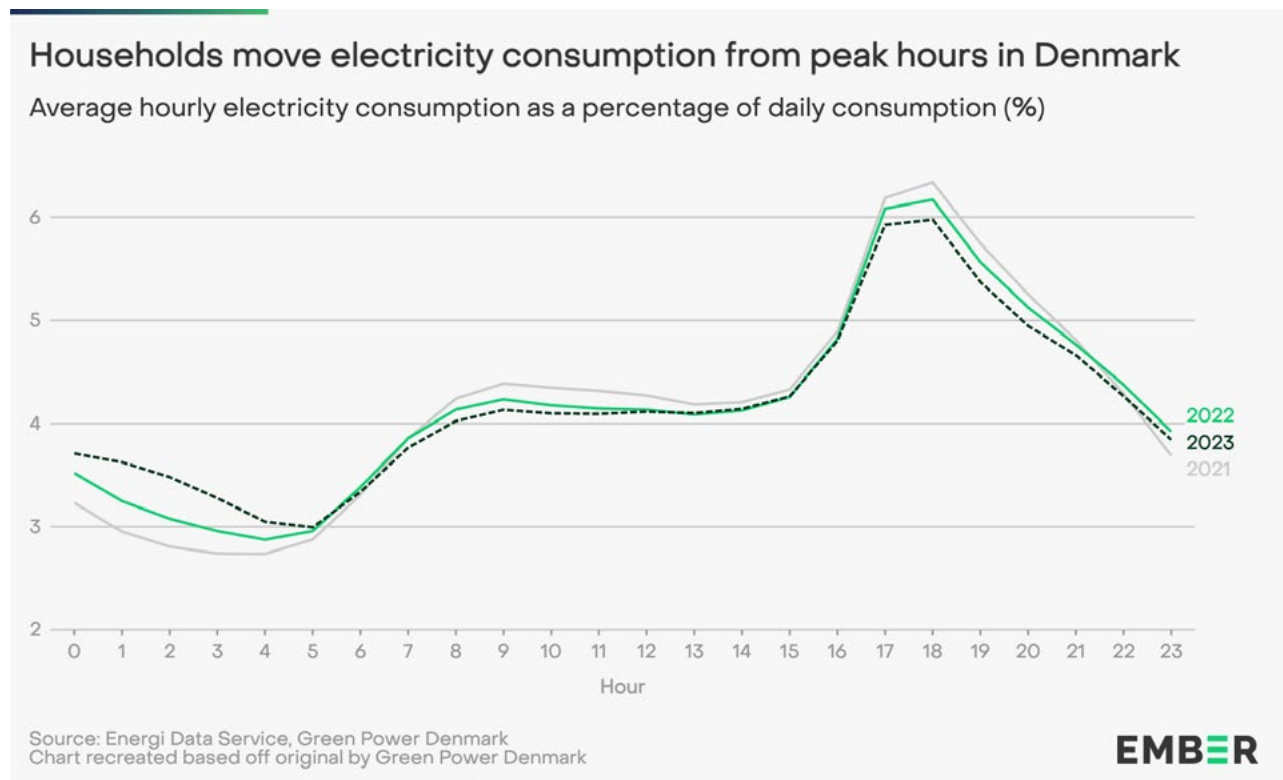
Over this period, 2.9 GWh of electricity demand was shifted from peak periods. This enabled 100% of the grid requirements, when it was under strain during certain times of the day due to high demand, to be met by consumer action. And it also resulted in reduced emissions.



As part of this Demand Flexibility Service, over only four hours during November 2022 Octopus energy customers reduced consumption by almost 450 MWh and [were paid over £1 million](#). That was an average of £4 per customer with the top 5% saving almost £20 each. This was achieved at very short notice and demonstrates consumers' appetite for this flexibility and control.

And as electrification and digitalisation expand, there will be even more potential for consumers to participate in demand side flexibility through avenues such as agile, time-of-use tariffs and smart electric vehicle charging.

In Denmark, around [70% of consumers are on time-varying tariffs](#) and this has incentivised households to reduce their consumption in morning and evening peak periods when electricity prices are more expensive.



This demand response is currently achieved through consumers manually switching off appliances. The benefits will increase exponentially with greater automation and digitalisation. The roll out of smart meters must be prioritised across Europe. It is also important to note that even those consumers that do not or cannot participate ultimately reap the rewards of increased demand side flexibility due to the related reduction in energy and system costs.

These are exciting, if challenging, times. And 2024 must be a pivotal year in terms of transposing these significant first steps in developing system flexibility policies into tangible actions and on-the-ground deployment.

# Data on the EU electricity sector in 2023

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

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# Electricity Generation



## Key highlights

01

Clean power sources generated a record two-thirds of the EU's electricity in 2023

02

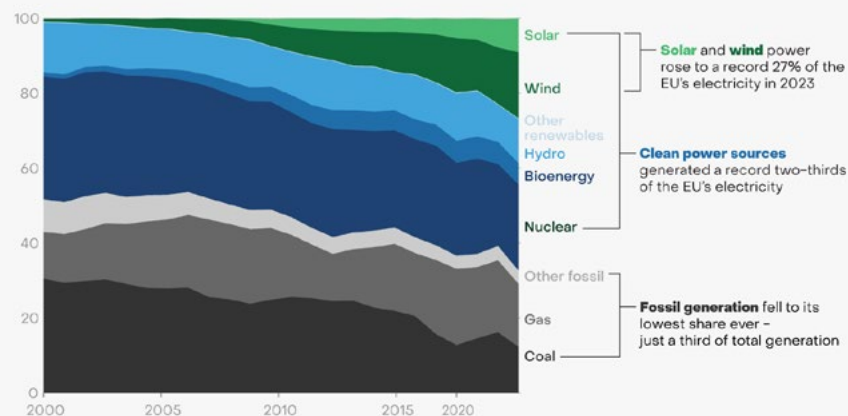
Fossil generation fell to its lowest share ever – just a third of total generation

03

Wind and solar power rose to a record 27% of the EU's electricity, with wind's share overtaking gas

### Wind and solar now account for a quarter of EU electricity; two-thirds of electricity came from clean sources

Share of electricity generation in EU countries (%)



Source: Annual electricity data, Ember

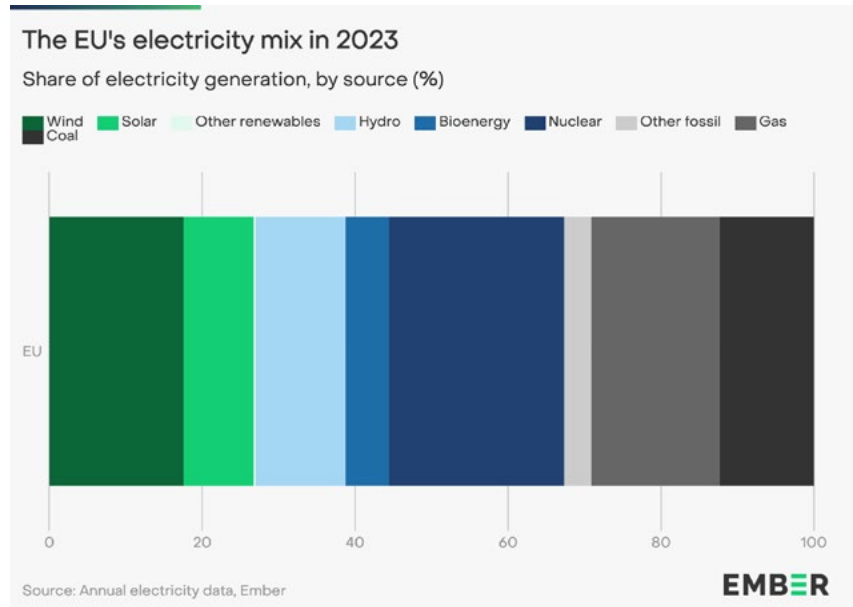
## Generation: Current status

### EU power mix reaches milestone of two-thirds from clean sources

In 2023, the EU electricity mix reached a new milestone with more than two-thirds of electricity coming from clean sources for the first time.

Wind and solar combined to produce 27% (721 TWh) of total EU electricity generation – more than nuclear at 23% (619 TWh) and hydro at 12% (317 TWh). Bioenergy and other renewables contributed a further 5.9% (159 TWh).

The share of fossil generation fell to its lowest ever – just a third (33%) of total generation, down six percentage points from 39% in 2022. Gas remained the largest source of fossil generation at 17% in 2023 (452 TWh), while coal generation only made up 12% (333 TWh). The rest came from other fossil generation, such as oil, at 3.5% (95 TWh).

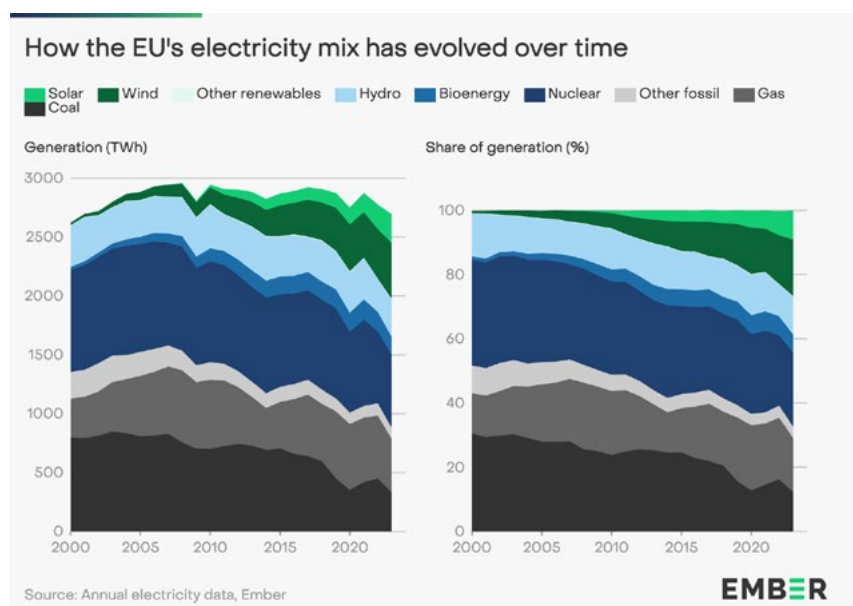


## Generation: Long-term trend

### Fossil fuels fell to a third of EU power, down from over half in 2000

The EU's reliance on fossil fuels for electricity has declined substantially since 2000, when over half (52%) of EU electricity came from coal, gas and other fossil sources. This fell to just 33% in 2023. Much of this fall happened since 2009 as wind and solar began to increase.

Wind and solar generation grew fivefold from 2009 to 2023, from just 139 TWh to 721 TWh. Their combined share in the EU's power mix rose from 5% to more than a quarter (27%) in the same period. This

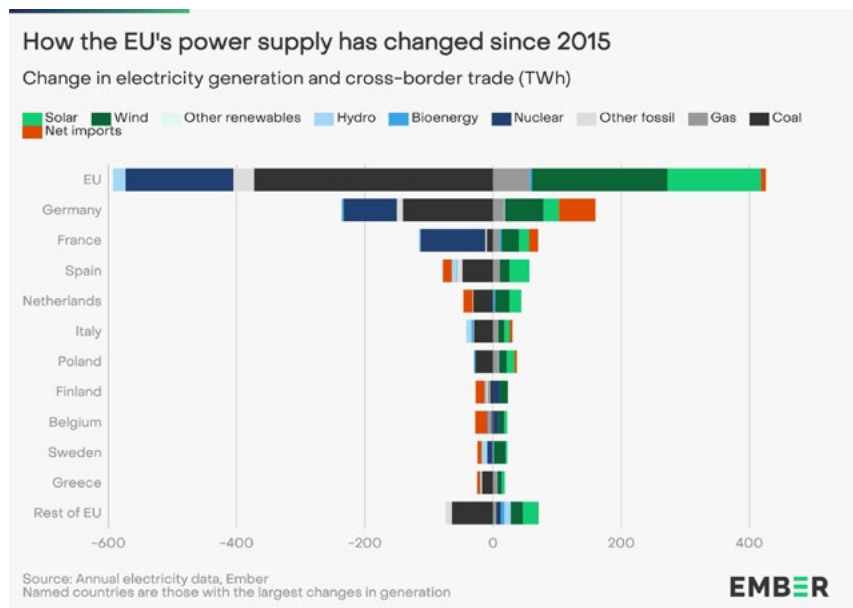


rapid growth happened as some EU countries, like Germany, became early adopters of wind and solar power at a large scale in the early 2010s.

Generation from other clean sources has moderately declined over the last two decades. Nuclear generation fell by 22%, from 860 TWh in 2000 to 619 TWh in 2023. Hydro generation declined 21% (from 350 TWh in 2000 to 317 TWh in 2023). The share of the two sources fell from 33% to 23% for nuclear and 13% to 12% for hydro generation, following lows in 2022 amidst maintenance, heat waves and droughts.

Since 2015, coal generation has fallen 372 TWh across the EU. Germany had the biggest fall, 140 TWh (-38%) followed by Spain (-48 TWh), Italy (-29 TWh) and Poland (-28 TWh).

In the same period, EU wind generation grew by 211 TWh with large additions in Germany (+60 TWh), France (+27 TWh) and Spain (+15 TWh). Similarly, solar saw a 146 TWh increase, with the largest contributions from Spain (+31 TWh) and Germany (+24 TWh).



In Germany, Europe's largest electricity generator, falls in nuclear (-83 TWh) and coal (-140 TWh) generation since 2015 were predominantly met by increases in wind (+60 TWh) and solar (+24 TWh) alongside net imports (+57 TWh) and gas generation (+17 TWh). In France, a fall in nuclear generation of 102 TWh since 2015 was met by an increase in wind and solar generation of 43 TWh as well as increases in net imports (+14 TWh) and gas generation (+10 TWh).



# Electricity Demand

49

## Key highlights

01

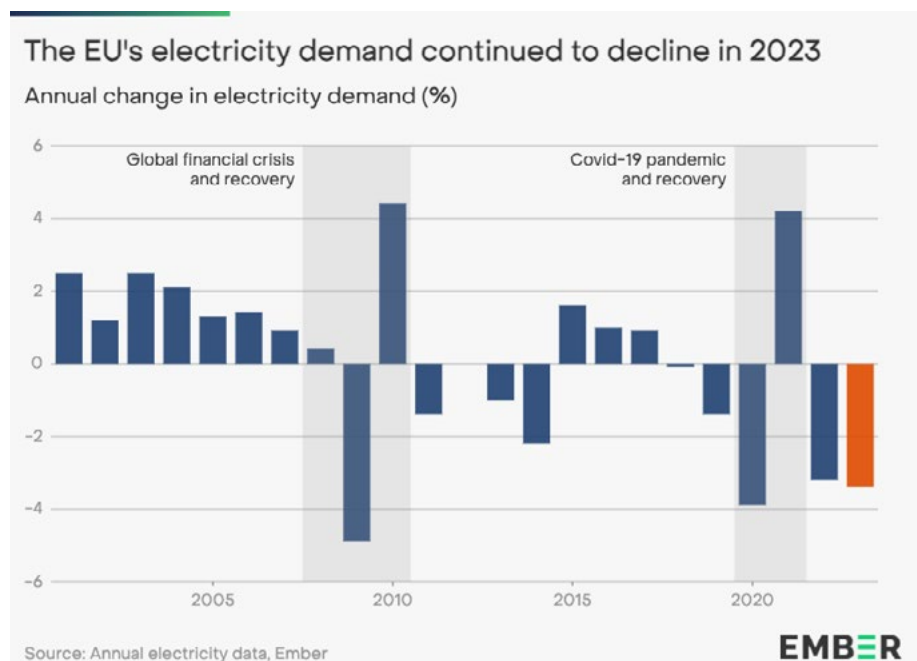
EU electricity demand fell 3.4% in 2023

02

The Nordic countries of Finland and Sweden have more than twice the demand per capita of other EU countries

03

In 2023, 21% of EU final energy consumption came from electricity, with an increase expected to come as electrified technologies are adopted



## Demand: Current status

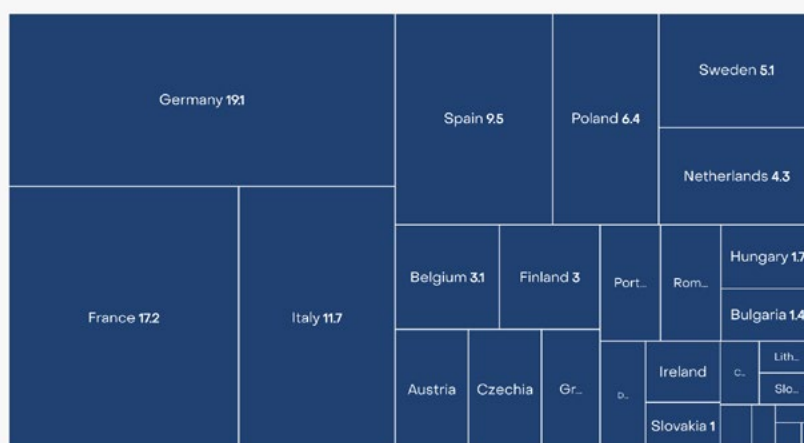
### EU electricity demand fell 3.4% year-on-year

In 2023, EU electricity demand was 2,697 TWh, a fall of 94 TWh (-3.4%) compared to 2,790 TWh in 2022. In 2023, the EU was responsible for 9% of global electricity demand.

The EU's four largest economies made up more than half (58%) of EU electricity demand. Germany accounted for 19% (515 TWh), France 17% (464 TWh), Italy 12% (315 TWh) and Spain 9.5% (256 TWh).

#### A breakdown of EU electricity demand in 2023

Share of EU electricity demand (%)



Source: Annual electricity data, Ember

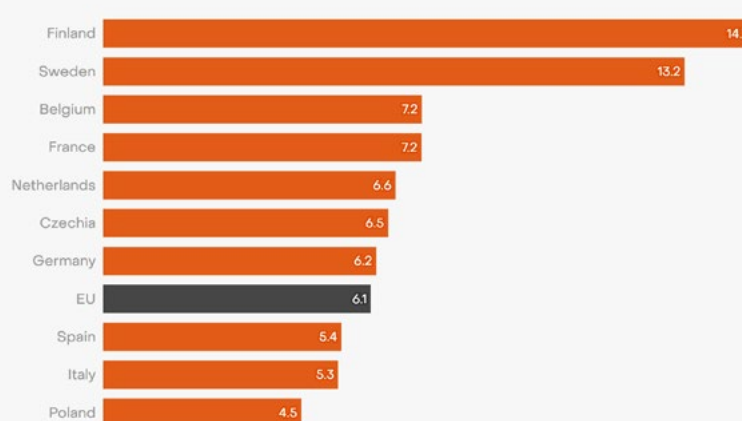
EMBER

Across Europe, per capita demand was 6.1 MWh in 2023.

Finland (14.7 MWh) and Sweden (13.2 MWh) have the highest electricity demand per capita among the ten countries with the highest electricity demand. Their demand per capita is more than twice the EU average. This is caused by higher energy demand due to their colder climates and high economic development as well as higher electrification rates, with greater adoption of electric vehicles and heat pumps than in other EU countries.

#### Demand per capita of top EU electricity producers in 2023

MWh



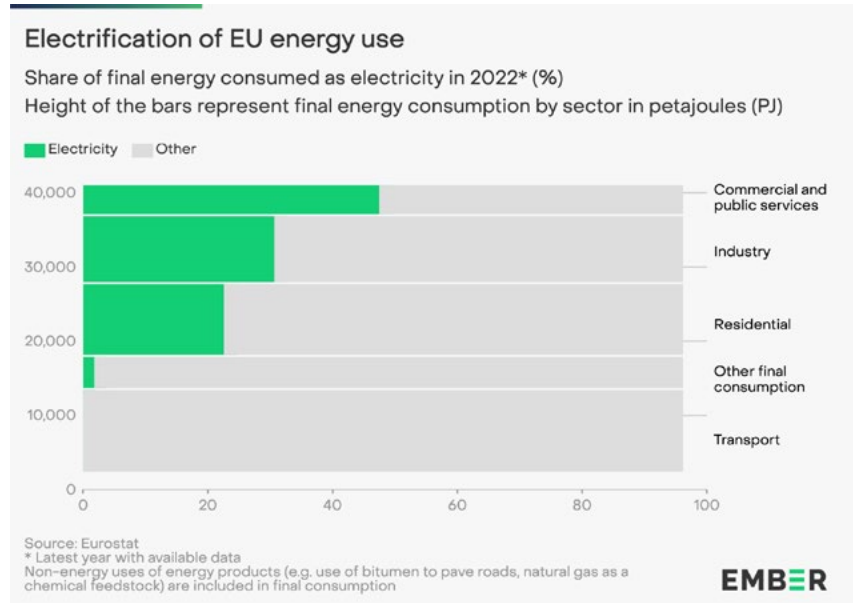
Source: Annual electricity data, Ember  
Graphic shows the 10 EU countries with the highest electricity demand

EMBER

Spain (5.4 MWh), Italy (5.3 MWh) and Poland (3.5 MWh) have lower than average electricity demand per capita.

As the power supply becomes cleaner, electrification will be the key lever in decarbonisation across industries. As of 2022 (the latest year with data available) only 21% of final energy consumption in the EU 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 (i.e. heating) and industry.



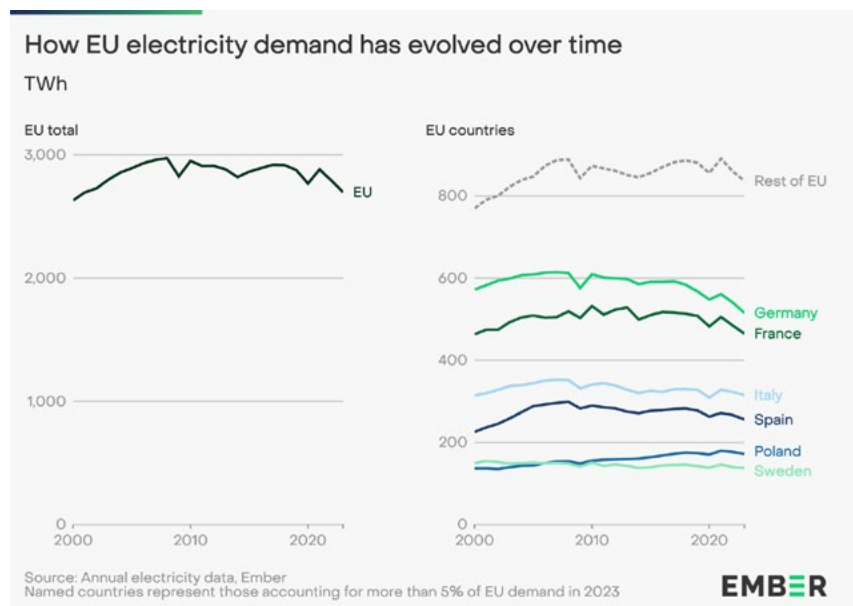
Only 2% of the EU's transport sector is electrified, according to 2022 data from [Eurostat](#). In residential energy use, a large-scale switch to heat pumps is also set to further increase electricity demand. A quarter (25%) of the residential sector's final energy consumption is currently in the form of electricity.

## Demand: Long-term trend

### EU electricity demand was 6% lower in 2023 than its peak in 2008

After rising throughout the 2010s, EU demand peaked at 1,036 TWh in 2008. It has since remained largely stable with only small declines. In 2023, demand was 6% lower than the peak, at 974 TWh.

Germany showed one of the largest declines since 2008, falling 16% (-97 TWh). Its share of EU demand dropped by 1.5 percentage points, from 20.6% in 2008 to 19.1% in 2023. Over the same period, Poland's electricity demand increased by 12% (+11 TWh) and made up 6.4% of EU electricity demand in 2023, up from 5.2% in 2008.

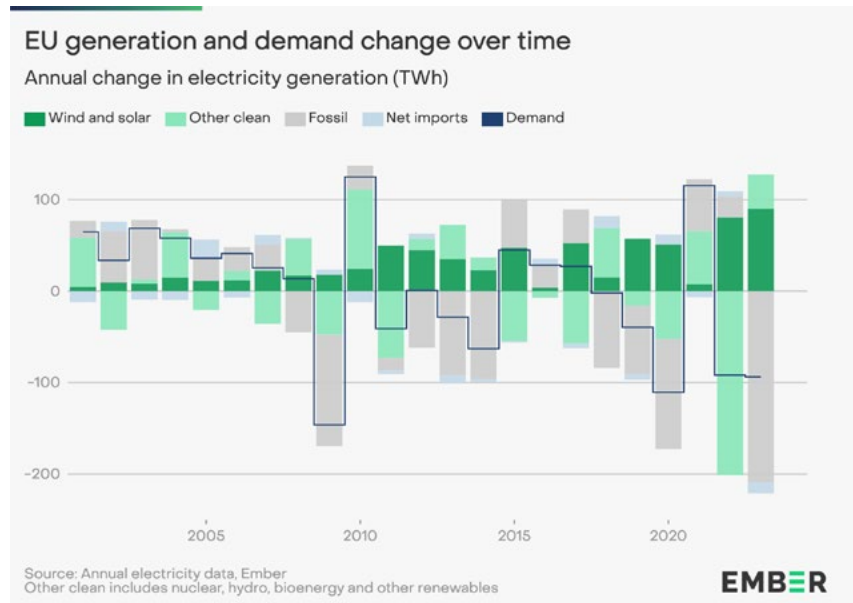


Over the last two decades, wind and solar additions displaced fossil generation and compensated for falls in other clean generation. This further accelerated the reduction of fossil generation in years where demand fell. In 2023, demand falls of 94 TWh, combined with wind and solar growth of 90 TWh and growth in other clean sources of 37 TWh, led to a fall in fossil generation of 209 TWh.

In order for emissions to continue to fall, clean electricity growth needs to meet and exceed new electricity demand.

In the EU, four out of the last five years saw demand fall, contributing to a reduced need for fossil generation.

As electrification is set to drive an increase in electricity demand over the coming years, clean generation additions will become even more crucial to meet new demand while decarbonising existing power generation.



# Power Sector CO2 Emissions

## Key highlights

01

EU power sector emissions fell 19% in 2023 – the largest decline on record

02

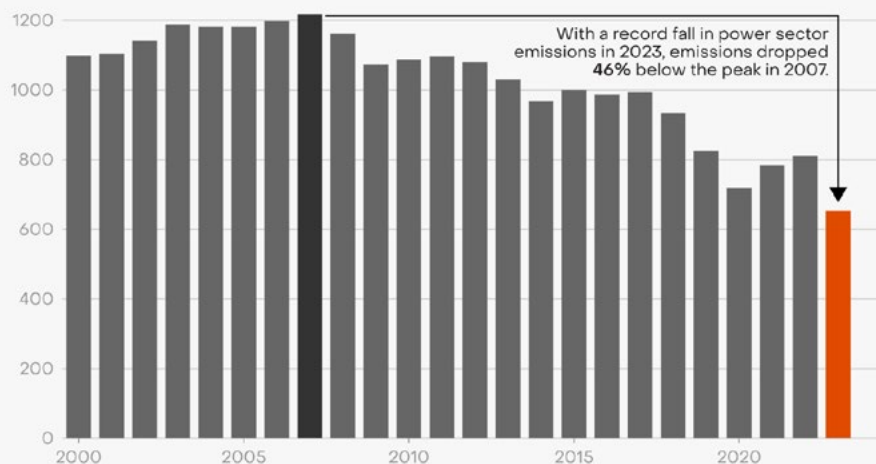
2023 had the largest annual reduction in EU carbon intensity since at least 2000

03

EU power sector emissions have nearly halved since their peak in 2007

### EU power sector emissions have nearly halved since their peak in 2007

Total power sector emissions (MtCO<sub>2</sub>)



Source: Annual electricity data, Ember

EMBER

## Emissions: Current status

### EU power sector emissions fell 19% in 2023 – the largest decline on record

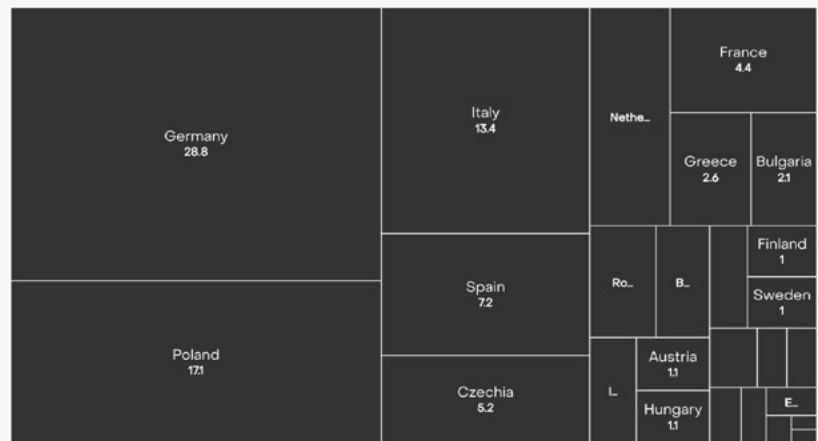
In 2023, EU countries emitted 653 million tonnes of CO<sub>2</sub> from electricity generation. This was a stark 19% drop in emissions (-157 MtCO<sub>2</sub>) compared to 2022 (811 MtCO<sub>2</sub>). Combined, EU countries contributed 4.6% of global power sector emissions in 2023.

Power sector emissions in the EU are dominated by the bloc's largest fossil generating countries. Germany (29%, 188 MtCO<sub>2</sub>), Poland (17%, 112 MtCO<sub>2</sub>) and Italy (13%, 87 MtCO<sub>2</sub>) made up 59% of emissions despite only representing 37% of EU electricity demand. France was the exception among the EU's large economies, representing just 4.4% (29 MtCO<sub>2</sub>) of EU power sector emissions in 2023, despite being responsible for 17% of electricity demand. This is due to its low share of fossil generation in the mix.

However, 22 countries – each representing only 5% or less of total EU emissions – still combined to make up nearly a third (32%) of EU power sector emissions. This highlights the need for shared responsibility in emissions reductions in the power sector.

#### A breakdown of EU power sector emissions in 2023

Share of EU power sector emissions in 2023 (%)



Source: Annual electricity data, Ember

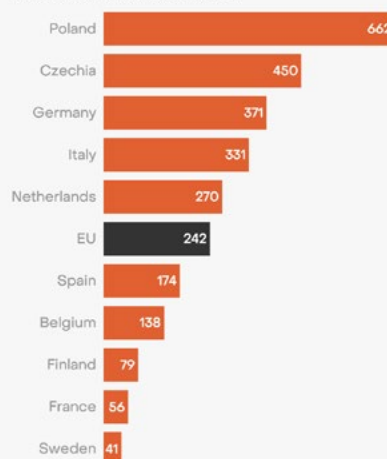
EMBER

In 2023, emissions intensity across the entire EU was 242 gCO<sub>2</sub>/kWh, down 17% from 292 gCO<sub>2</sub>/kWh in 2022. This represents the largest year-on-year reduction in carbon intensity since at least 2000 in both absolute and percentage terms.

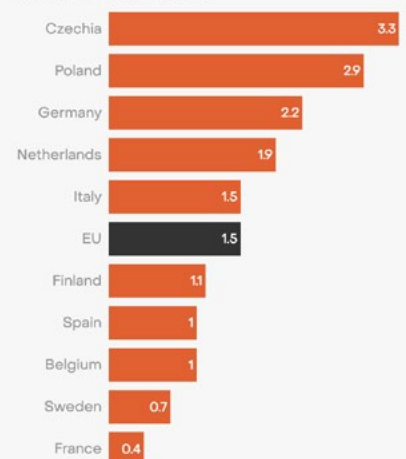
The three largest coal power countries had the highest carbon intensity for electricity generation in 2023: Poland (662 gCO<sub>2</sub>/kWh), Czechia (450 gCO<sub>2</sub>/kWh) and Germany (371 gCO<sub>2</sub>/kWh).

#### Emissions of top EU electricity producers in 2023

Emissions intensity (gCO<sub>2</sub>/kWh)



Emissions per capita (tCO<sub>2</sub>)



Source: Annual electricity data, Ember  
Graphic shows the 10 EU countries with the highest electricity demand

EMBER

gCO<sub>2</sub>/kWh). All still have a high share of coal in their mix (Poland 61%, Czechia 40%, Germany 26%), significantly above the EU average (12%).

Czechia's emissions per capita (3.3 tonnes of CO<sub>2</sub>) were more than twice the EU average of 1.5 tCO<sub>2</sub> in 2023. Likewise, Poland (2.9 tCO<sub>2</sub>) and Germany (2.2 tCO<sub>2</sub>) were significantly above average. Belgium (1 tCO<sub>2</sub>), Sweden (0.7 tCO<sub>2</sub>) and France (0.4 tCO<sub>2</sub>) had some of the lowest emissions per capita in 2023 due to their low share of fossil and high share of low carbon sources like nuclear, hydro, wind and solar.

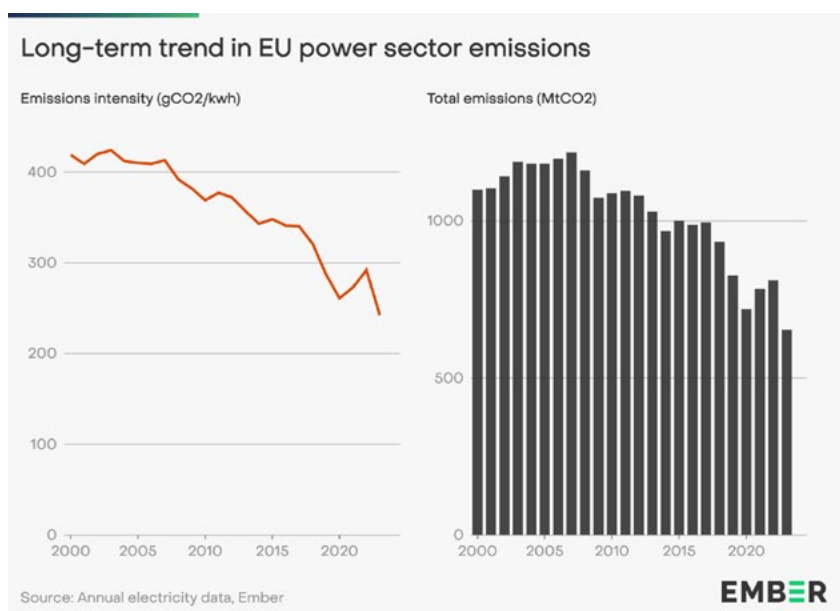
## Emissions: Long-term trend

### EU power sector emissions have nearly halved since their peak in 2007

Power sector emissions in the EU have nearly halved since their peak in 2007 – falling by 46% from 1,218 MtCO<sub>2</sub> to 653 MtCO<sub>2</sub> in 2023. This equates to an average annual decline of 3.8%. The fall has accelerated in recent years, with emissions declining at a rate of 5.2% annually in the period since 2015.

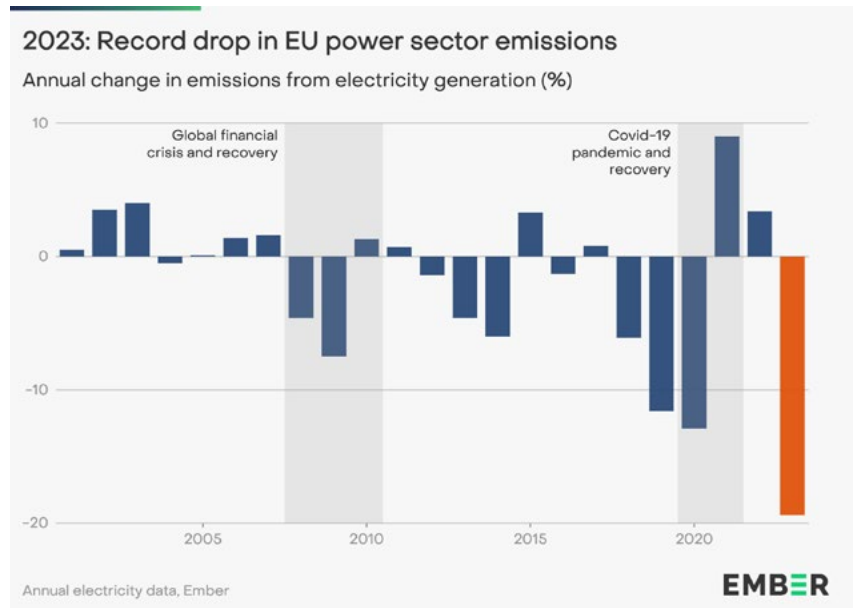
The decline in emissions is driven by an increase in generation from wind and solar and the subsequent reduced dependence on fossil fuels. Electricity demand in the EU has also fallen 9.3% since its peak in 2008, contributing further.

The large reduction in EU emissions intensity reflects these trends. One kilowatt hour of electricity produced in 2003 resulted in 424 grams of CO<sub>2</sub> emitted. In 2023 this was just 242 grams of CO<sub>2</sub>, a reduction of 43%.

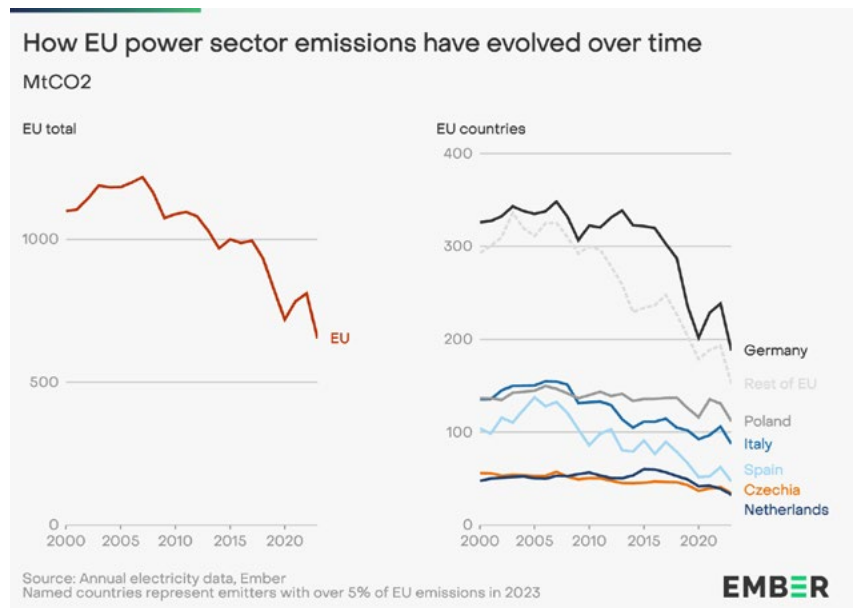


Prior to 2023, the largest relative drop in power sector emissions in the EU came as a result of the demand reduction driven by the Covid-19 pandemic in 2020, as emissions fell 13% compared to 2019. 2023 beat this record with emissions falling 19% (-157 MtCO<sub>2</sub>). There was a moderate recovery in 2021 and 2022, although power sector emissions have not returned to pre-pandemic levels.

While emissions decline in the EU had accelerated to an average of 5.2% annually since the Paris Agreement, 2023 represented a significant step change with emissions falling more than three times as fast.



While total EU emissions have been falling since 2007, some countries have achieved faster declines than others, driven largely by the adoption of wind and solar. Among the largest EU emitters, Spain's emissions declined fastest. Its 2023 emissions of 47 MtCO<sub>2</sub> were 55% lower than those in 2000 (104 MtCO<sub>2</sub>). As a result, Spain's share of EU emissions fell from 9.5% to 7.2%.



In contrast, Poland's share of EU emissions has increased by 4.7 percentage points from 12.4% in 2000 to 17.1% in 2023, as the country's emissions decline of just 18% failed to keep pace with EU-wide reductions of 41% over the same period.

Germany remains the largest single contributor with an emissions fall of 42% since 2000, in line with the EU-wide trend.



# Analysis of the different electricity sources in 2023

Data on EU 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. We have ordered the sections according to the fastest growing sources of electricity.

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## Chapter contents

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62	Wind
66	Coal
70	Gas
74	Hydro
78	Nuclear
82	Bioenergy

# Solar

## Key highlights

**01** Solar generated 9% of the EU's electricity in 2023

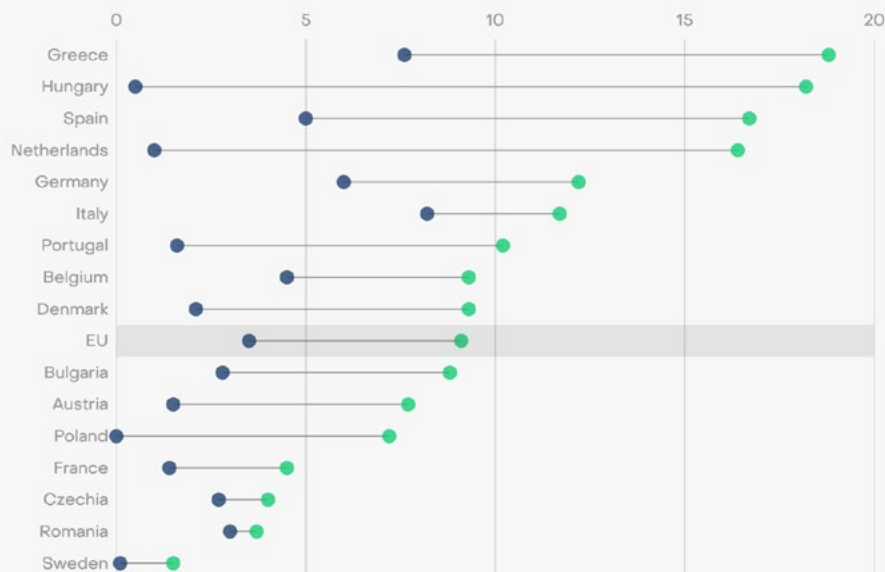
**02** Solar is growing at a faster rate than wind but still only provides half the generation of wind

**03** In Greece solar reached 19% of its electricity share, and in the Netherlands solar generated over 1 MWh per person

### How solar has advanced in EU countries

Share of electricity generation from solar (%)

● 2023 ● 2015



Source: Annual electricity data, Ember  
Countries with solar generation below 1 TWh were excluded from this graphic

## Solar: Current status

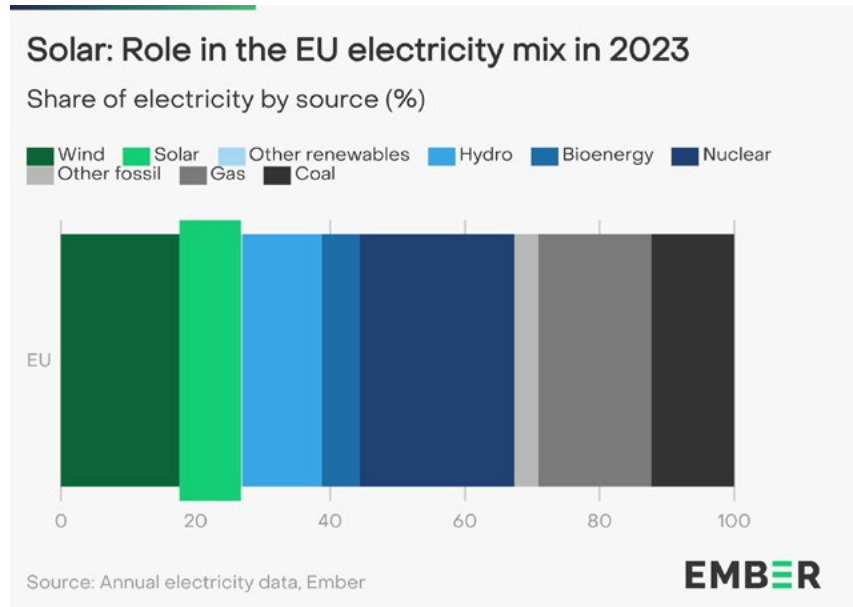
### EU solar generation met 9% of the EU's electricity in 2023

Solar power produced a record 9.1% (246 TWh) of EU electricity in 2023.

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

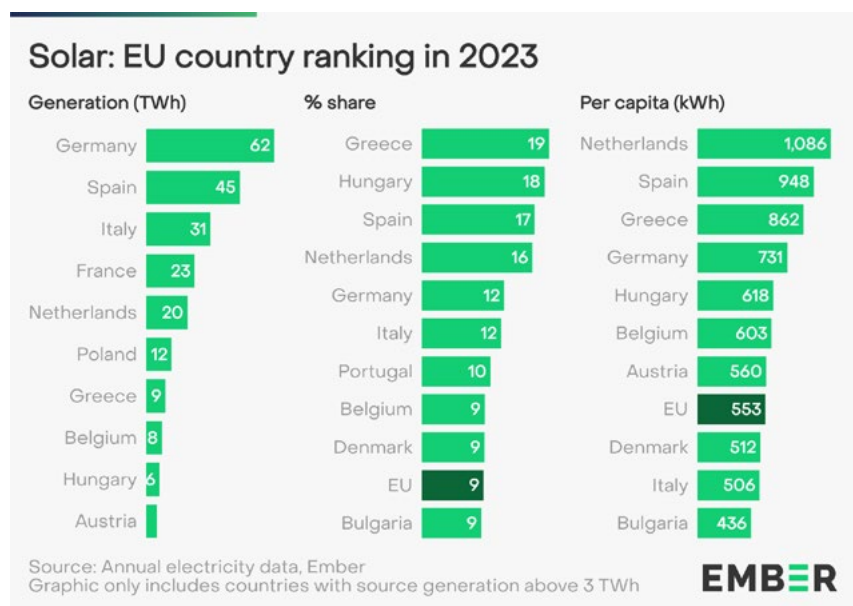
Under [REPowerEU](#), renewables are set to account for 69%

of total EU electricity consumption by 2030, with 55% of this from wind and solar alone. Wind and solar's share of total EU installed generation capacity should be 67% by 2030.



Germany was the largest solar power producer in the EU in 2023. Its 62 TWh of solar generation represented a quarter of EU solar generation. The Mediterranean countries of Spain (45 TWh), Italy (31 TWh) and France (23 TWh) are the second, third and fourth largest solar producers.

In 2023, Greece had the highest share of solar power in its electricity mix with 19%, followed by Hungary at 18% and Spain at 17%, far above the EU average of 9.1%.



At 1,086 kWh, the Netherlands had the highest solar generation per capita in 2023. This was more than double the EU average of 553 kWh per capita.

## Solar: Change in 2023

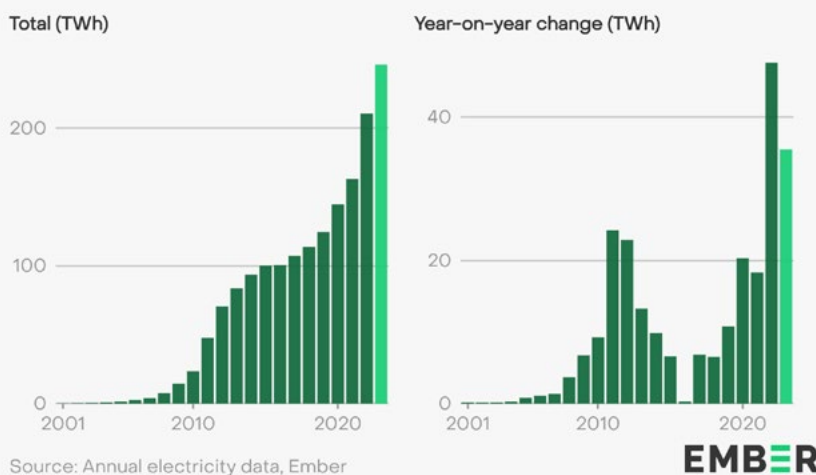
### EU solar generation reached a new all-time high

EU solar generation reached a new all-time high of 246 TWh, up 36 TWh compared to 2022 (211 TWh).

Despite record solar capacity additions, the year-on-year generation increase of 36 TWh (+17%) was only the second largest after the increase of 48 TWh (+29%) in 2022.

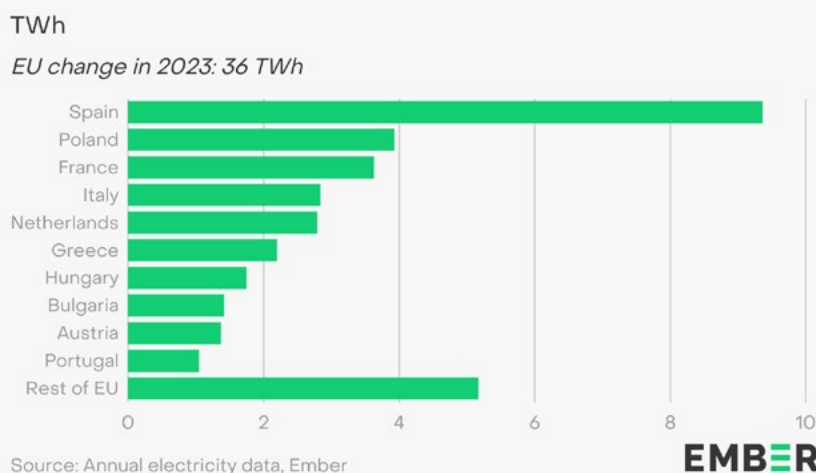
With increased capacity installed, the rise in generation could have been even higher. However, lower solar irradiation in the EU compared to 2022 meant that the capacity generated slightly less per GW in 2023. As solar installation keeps up a strong pace, larger generation gains are likely in 2024.

### Solar: EU generation in 2023 compared to the historical trend



EU solar generation additions in 2023 were led by Spain (+9.4 TWh), Poland (+3.9 TWh) and France (+3.6 TWh), but growth was seen across the bloc. Spain accounted for a quarter of the EU's solar growth in 2023.

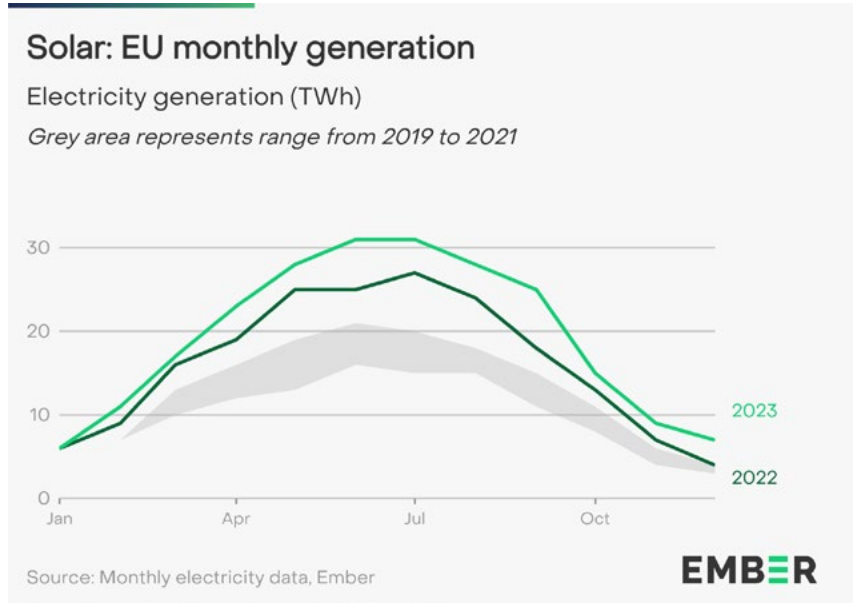
### Solar: EU countries with the largest generation change in 2023



Every month in 2023 set a new seasonal record for solar generation in the EU. This continued the trend of 2022.

May, June and July set three consecutive all-time monthly records for solar generation in the EU. In May, solar generated 28 TWh, followed by 31 TWh in June and July respectively. These beat the previous record monthly high of 27 TWh set in July 2022.

September saw the largest year-on-year increase in 2023. September 2023 (25 TWh) was 7 TWh higher than 2022 (18 TWh).



## Solar: Long term trend

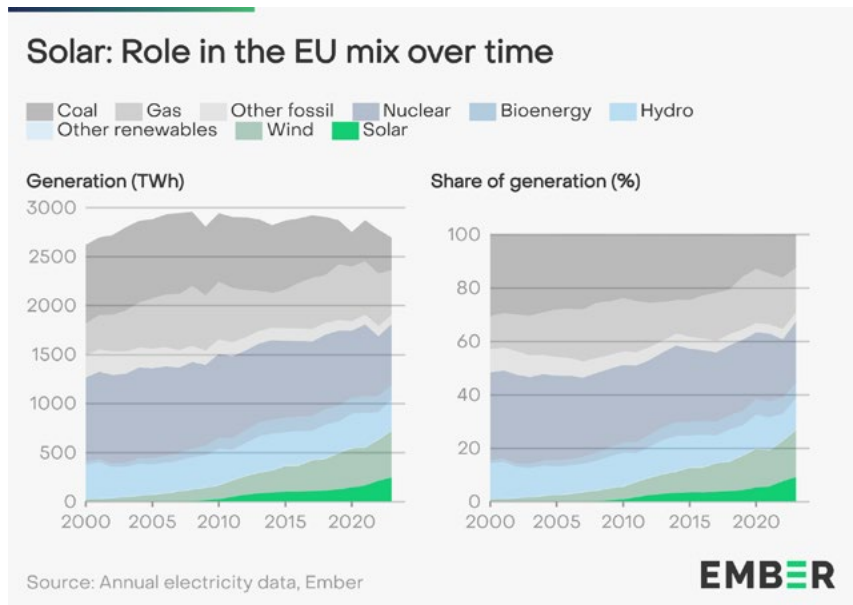
**EU solar generation has grown 146% since 2015**

EU solar generation has grown dramatically over the last two decades, from just 0.1 TWh in 2000 to 246 TWh in 2023, making it the second fastest growing source after wind generation.

The EU was an early adopter of solar, starting in the late 2000s. Solar generation grew from just 3.8 TWh in 2007 to surpass 100 TWh in 2015.

Following a period of stagnation in the mid-2010s, solar energy expansion in the EU has been gaining momentum again since 2017. Both 2022 and 2023 saw further acceleration amid the energy crisis and high consumer electricity prices caused by high prices for coal and gas.

Solar generation in 2023 (246 TWh) was 146% higher than in 2015. Consequently the share of generation has grown from just 3.5% in 2015 to 9.1% in 2023.



# Wind

## Key highlights

### 01

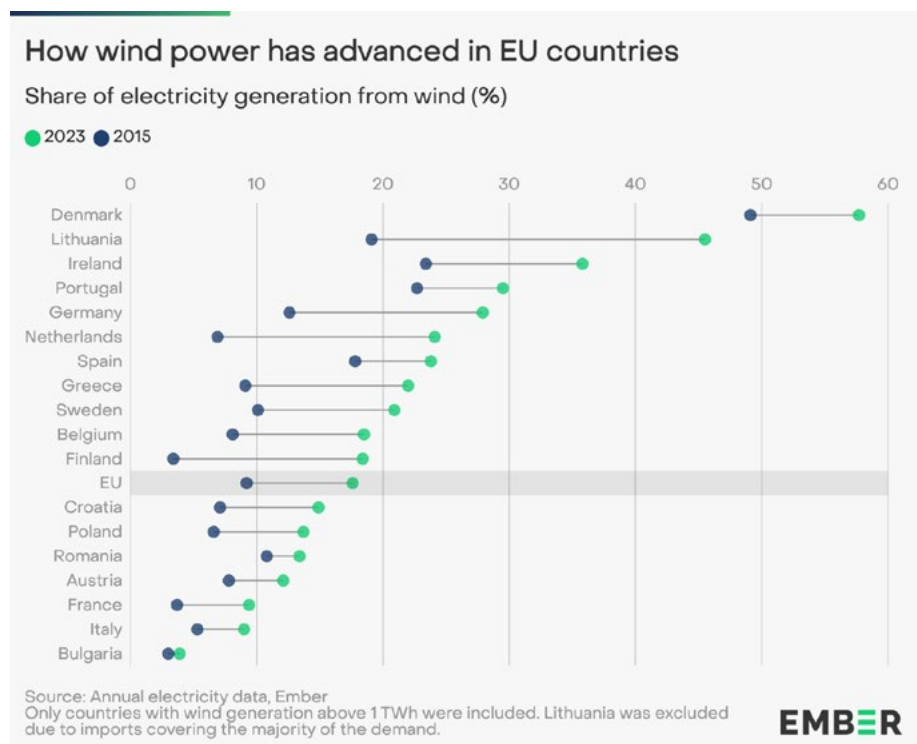
Wind rose to generate 18% of the EU's electricity in 2023, surpassing gas for the first time

### 02

Wind generation grew by a record 55 TWh in 2023, with large increases from Germany, France and the Netherlands

### 03

The share of wind generation has grown from 0.8% to 18% over the last two decades



## Wind: Current status

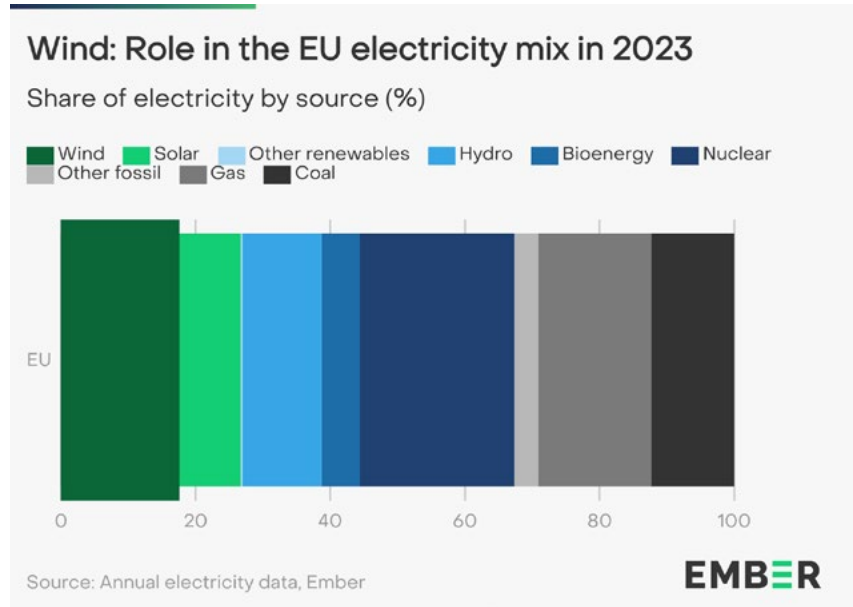
### Wind rose to generate 18% of the EU's electricity in 2023, surpassing gas for the first time

Wind power produced 18% (475 TWh) of EU electricity in 2023, for the first time surpassing gas generation (17%, 452 TWh).

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.

Under [REPowerEU](#), renewables

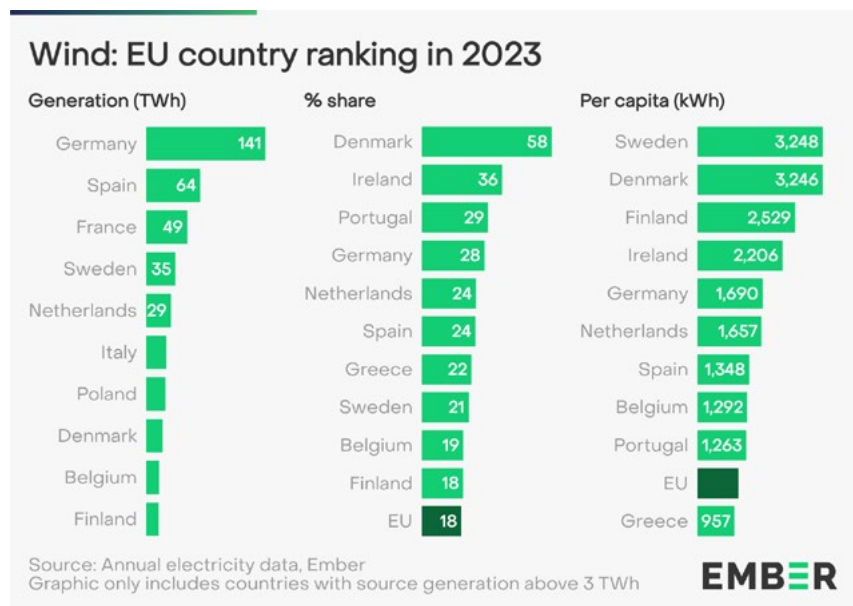
are set to account for 69% of total EU electricity consumption by 2030, with 55% of this from wind and solar alone. Wind and solar's share of total EU installed generation capacity should be 67% by 2030.



Germany led the EU in wind generation with 141 TWh, followed by Spain (64 TWh), France (49 TWh) and Sweden (35 TWh).

Denmark produced 58% of its electricity from wind, far more than any other EU country. Ireland (36%) and Portugal (29%) had the second and third highest shares.

Nordic countries produced the most wind power per capita. In 2023, Sweden generated 3,248 kWh per capita, slightly ahead of Denmark (3,246 kWh per capita) and Finland in third (2,529 kWh per capita).



# Wind: Change in 2023

## Wind increased by a record 55 TWh in 2023

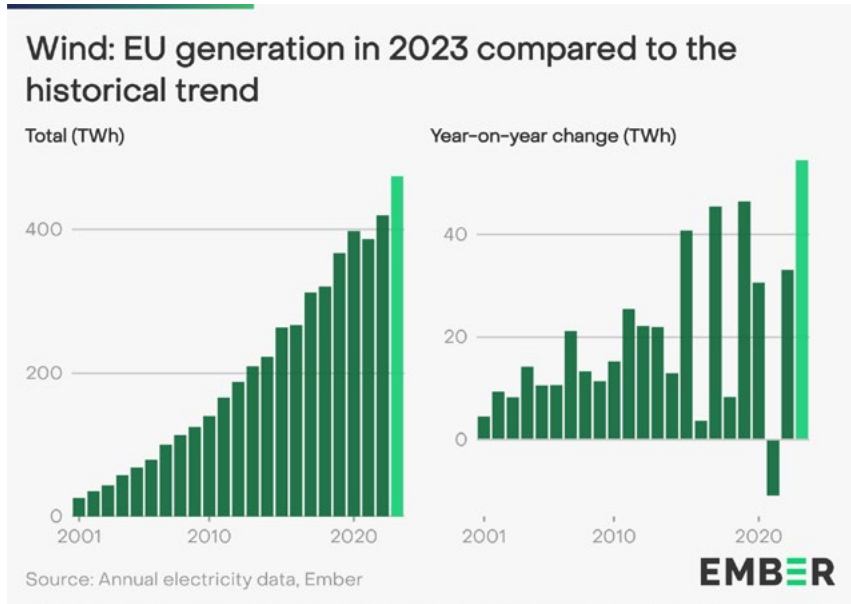
EU wind generation reached a new record high of 475 TWh in 2023, up from 420 TWh in 2022.

Wind generation increased by 55 TWh (+13%) in 2023, the largest absolute increase on record. This surpassed the previous highest generation increase of 47 TWh in 2019.

2023 saw record new wind installations of 17 GW, despite wind capacity additions slowing in recent years. Wind generation can see large fluctuations each year due

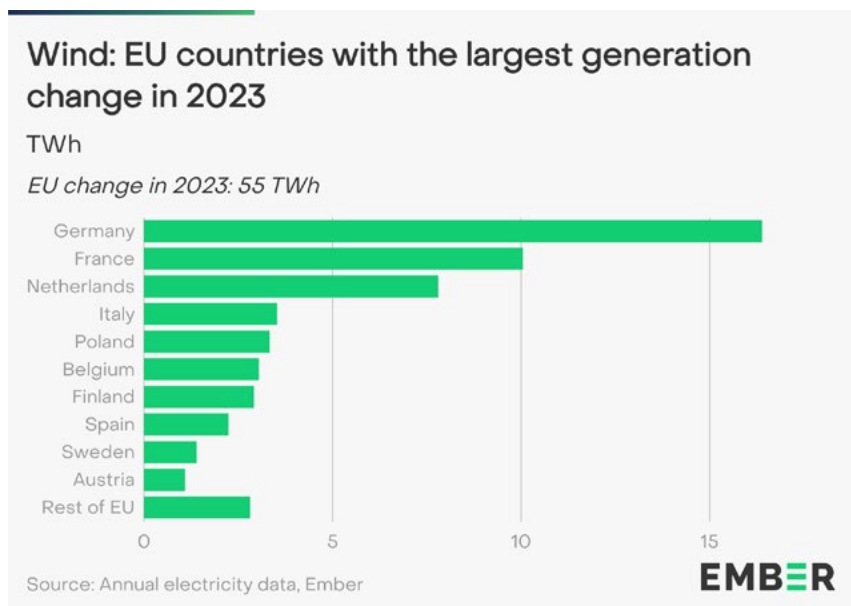
to differences in wind conditions. In 2023, the capacity factor for wind increased as a result of favourable wind conditions, leading to a larger increase in generation.

2023 represents the second consecutive year of growth after generation fell for the first time ever (-11 TWh) in 2021.



Germany saw the largest increase in wind generation (+16 TWh, +13%) ahead of France (+10 TWh, +26%) and the Netherlands (+7.8 TWh, +36%). Together they accounted for 62% of the EU's growth in wind generation.

For the Netherlands, the 2023 increase was the largest increase in wind generation yet, more than twice as big as the previous largest additions of 3.8 TWh in 2020.

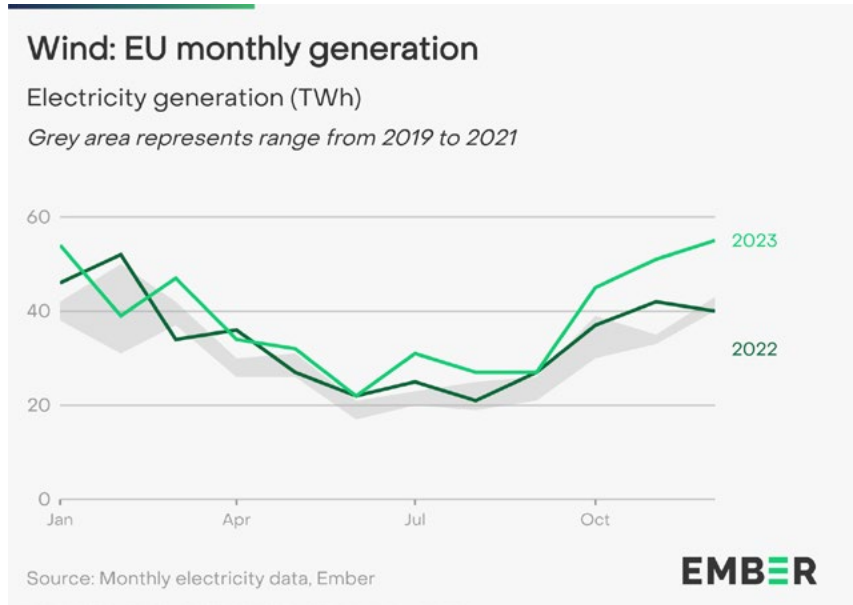


Good wind conditions, particularly in November and December, meant that no country saw any significant reductions in generation.



Wind generation in 2023 was higher than in 2022 for most of the year. January, November and December saw particularly high wind generation. January and December set new all-time records for monthly wind generation in the EU of 54 TWh and 55 TWh respectively. This beat the previous record of 52 TWh set in February 2022.

Wind generation is generally higher in winter and lower in summer months, driven by differences in wind speeds.

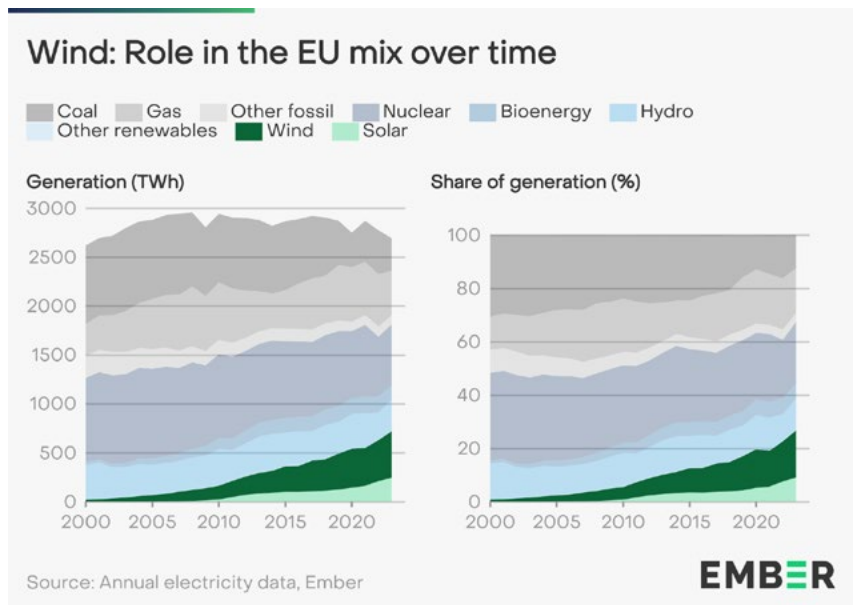


## Wind: Long term trend

**The share of wind generation has grown from 0.8% to 18% over the last two decades**

Wind generation in the EU has been consistently growing over the last two decades, from just 21 TWh in 2000 to 475 TWh in 2023. The share of generation increased from 0.8% to 18% over the same period.

This growth in generation meant that wind power surpassed gas generation in the EU in 2023, having already surpassed coal generation in 2020.



# Coal

## Key highlights

01

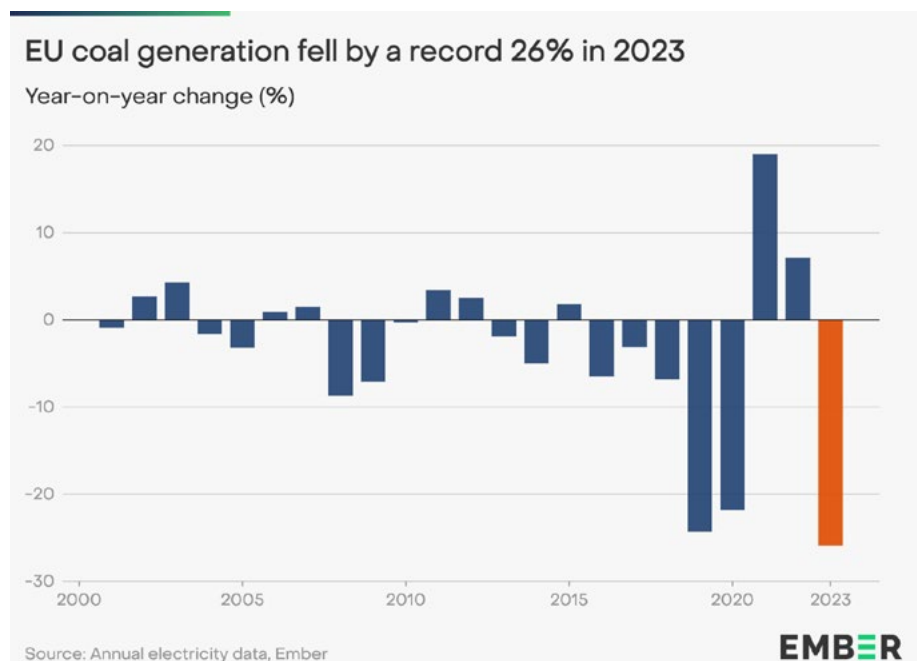
EU coal generation reached an all-time low of 12% of the EU's electricity, falling by a record 26% in 2023

02

Germany and Poland accounted for 71% of EU coal generation in 2023

03

Coal generation fell below both gas and wind in 2020, and remains lower today



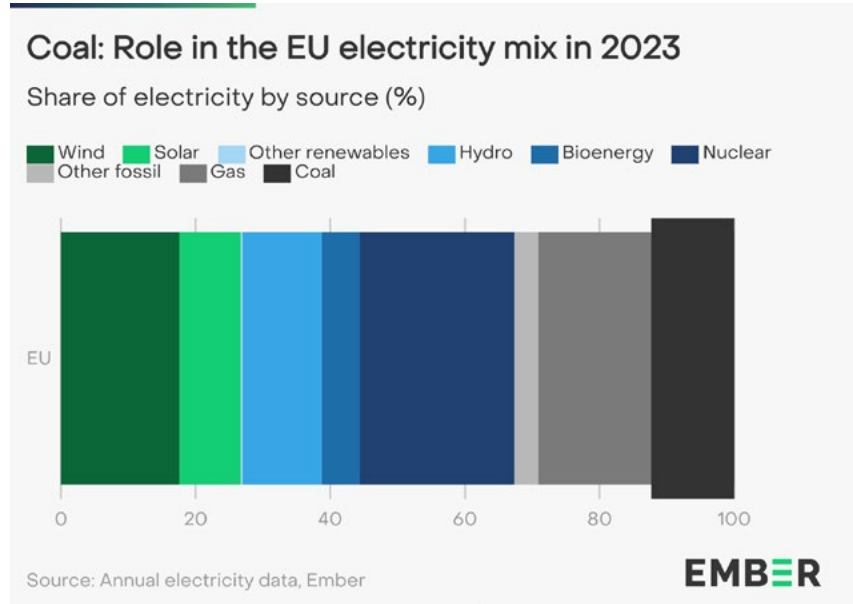
## Coal: Current status

### Coal power generated 12% of EU electricity in 2023, with Germany and Poland the biggest producers

Coal power produced 12% (333 TWh) of EU electricity in 2023.

Coal is the single largest contributor to emissions from the power sector. As per the [IEA's Net Zero scenario](#), unabated coal plants must be phased out by 2030 in the EU.

The story of coal in the EU is one of decline. It continues to be undercut by new wind and solar. Except for Poland and Bulgaria, all EU countries have pledged to exit coal generation by 2033 at the latest. Germany's official exit date is still in 2038, but its government has signalled its intent to bring this forward as only a handful of lignite power plants are scheduled to remain open after 2030. As such, coal's role in the EU's electricity system will continue to diminish.

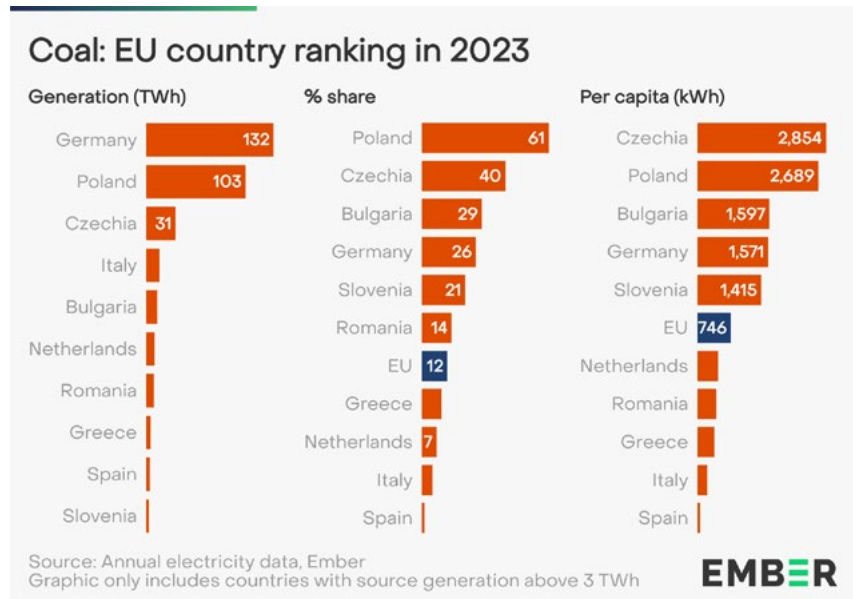


Germany (132 TWh) and Poland (103 TWh) were the largest coal power producers in the EU in 2023. Czechia is a distant third with 31 TWh of coal generation in 2023.

Poland and Germany combined make up 71% of EU coal generation.

Poland is the most coal-reliant country in the EU by far, with coal making up 61% of electricity generation. Other countries where the share of electricity generation from coal is above the EU average of 12% are Czechia (40%), Bulgaria (29%), Germany (26%), Slovenia (21%) and Romania (14%).

At 2,854 kWh, Czechia had the highest coal generation per capita in 2023, closely followed by Poland with 2,689 kWh. Both countries were more than three times the EU average of 746 kWh.

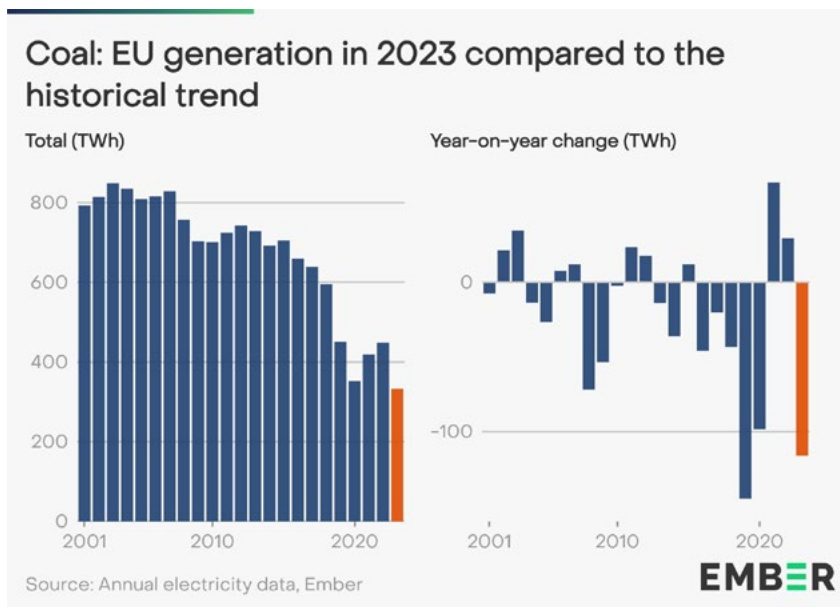


## Coal: Change in 2023

**Coal generation reached an all-time low, with Germany's decrease accounting for more than 40% of the EU's total fall**

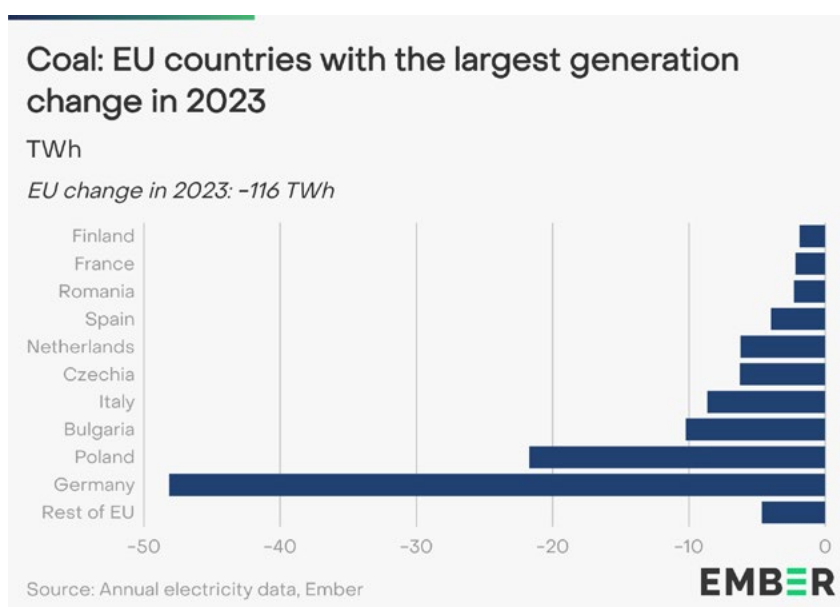
EU coal generation reached a new all-time low of 333 TWh in 2023, down by 116 TWh from 2022 (449 TWh), and 19 TWh below the previous all-time low set in 2020 (352 TWh).

The overall fall in coal generation of 116 TWh (-26%) was the highest year-on-year percentage reduction of all time. It was also the second largest absolute fall behind 2019 which saw a fall in generation of 145 TWh. Following two consecutive years of generation increases—driven by a post-Covid-19 recovery in 2021 and the energy price crisis in 2022—the fall in 2023 suggests the EU is firmly on track to continue its shift away from coal.



Coal generation dropped across Europe in 2023. The biggest falls came in Germany (-48 TWh) and Poland (-22 TWh), with Bulgaria (-10 TWh) and Italy (-8.7 TWh) also showing significant decreases.

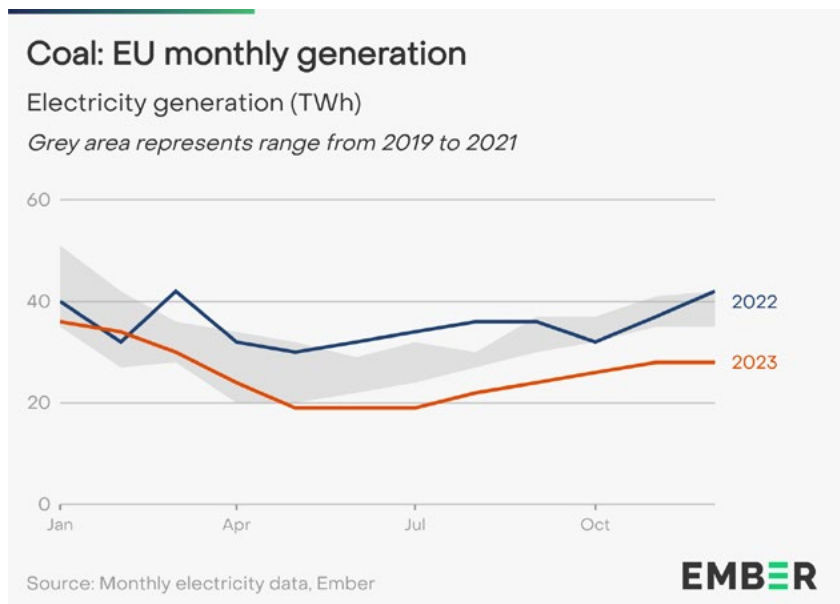
Germany's decrease in coal generation accounted for more than 40% of the EU's total fall. This was driven by record generation from wind and solar, as well as an economic recession accompanied by lower demand from its energy-intensive industries. Poland saw a small decrease in overall electricity demand, with most of the reduction in coal generation being driven by an increase in wind and solar.



Except for February, every month of 2023 saw lower coal generation compared to 2022.

The EU has recorded five-year coal lows every month since May 2023, with generation particularly low in November and December compared to previous years, as strong wind conditions further reduced the need for coal burning.

Coal is expected to continue to set new monthly lows. The short-lived uptick due to the gas price crisis in 2022 has passed and coal generation continues to be displaced, primarily by solar and wind generation.

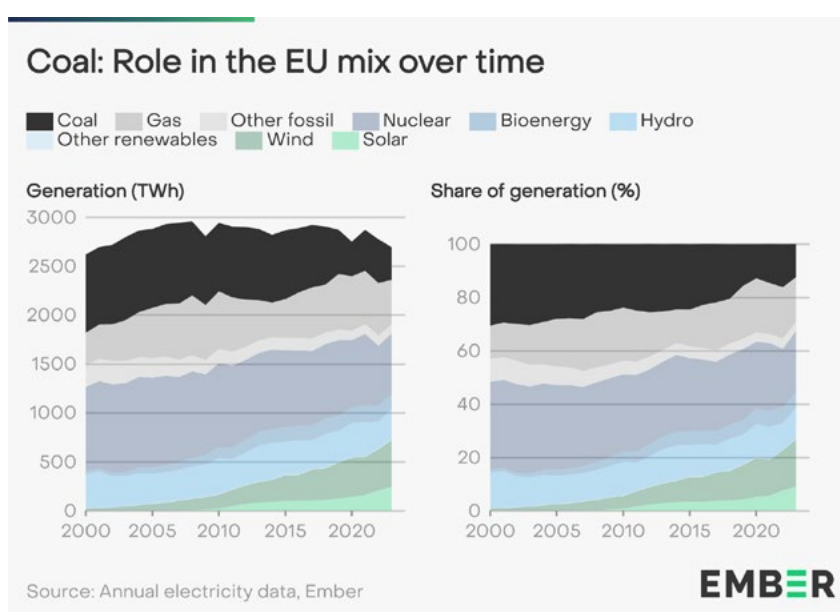


## Coal: Long term trend

**Coal has fallen from second to fourth largest source of EU electricity over the last two decades**

EU coal generation has fallen by nearly 60% over the last two decades, from over 800 TWh in 2000 to 333 TWh in 2023.

Coal generation was still rising for the first few years of the 2000s, peaking at 829 TWh in 2007. Since then, coal has been on a mostly steady decline, apart from the increases seen following the economic shocks of the financial crisis in 2010, the Covid-19 pandemic in 2021 and the gas price crisis in 2022.



In 2000, coal was the second largest source of EU electricity, with a share of generation of 31%. It has since fallen to fourth place, accounting for only 12% of the EU's electricity mix in 2023. After being overtaken by wind for the first time in 2020, record capacity additions for both solar and wind in 2023 will continue to displace coal in favour of renewables in 2024 and beyond.

# Gas

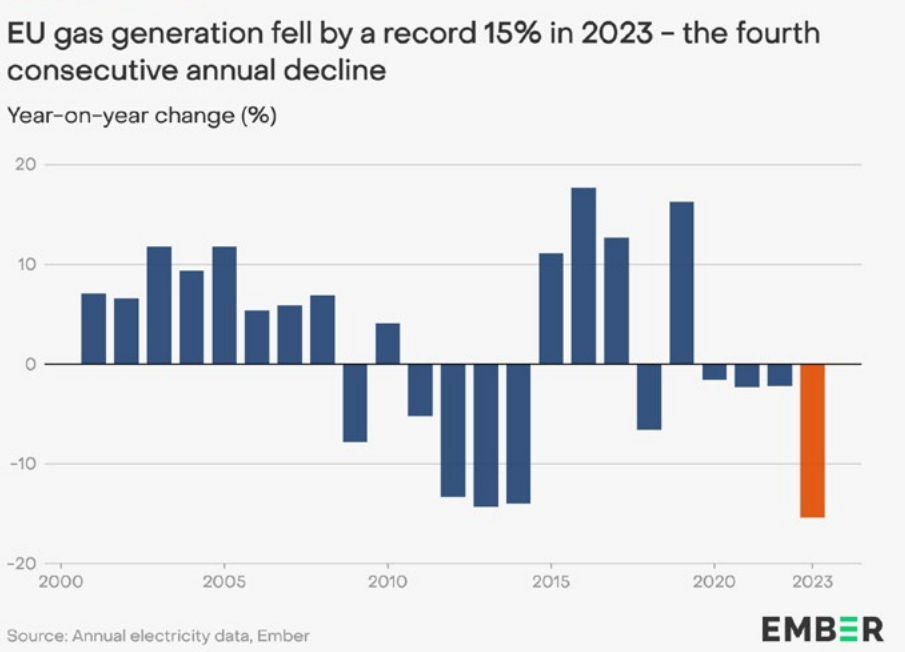


## Key highlights

**01** EU gas generation fell by a record 15% in 2023

**02** Gas generation has fallen four years in a row, returning to 2016 levels

**03** Italy generated more than a quarter of the EU's gas power in 2023



## Gas: Current status

### Gas use is falling in the EU, following emergency EU-wide gas consumption reduction targets

Gas power produced 17% (452 TWh) of EU electricity in 2023, down from 19% in 2022.

Gas, after coal, is the second largest contributor to emissions from the power sector. Gas will play a useful role in the short-term, helping with the power system flexibility to accommodate a large influx of wind and solar. However, according to the [IEA's Net Zero scenario](#), the EU's power sector needs to get to net zero by 2035. Ember's analysis shows that this means unabated gas must be reduced to less than 5% of the EU's generation by 2035.

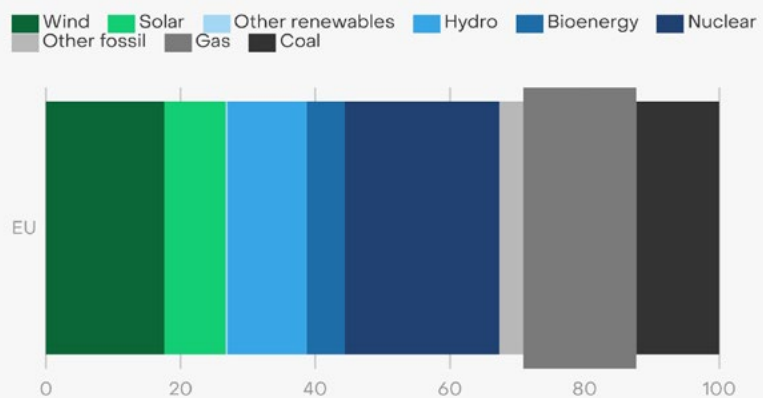
Before Russia's invasion of Ukraine in February 2022, gas was seen as a necessary bridge fuel for the energy transition. However, many European countries have since undertaken initiatives to reduce their dependence on gas. The European Commission set Member States voluntary targets to reduce their gas consumption by 15% from October to March 2023 and this has been extended to March 2024.

Italy generated the most electricity from gas in the EU in 2023. The country's 120 TWh of generation represents more than a quarter of the total electricity generated from gas in the EU. Together the five biggest consumers – Italy, Germany (79 TWh), Spain (63 TWh), the Netherlands (46 TWh) and France (31 TWh) – accounted for three quarters of all gas generation.

There are a number of countries where gas plays an outsized role

### Gas: Role in the EU electricity mix in 2023

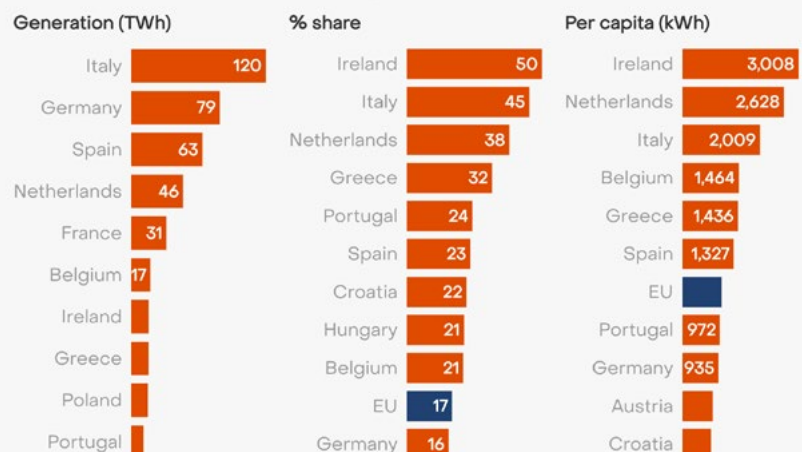
Share of electricity by source (%)



Source: Annual electricity data, Ember

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### Gas: EU country ranking in 2023



Source: Annual electricity data, Ember  
Graphic only includes countries with source generation above 3 TWh

EMBER

in the electricity system. Overall, eight EU countries have a share of gas in their electricity mix above the EU average, with Ireland (50%) and Italy (45%) being the highest.

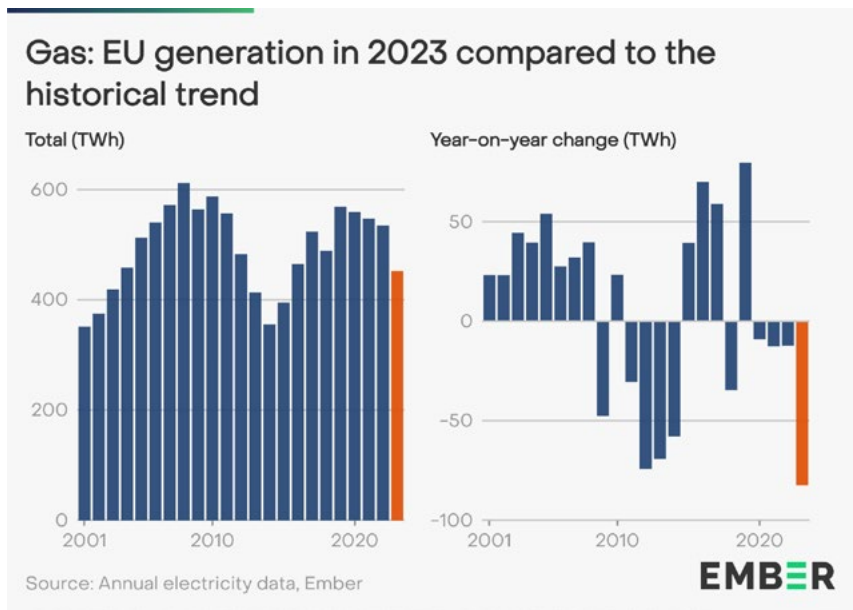
The country with the largest gas generation per capita was Ireland (3,008 kWh) followed by the Netherlands (2,628 kWh) and Italy (2,009 kWh).

## Gas: Change in 2023

### EU gas generation had its biggest year-on-year fall of all time

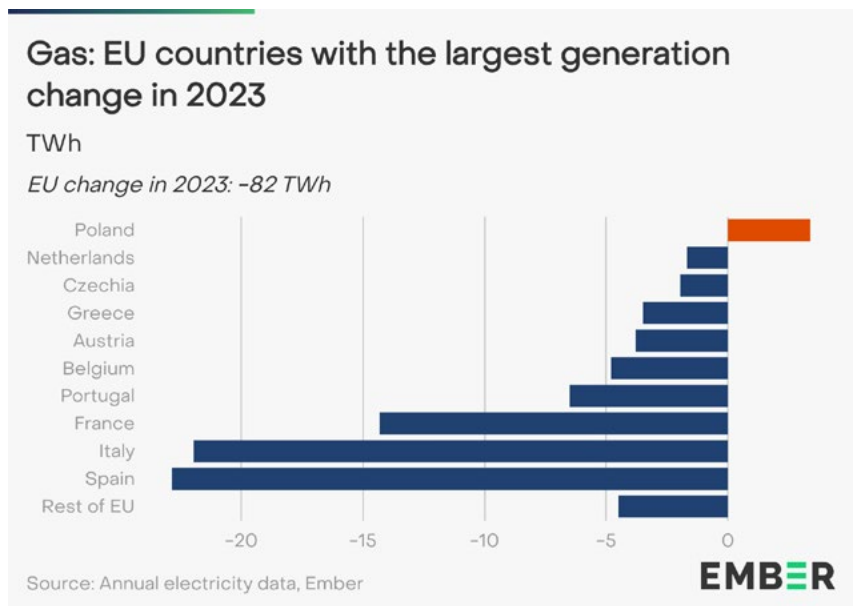
EU gas generation saw a reduction of 82 TWh in 2023, its biggest year-on-year fall of all time. Gas generation in 2023 (452 TWh) was 15% lower than 2022 (535 TWh).

This is the fourth consecutive year-on-year fall in gas generation. Following the Covid-19 pandemic in 2020, gas prices started to rise in the second half of 2021 before surging to record levels due to Russia’s invasion of Ukraine. While gas prices fell in 2023, they are still above pre-Covid levels.



Most EU countries saw a decline in generation from gas in 2023. Leading the way were Spain (-23 TWh), Italy (-22 TWh) and France (-14 TWh). Together they accounted for 72% of the fall in EU gas generation. The only country with a noteworthy increase was Poland (+3.4 TWh).

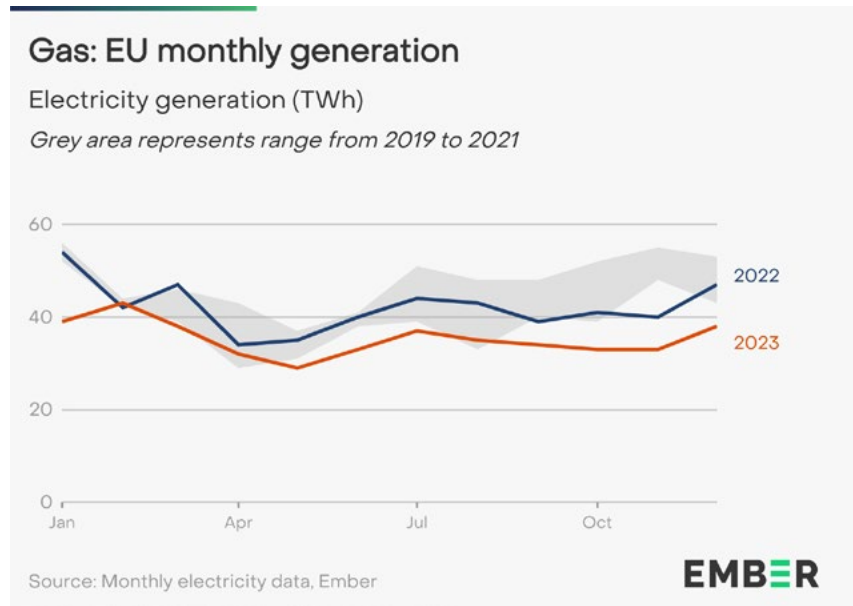
In Spain, falls in gas generation in 2023 followed a 15 TWh (+20%) increase in gas generation in 2022.





Except for February, every month in 2023 saw lower gas generation year-on-year.

Especially noteworthy were very low values for gas generation in January 2023, as well as November and December 2023. Traditionally these are the months with the highest gas generation, but a combination of high prices, warm winters and high wind output led to lower gas use.



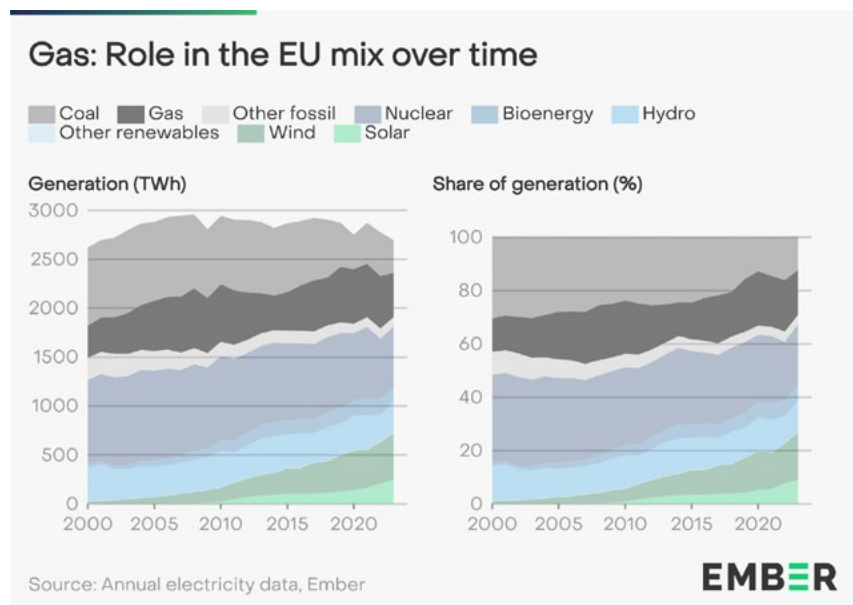
## Gas: Long term trend

### Gas generation has fallen four years in a row, returning to 2016 levels

Gas generation in the EU nearly doubled from 2000 to its peak in 2008. 2023 levels are now 26% below the 2008 peak of 612 TWh.

The share of gas generation has followed a similar trend, starting at 13% in 2000, peaking at 21% in 2008, and settling at 17% in 2023 after falling for four consecutive years.

Now that coal generation is close to being phased out in almost all the major gas generating countries, solar and wind will make major steps towards reducing gas generation in the coming years.



# Hydro

## Key highlights

01

Hydro generation recovered from its low in 2022 following impacts from one-in-500 year droughts

02

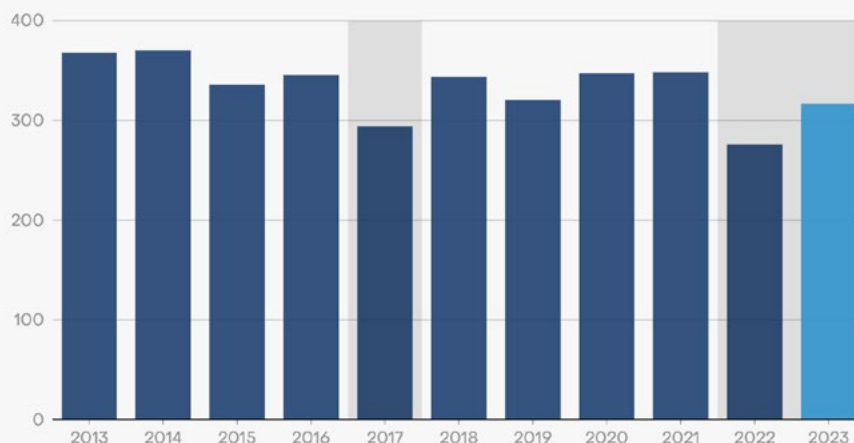
2023 hydro generation was still the third lowest in the last decade

03

Hydro generation in Italy and France were hardest hit in 2022, and showed the largest rebound in 2023

EU hydro generation recovered from its low in 2022, but is still at its third lowest in the last decade

Electricity generation (TWh)



Source: Annual electricity data, Ember

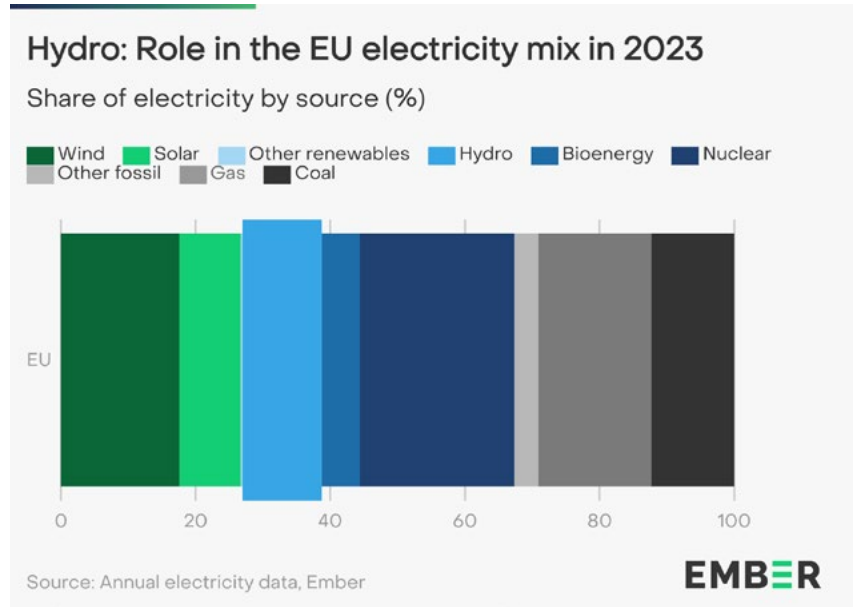
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## Hydro: Current status

**Hydro power generated 12% of EU electricity last year, with Sweden, France and Austria as the biggest producers**

Hydro power produced 12% (317 TWh) of EU electricity in 2023.

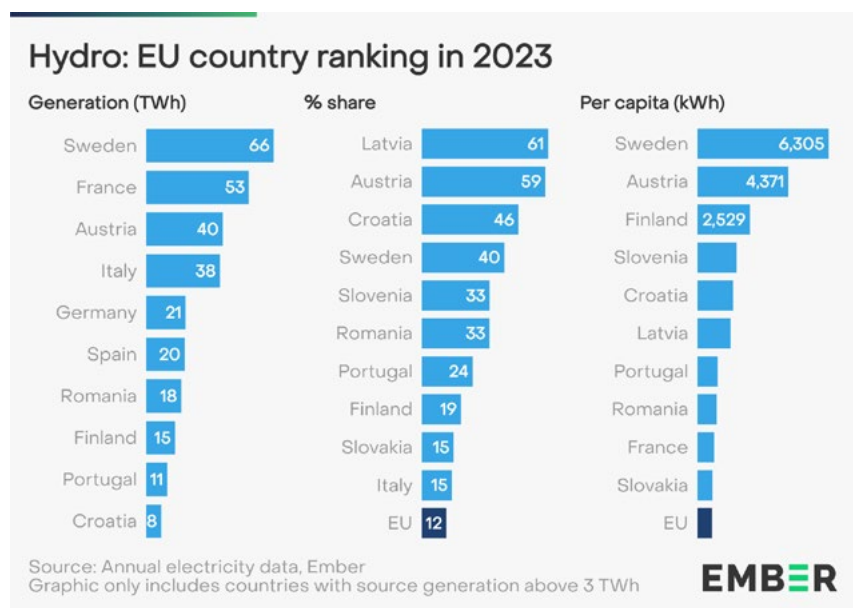
Unlike wind and solar, hydro does not have specific targets in the EU's [REPowerEU](#) plan. Hydro's generation share has remained stagnant for the last two decades. Exceptions like the drought-stricken year of 2022 highlight the risk of relying on hydro generation. Mediterranean countries, such as Spain, France and Italy are already feeling the effects of climate change and the increased probability of droughts.



Sweden was the EU's largest hydro power producer in 2023, producing 66 TWh, ahead of France (53 TWh) and Austria (40 TWh).

Austria recorded the highest share of hydro generation with 59%, followed by Croatia (46%) and Sweden (40%).

Sweden also had the highest hydro generation per capita at 6,305 kWh, significantly more than Austria (4,371 kWh) and Finland (2,529 kWh) which ranked second and third.

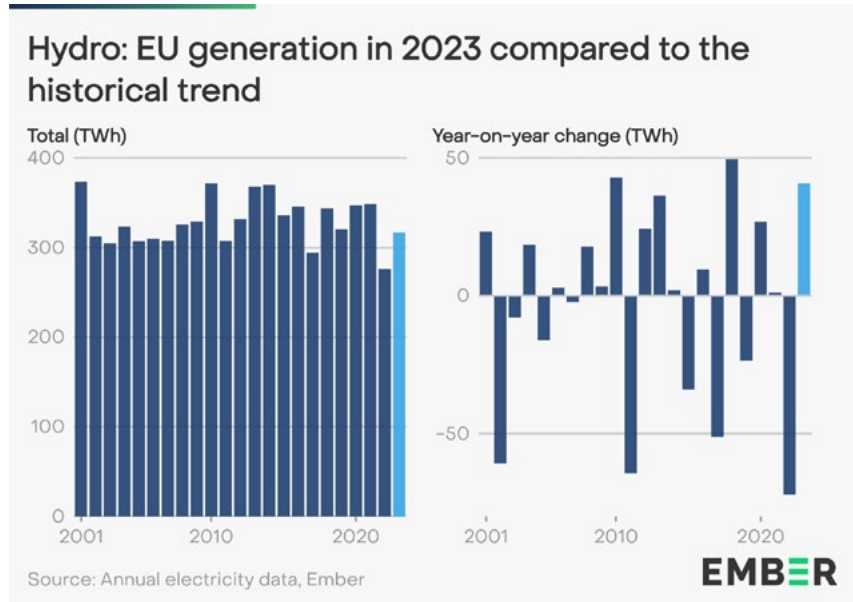


## Hydro: Change in 2023

### Hydro generation showed a modest recovery from 2022 lows

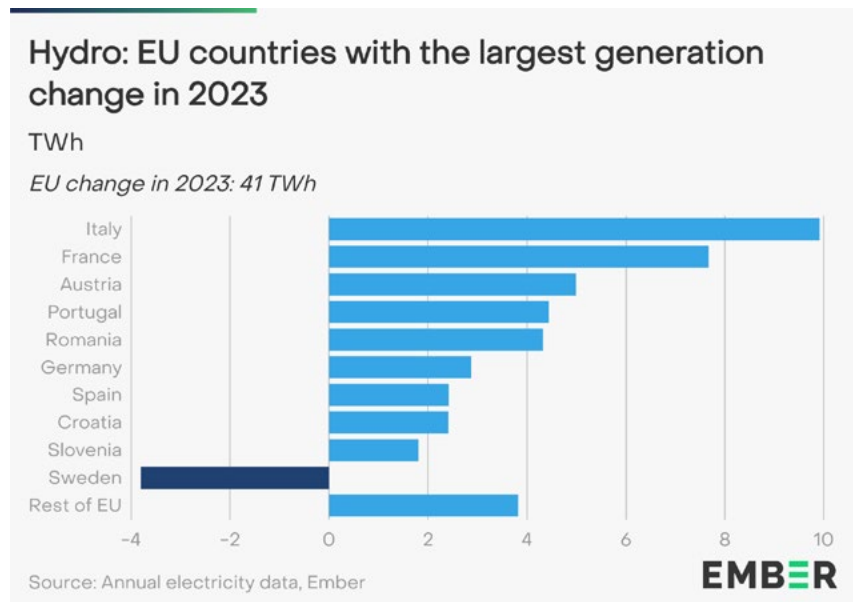
EU hydro generation recovered from a recent low in 2022 to reach 317 TWh. This represented an increase of 41 TWh (+15%).

Amid heat waves and droughts, hydro generation had fallen significantly in 2022. While 2023 represents a recovery, it was still the year with the third lowest hydro generation in the last decade, despite capacity additions over that time period.



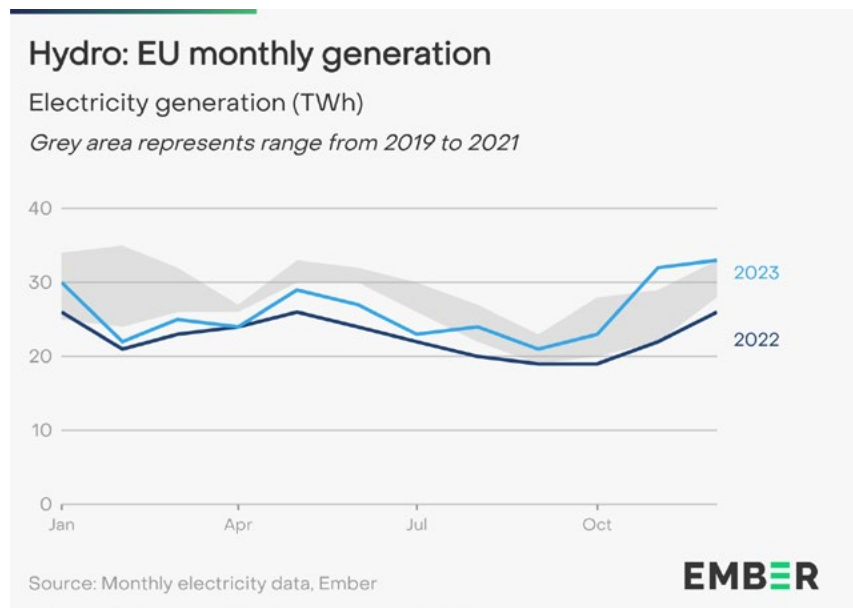
The largest hydro generation increases were recorded in Italy which saw an increase of 9.9 TWh (+35%). This marked a recovery from being hit hard by droughts in 2022. Similarly, France (+7.7 TWh, +17%) and Austria (+5 TWh, +14%) saw generation rebound from 2022 lows.

Sweden was the only EU country with significant declines in 2023, with hydro generation falling 3.8 TWh (-5.4%).



Despite showing improvement over 2022, large stretches of 2023 still had hydro generation below historical output between 2019 and 2021.

Conditions improved towards the end of the year, with a five year high in generation for the month of November and a 48% increase over generation in November 2022.



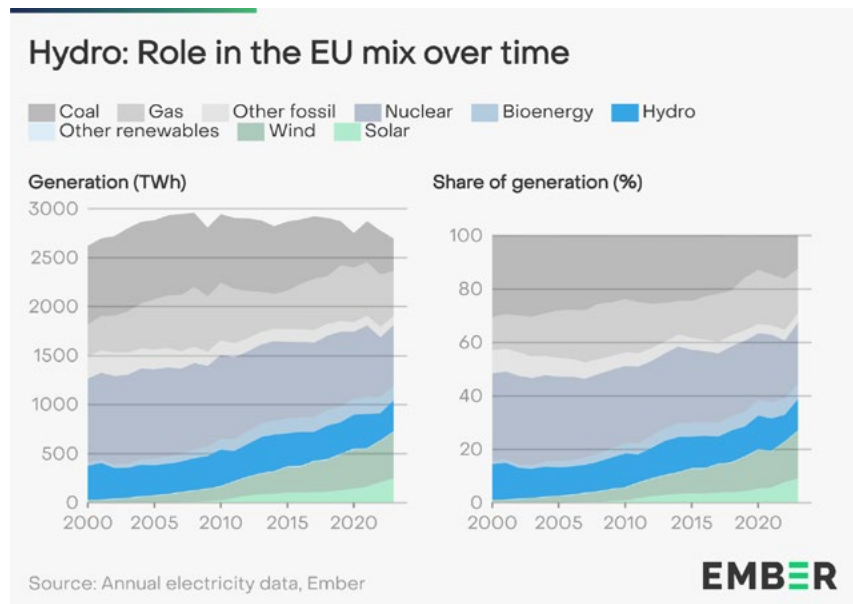
## Hydro: Long term trend

### Hydro power has shown little change in the last two decades

Since 2000, hydro generation has consistently ranged between 276 TWh (2022) and 373 TWh (2001). 2023's hydro generation of 317 TWh falls in the middle of this range.

The last few years have shown stronger variability in hydro output from year to year caused by droughts. However, there is no clear trend of hydro generation showing structural decline.

While other clean sources like wind and solar have seen their share increase, this has not been the case for hydro power. The share of hydro in the EU's electricity mix has remained stable over time. In 2000, the share was 13%. In 2023, hydro made up 12% of the mix.



# Nuclear

## Key highlights

01

Nuclear continues to be the EU's largest single source of electricity

02

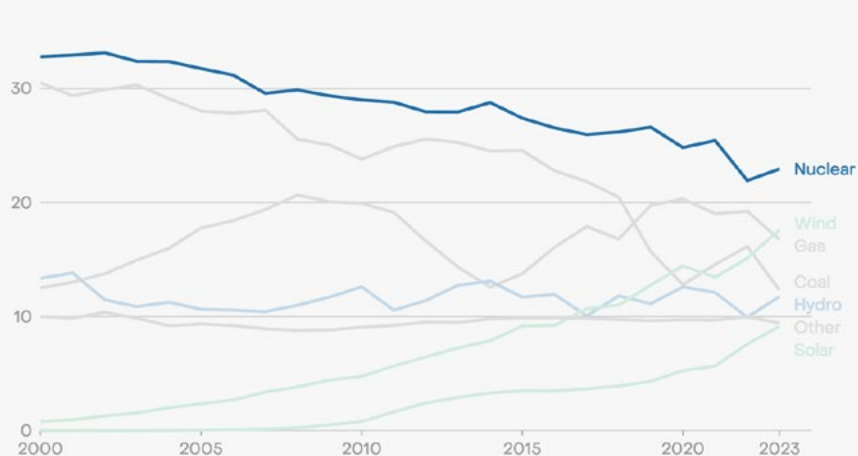
Generation recovered slightly from the 30-year low seen in 2022, as a rebound in France more than offset the fall from Germany's nuclear exit

03

Nuclear generation hit new records in Finland and Slovakia as new plants came online

### Nuclear remains the EU's leading electricity source, yet its share in the electricity mix has declined since 2000

Share of EU electricity generation, by source (%)



Source: Annual electricity data, Ember

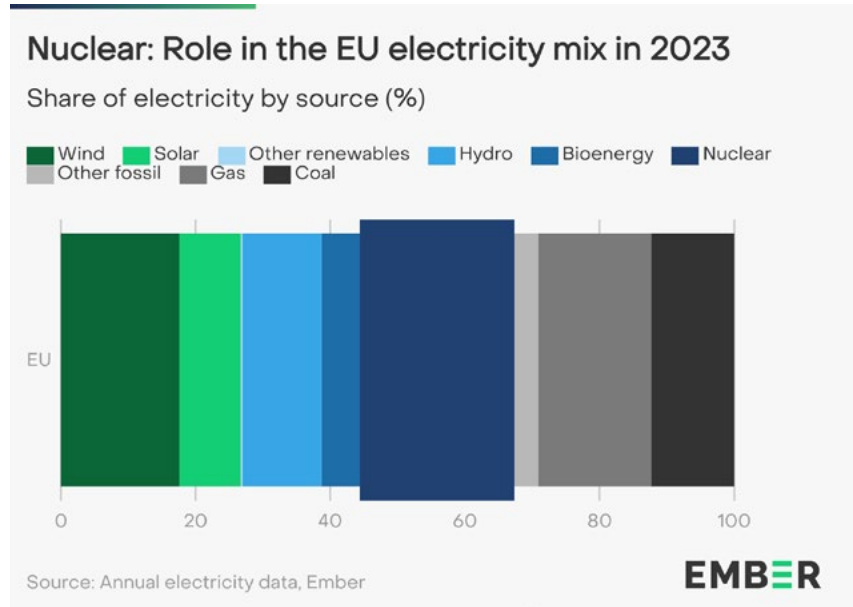
EMBER

## Nuclear: Current status

### Nuclear continues to be the EU's single largest source of electricity

In 2023, nuclear power plants produced 619 TWh, making up 23% of the EU's generation share.

Nuclear power is an important source of zero-carbon energy. In the EU, keeping older units open longer, where possible, has been recommended to prevent generation falling further.

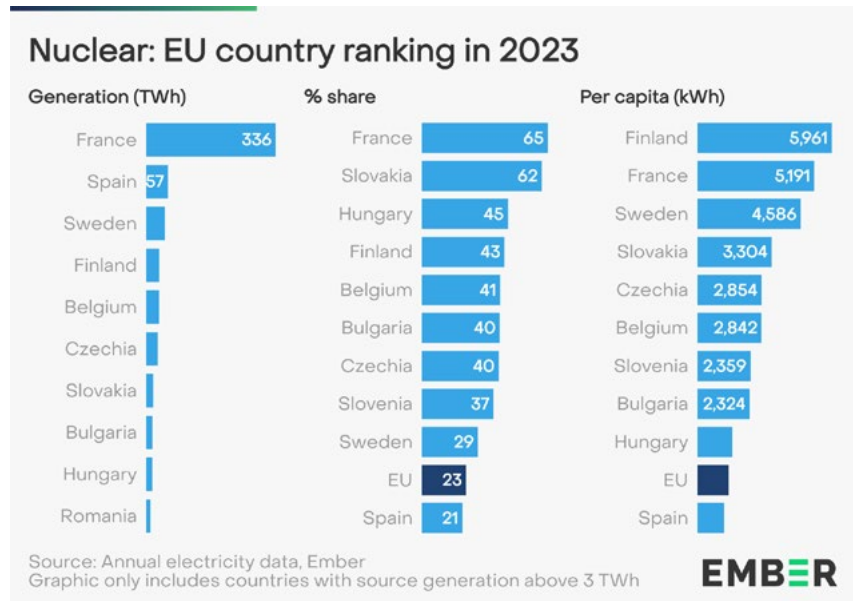


France was by far the largest producer of electricity from nuclear power in the EU. Its 336 TWh represented more than half (54%) of all nuclear power produced in the EU in 2023.

Spain (57 TWh) and Sweden (48 TWh) are the second and third largest producers.

France also had the highest share of nuclear power in the mix with 65%, ahead of Slovakia (62%) and Hungary (45%).

Finland had the highest nuclear power generation per capita at 5,961 kWh.



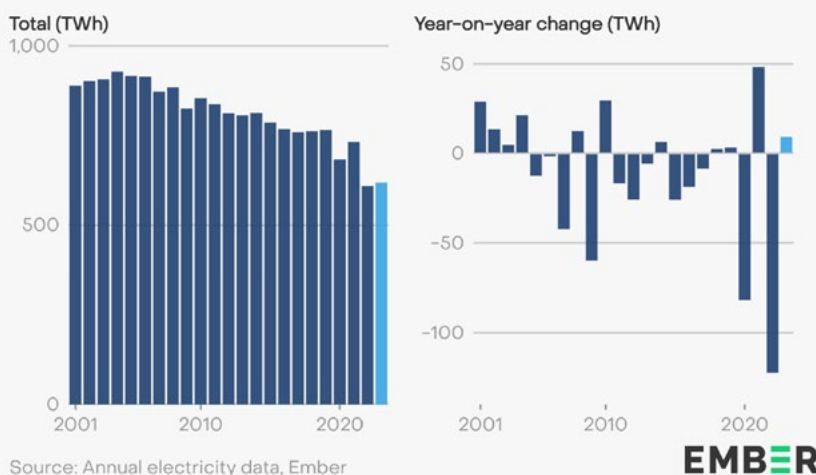
## Nuclear: Change in 2023

**In 2023, nuclear generation recovered slightly from a 30-year low in 2022**

In 2023, nuclear generation recovered only slightly from 2022, when it fell to the lowest output in more than thirty years. Generation in 2023 was at 619 TWh, only a 9 TWh (+1.5%) increase over 2022.

2023 was marked by a recovery of French nuclear generation, which suffered from severe plant outages in 2022. At the same time, Germany completed its phase-out of nuclear power, with the last reactors shut down in April 2023. This prevented a larger EU-wide recovery of nuclear generation.

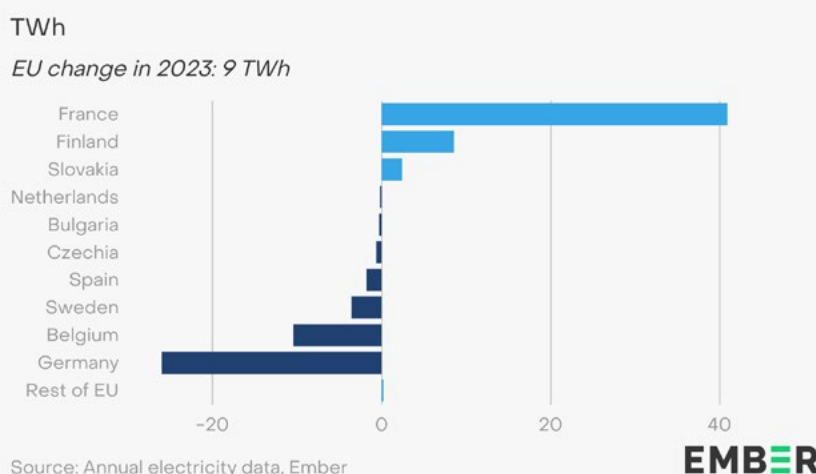
### Nuclear: EU generation in 2023 compared to the historical trend



Higher reactor availability meant that nuclear generation recovered significantly in France (+41 TWh, +14%) in 2023. Finland and Slovakia were the only other two countries with generation increases. A new plant in Finland meant its nuclear generation increased by 8.6 TWh (+34%). Similarly, Slovakia saw a 2.4 TWh (+15%) increase after a new unit of its Mochovce power plant began operation in 2023.

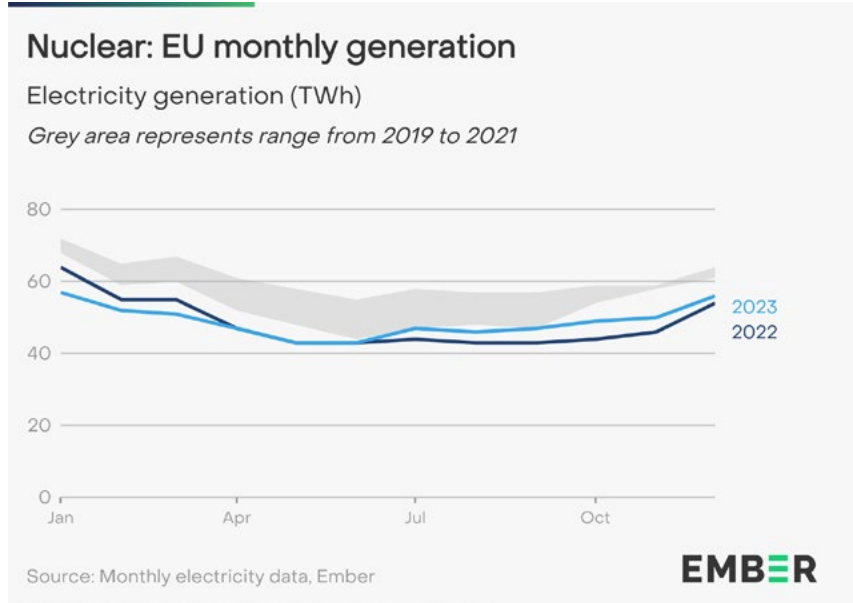
The falls in Belgium (-11 TWh) and Germany (-26 TWh) came as a result of permanent reactor retirements.

### Nuclear: EU countries with the largest generation change in 2023





Nuclear generation in 2023 was consistently at or above generation in 2022. May and June were impacted by reactor retirements in Germany at the end of April. In the latter half of the year, improved availability of French nuclear plants made up for the absence of German generation and even led to a small increase year-on-year.



## Nuclear: Long term trend

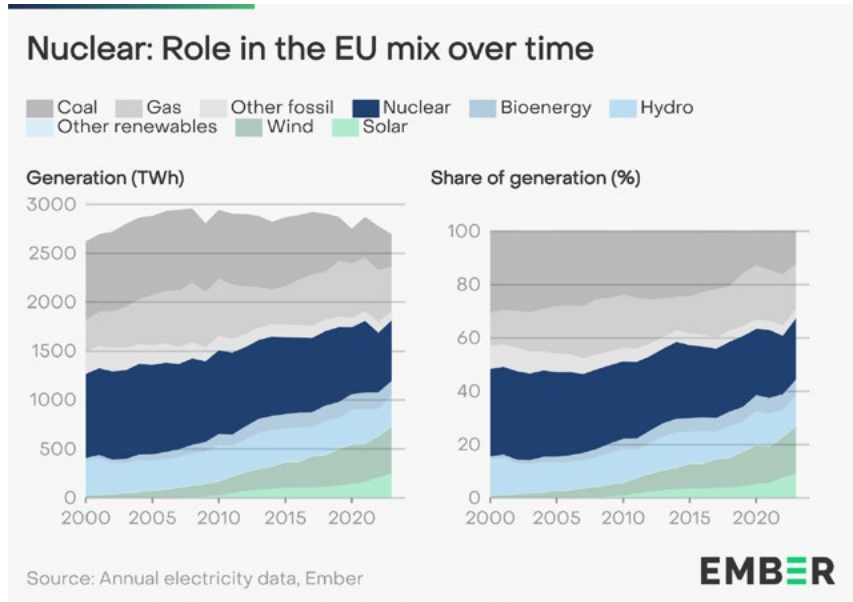
**Nuclear’s role in the electricity mix has declined since 2000**

Along with declines in generation, nuclear’s role in the EU’s mix has also declined over the last two decades.

Generation fell from 860 TWh in 2000 to 619 TWh in 2023, peaking in 2004 at 928 TWh. Consequently, the share in the mix fell from 33% in 2000 to 23% in 2023.

This reduction was largely caused by a shift in policies around nuclear power. In 2010, Germany produced 141 TWh from its nuclear fleet. In 2011, the German government

decided to phase out nuclear power entirely. Germany’s phase-out represents nearly half of the reduction in nuclear generation in the EU, with other governments like Belgium also aiming to phase down nuclear power in the near future.



# Bioenergy



## Key highlights

01

Bioenergy produced 5% of EU electricity in 2023

02

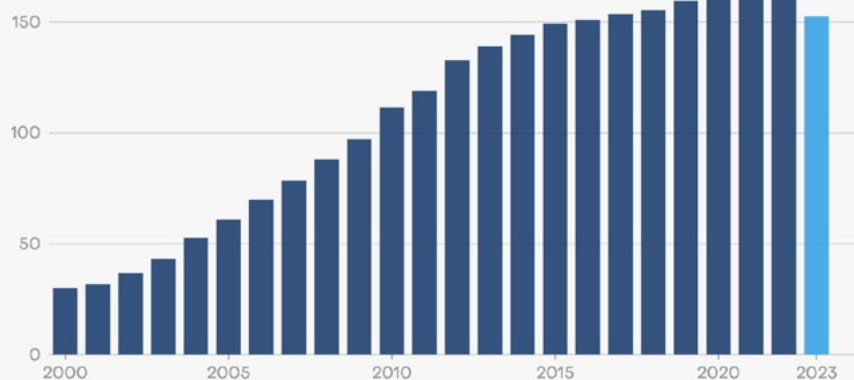
Bioenergy generation fell by 8% in 2023 and is now 11% below its 2021 peak

03

The two biggest generators of bioenergy are Germany and Italy, burning predominately biogas, although wood is burnt in many other countries

EU bioenergy generation is now 11% below its 2021 peak - after falling for only the second time in two decades in 2023

Electricity generation (TWh)



Source: Annual electricity data, Ember

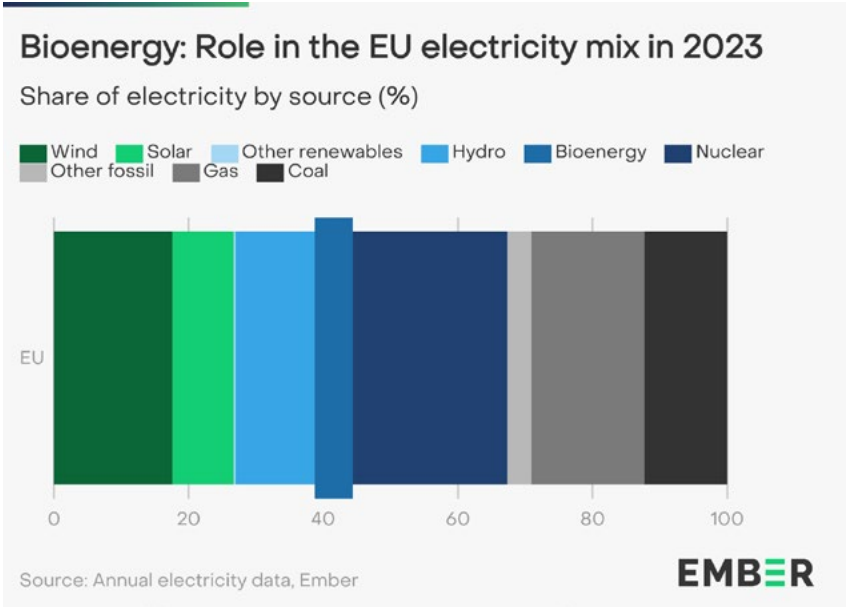
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# Bioenergy: Current status

**Bioenergy produced just above 5% of EU electricity, a third of which was produced by Germany**

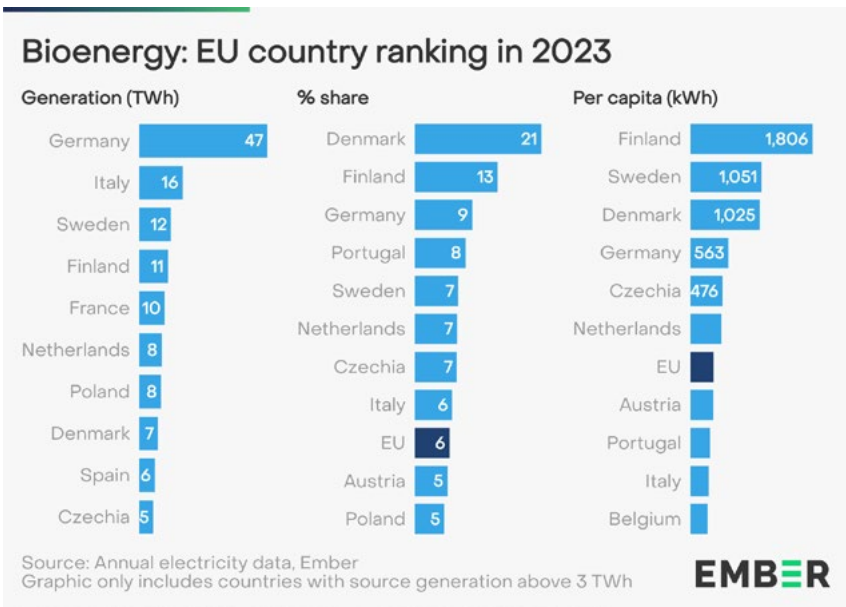
Bioenergy produced 5.7% (153 TWh) of EU electricity in 2023.

Bioenergy has been widely assumed to be carbon neutral. However, recent scientific evidence is clear that there is a major risk of significant carbon emissions from many forms of biomass, particularly woody biomass. Given these risks, countries should aim to minimise or eliminate the inclusion of large-scale bioenergy in the power sector.



Germany produced the most electricity from bioenergy in the EU in 2023 with 47 TWh, representing nearly a third of total EU generation from bioenergy. Italy (16 TWh) and Sweden (12 TWh) are the second and third largest producers. The main bioenergy fuel in Germany and Italy is predominantly biogas, but in many other countries it is biomass.

Denmark (21%), Finland (13%) and Germany (9%) had the highest shares of bioenergy in their energy mix in 2023.



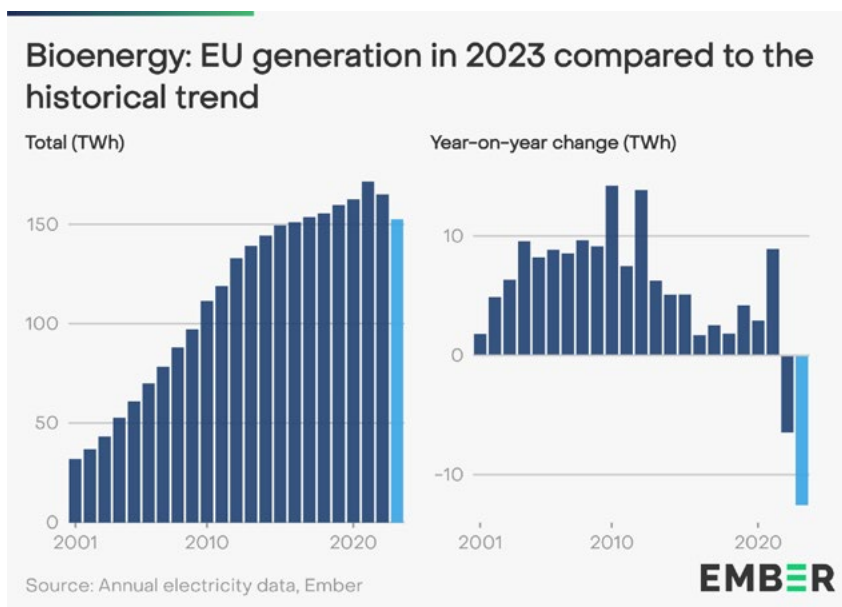
At 1,806 kWh, Finland had the highest generation per capita, ahead of Sweden (1,051 kWh) and Denmark (1,025 kWh).

## Bioenergy: Change in 2023

**Bioenergy generation fell in the EU for the second year running, following stricter EU rules on biomass use**

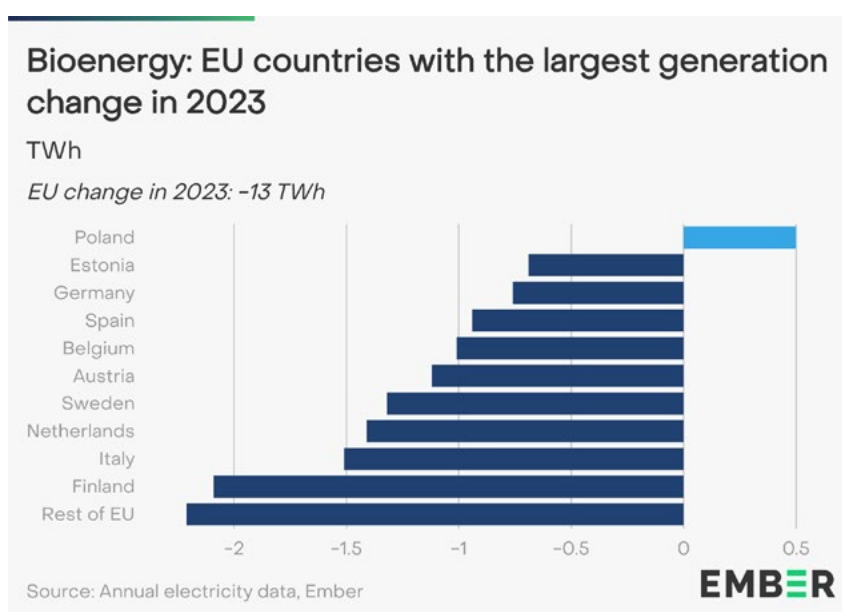
Total bioenergy generation in the EU fell for the second year in a row to 153 TWh in 2023. The fall of 13 TWh (-7.6%) in 2023 was only the second fall in the last two decades, after 2022 also saw generation decline.

The decline comes amid stricter EU rules on biomass use and new biomass installations. These were set in the EU's updated [Renewable Energy Directive](#), which strengthened rules first introduced in 2021.



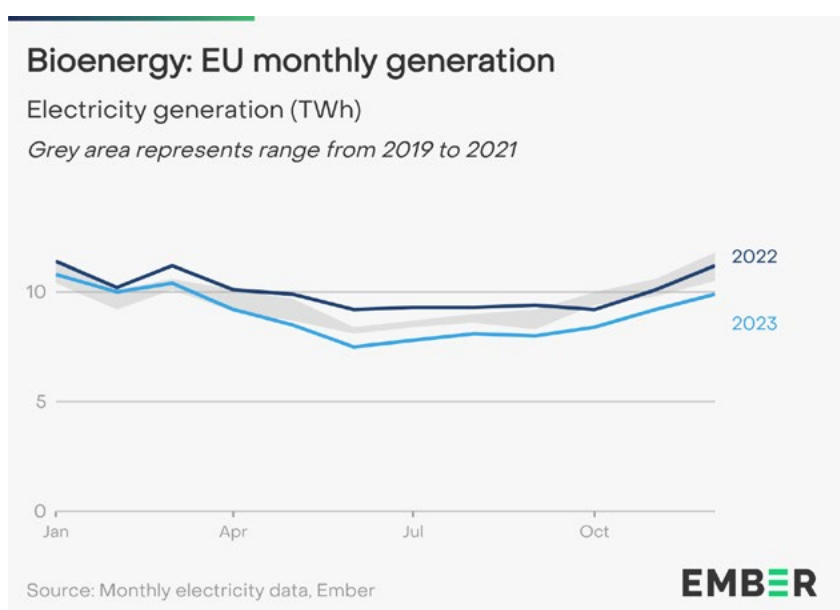
While Poland saw a small increase of 0.5 TWh in 2023, bioenergy generation fell in many European countries. Finland saw generation fall by 2.1 TWh. Italy (-1.5 TWh), Sweden (-1.3 TWh), the Netherlands (-1.4 TWh) and others also saw falls.

Finland's substantial reductions came despite total electricity generation in the country increasing by 10% compared to 2022. The addition of other low carbon sources, namely nuclear (+8.6 TWh) and wind (+2.9 TWh), reduced the need for additional bioenergy.



Since the second quarter of 2023 bioenergy generation has consistently remained at a five-year low. June 2023 saw the lowest monthly bioenergy generation since 2018.

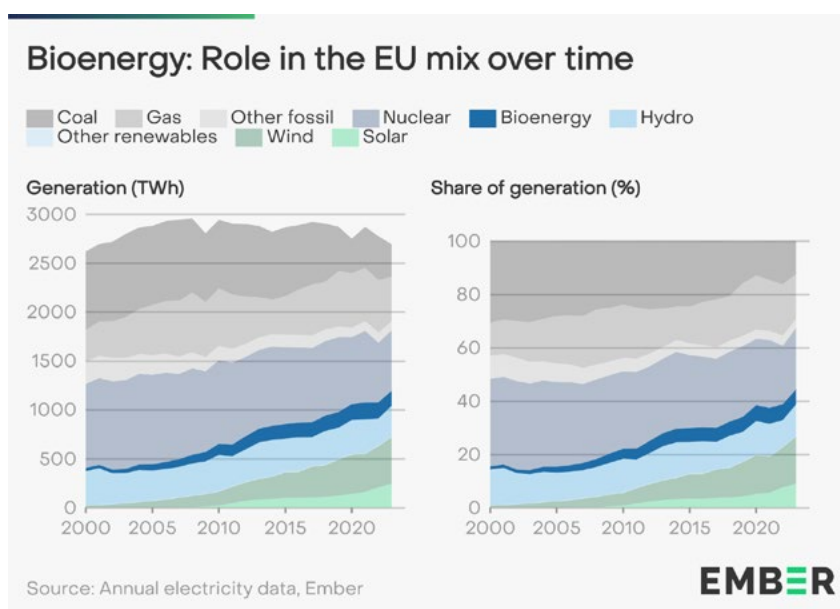
Similar to other dispatchable fuels, such as coal and gas, bioenergy saw generation reductions in 2023 as demand in the EU fell more than in 2020 during the height of Covid-19 lockdowns.



## Bioenergy: Long term trend

**Bioenergy generation may have peaked in 2021, with falls recorded in 2022 and 2023, though it is too early to say**

Since 2000, generation from bioenergy has risen substantially in the EU. In 2000, generation was at just 30 TWh. In 2021, this reached 172 TWh. In 2022 and 2023, the EU saw the first falls in bioenergy, falling first to 165 TWh in 2022 and further to 153 TWh in 2023. It is too early to say whether these falls simply represent a bump in a previously steady trend, or the onset of a sustained downward movement.



Mirroring its trajectory in total generation, the share of bioenergy in the EU's electricity mix has grown over the last two decades. While bioenergy only made up 1.1% of the mix in 2000, this had risen to 4.8% by 2013 and has stayed around 5% for the last decade, reaching 5.7% in 2023.

## Conclusion

# Strides forward must be larger and faster

**The clean transition took significant steps forward in 2023, with focus shifting to the creation of a flexible, efficient decarbonised power system. Faster implementation is now key to delivering the full benefits of the transition.**

The EU is entering a new era in its energy transition. Russia's invasion of Ukraine in February 2022 instigated a turning point away from fossil fuel reliance that has manifested into a structural shift and created an accelerated charge towards clean power.

In 2023, the EU substantially stepped up its move away from not only coal, but also gas. If 2022 saw a slight uptick in coal generation due to emergency supply measures and substantial issues with both hydro and nuclear supply, 2023 has reconfirmed the demise of coal across the EU. Gas generation has also been falling for the last four years and fossil fuels have reached new lows, accounting for less than a third of the EU's electricity generation for the first time ever.

The lessons learnt that reliance on fossil fuels creates huge economic and security risks must not be, and do not appear to have been, forgotten.

It is widely accepted that an accelerated energy transition is the only solution to mitigate these risks. And wind and solar are driving the EU towards its new renewables target. While solar continues to lead the way in terms of rate of growth, wind is the major player, reaching a significant milestone in 2023 by overtaking gas generation for the first time. Despite record generation and capacity additions for both wind and solar, however, it is clear that deployment is not yet increasing at the required speed.

For the second year in a row, we have seen a significant annual fall in electricity demand, which has assisted progress in weaning off fossil fuels. But it is certainly not time to get complacent. EU power sector emissions saw their highest ever fall in 2023, but as the growth of electrification across all sectors brings increasing demand, ensuring this is covered by a step-up in renewables and their key enablers is crucial to achieving climate goals.

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## Supporting Materials: Methodology

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### Generation, imports and demand

Annual data from 1990 to 2022 is gross generation, published primarily by [Eurostat](#) with wind generation data from [IRENA](#). 2023 data is an estimate of gross generation, based on net generation gathered from monthly data. This estimate is calculated by applying absolute changes in net generation to the most recent gross baseline.

Net imports from 1990 to 2022 are also published by Eurostat, with recent data estimated in the same manner as generation. Demand is calculated as the sum of generation and net imports, and validated against direct demand figures published by ENTSO-E.

Monthly data is gathered from a number of sources, including both centrally reported [ENTSO-E](#) data and directly reported national transmission system operators. In some cases data is published on a monthly lag; here we have estimated recent months based on relative changes in previous years. 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.

Below is a list of countries included, and sources for monthly data:

- Austria: [E-Control GmbH](#); hourly hydro data used in analysis based on ENTSO-E and E-Control
- Belgium: ENTSO-E
- Bulgaria: ENTSO-E
- Croatia: ENTSO-E
- Cyprus: Eurostat; hourly data used in analysis from [Cyprus Transmission System Operator](#)
- Czechia: ENTSO-E
- Denmark: ENTSO-E
- Estonia: ENTSO-E
- Finland: Biomass, gas, hydro, solar and wind from Eurostat; other fuels from ENTSO-E; hourly biomass data used in analysis based on ENTSO-E and Eurostat
- France: ENTSO-E
- Germany: Gas and solar from [Energy-Charts](#); other fuels from [Agora Energiewende](#); flow data from ENTSO-E; yearly gas generation data from the [Energy Institute](#)

- 
- Greece: ENTSO-E
  - Hungary: Solar data before 2020 from Eurostat; other fuels from ENTSO-E
  - Ireland: Generation and flow data from [Sustainable Energy Authority of Ireland](#); hourly data not included in analysis due to data quality issues
  - Italy: Biomass and solar from [Terna](#); other fuels from ENTSO-E; flow data from Terna
  - Latvia: ENTSO-E
  - Lithuania: ENTSO-E
  - Luxembourg: ENTSO-E
  - Malta: Eurostat; no hourly data available for use in analysis
  - Netherlands: Base data provided by [Statistics Netherlands \(CBS\)](#); more recent months estimated based on ENTSO-E and data kindly provided by [NetAnders](#); hourly solar data until October 2023 used in analysis kindly provided by [Solcast](#), thereafter modelled based on insolation data from [Open-Meteo](#) and monthly generation data; hourly wind, gas and biomass data used in analysis based on ENTSO-E and CBS
  - Poland: Solar data from [ARE](#) via [Instrat](#); other fuels from ENTSO-E; pre-2021 hourly solar data used in analysis modelled based on capacity from Instrat and insolation data from [Open-Meteo](#)
  - Portugal: ENTSO-E
  - Romania: ENTSO-E
  - Slovakia: ENTSO-E
  - Slovenia: ENTSO-E
  - Spain: ENTSO-E; flow data from [Red Eléctrica](#)
  - Sweden: ENTSO-E; hourly solar data used in analysis from [Elstatistik](#)

## 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.



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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 [matt.ewen@ember-climate.org](mailto:matt.ewen@ember-climate.org).**

Our sources and methodology for different fuels is 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.

## 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 hard coal and lignite. The range of factors used in the EU from 2000–2023 is

- Hard coal: 952–1045 g/kWh
- Lignite: 1033–1080 g/kWh

## 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. The range of factors used in the EU is:

- 334–620 g/kWh.

## Nuclear and wind

We use region-level data from UNECE. The values used are:

- Onshore wind: 12 g/kWh
- Offshore wind: 15 g/kWh
- Nuclear: 5 g/kWh

## 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 CO<sub>2</sub>. However, the short-term impact of methane is actually four times higher, at 86 times the potency of CO<sub>2</sub> over the first 20 years in the atmosphere. 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 cofiring. 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 cofiring plants, which actually have greater efficiency than reported when considering total useful energy output. Our gas factors account for CHP.

### Coal and gas generation costs

Generation costs are calculated as short run marginal costs. These are dispatch costs accounting for fuel and carbon costs, and do not include capital or operational costs. Input price data is:

- Coal: API2 Rotterdam front month contract
- Gas: Dutch Title Transfer Facility (TTF) day ahead contract
- Carbon: EU Emissions Trading Scheme front December contract

Plant efficiency assumptions are:

- Coal: 40%
- Gas: 55% (Lower Heating Value/Net Calorific Value)

### Missing solar generation additions

Solar generation is analysed in countries where we have confirmation that some solar is absent in reporting (Austria, Czechia, Portugal, Romania, Spain, and Sweden) and also in Germany which displayed unusually low solar growth. Solar performance is analysed by calculating a performance factor from generation, capacity and solar irradiation and applying a recent historical average to 2023 generation, adjusting for the proportion of capacity we believe to not be reported. In Germany and Spain this analysis accounts for the timing, location and type (metered/unmetered) of solar capacity installations and irradiance; in other countries it is based on national end-of-year figures.

### Demand analysis

Industrial production impact on electricity demand is calculated based on Eurostat data on [final electricity consumption in industry by sub sector](#) and Eurostat data on industrial production by sub-sector with [annual data until 2022](#) and [monthly data for January–October 2023](#). Final electricity consumption in each industry sub-sector as of 2021 (in TWh) is assumed to have changed by the same percentage as a relevant industrial production index in 2022 and 2023. For 2023, the average

annual change in industrial production in January–October is used.

The electrification impact on the 2023 vs 2021 change in EU electricity demand is estimated separately for electric vehicles (EVs), heat pumps and electrolyzers:

- The additional electricity demand attributed to EVs is calculated using data on the EU battery–electric vehicles fleet from the [European Alternative Fuels Observatory](#) (battery–electric vehicles number for 2023 estimated based on the annual change in monthly registrations for January–October 2023). Passenger cars are assumed to consume on average 2.41 MWh per year based on 200 Wh per km average consumption and 12,000 km per year average travel (33 km per day). The average travel is calculated from the [annual vehicle–km data](#) available for 15 EU countries divided by the stock of vehicles in each country and weighted by the number of vehicles per country. Average consumption for a light commercial vehicle is assumed to be 5.62 MWh per year (70 km per day, 220 Wh per km, taking into account mileage data from [Klaunberg et al., 2016](#)) and a bus is assumed to consume on average 80.3 MWh per year (200 km per day, 1,100 Wh per km).
- For electrolyzers, 500 MW installed by the end of 2023, as per the IEA's [Global Hydrogen Review 2023](#), assuming 65% utilisation rate.
- For heat pumps, three million units were sold in 2022, as per the [European Heat Pump Market and Statistics Report 2023](#), assuming the same level of sales in 2023. The electricity consumption estimates assume that heat pumps consume about 5MWh/unit/year.

### Value factor analysis

Value factors are calculated using hourly day–ahead prices from ENTSO–E and hourly generation data as described above. A marginal price–taking solar + storage unit is modelled with the following assumptions, based on a [representative unit described by NREL](#).

- 130 MW DC solar array with output based on national generation data
- 60 MW DC battery with 2 hr (120 MWh) energy capacity
- 100 MW AC inverter
- 87% round trip efficiency, implemented on charging side, such that the battery charge rate is 87% of the panel discharge rate into the battery (i.e. a maximum charge rate of 52.2 MW)
- 0 MWh minimum state of charge

The cycle strategy is as follows:

- Peak charging and discharging hours are parameterised by finding average minimum daytime and maximum evening price hours per quarter per country. These tend to be around midday and 6–7pm.
- Charge symmetrically around peak hours, maintaining a level output profile to the grid. Any generation that would otherwise be curtailed (e.g. when the array output is bigger than the inverter capacity) is used to charge the battery if possible. The battery is charged as much as is

possible.

- Discharge symmetrically around peak hour at maximum possible rate
- No charging from the grid is allowed

This strategy is intentionally simple and is not optimised with real-time price information. It therefore represents an underestimate of the true marginal value of storage.

### **Other data sources**

Solar capacity data is provided by [SolarPower Europe](#), measured in [MW DC](#). Coal capacity is the latest data from Beyond Fossil Fuels' [European Coal Plant Database](#). Gas demand is from [Eurostat annual data](#) 2000–2022, with 2023 estimated based on average annual change over January–September 2023 from [Eurostat monthly data](#). Weather data is ERA5 reanalysis data, in most cases extracted via [Teal](#).

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