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European Electricity Review 2025

The EU's electricity transition continued at pace in 2024, as solar overtook coal for the first time and gas declined for the fifth year in a row.

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Dr Chris Rosslowe
Dr Beatrice Petrovich

About

The European Electricity Review analyses full-year electricity generation and demand data for 2024 in all EU-27 countries to understand the region's progress in transitioning from fossil fuels to clean electricity. It is the ninth 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.

Highlights

11%

Share of solar in EU electricity in 2024, higher than coal.

5

EU fossil gas power fell for the fifth year running.

€59 bn

Avoided fossil fuel import costs due to new wind and solar since 2019.

Contents

Executive summary

Progress in the EU's electricity transition builds confidence to 2030

The transition of the EU electricity sector maintained momentum in 2024, despite challenging political and economic conditions. Solar power grew strongly and overtook coal power for the first time. Another year of coal and gas decline – the fifth year in a row for gas – cut EU power sector emissions to below half their 2007 peak and further reduced reliance on imported fossil fuels. Significant progress has been made over the last EU political cycle, but delivery needs to be accelerated.

The European Green Deal has delivered a deep and rapid transformation of the EU power sector. Driven by expanding wind and solar power, renewables have risen from a share of 34% in 2019 to 47% in 2024, as the fossil share declined from 39% to a historic low of 29%. Solar remained the EU's fastest growing power source in 2024, rising above coal for the first time. Wind power remained the EU's second largest power source, above gas and below nuclear.

The significant progress has brought benefits beyond reducing emissions. Structural growth in wind and solar power has reduced the EU's fossil import bill and the bloc's vulnerability to imported gas. While the progress made in the first half of this decade is impressive, an acceleration is needed between now and 2030.

Key takeaways

01 Solar overtakes coal

Solar was the fastest growing EU power source in 2024; capacity additions hit a record high and generation was 22% higher than in 2023. Solar (11%, 304 TWh) overtook coal (10%, 269 TWh) for the first time in 2024, meaning coal has fallen from being the third largest EU power source in 2019 to the sixth largest in 2024. This trend is widespread; solar is growing in every EU country, while coal is becoming increasingly marginal. More than half of EU countries either have no coal power or a share below 5% in their power mix. Accelerated clean flexibility and smart electrification are needed to sustain solar growth.

02 Gas declined five years in a row

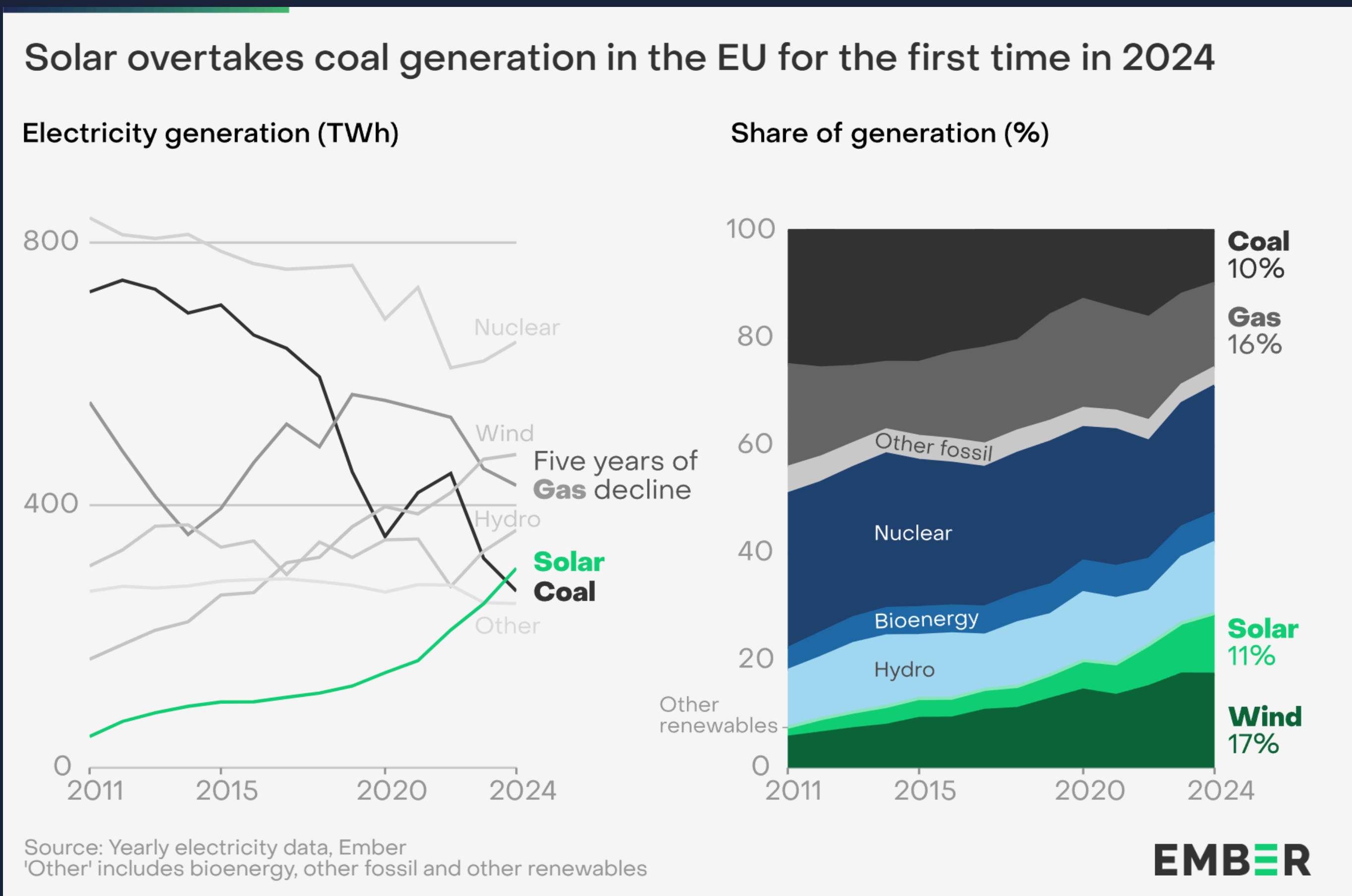
Gas power generation declined for the fifth year in a row - despite a small rebound in electricity demand. Combined with another coal decline, this cut total power sector emissions in 2024 to below half of their 2007 peak. This sustained decline has played a key role in reducing total EU gas consumption by 20% in the past five years: about a third of this decline occurred in the power sector. Without wind and solar added in 2024, EU gas consumption for power would have been 11% higher.

03 Wind and solar avoided €59 billion in fossil fuel imports since start of Green Deal

In five years of the European Green Deal, a surge in wind and solar generation is the main reason for declining fossil generation. Without wind and solar capacity added since 2019, the EU would have imported 92 billion cubic metres more of fossil gas and 55 million tonnes more of hard coal, costing €59 billion. To maximise future benefits, Member States must continue to implement reforms to accelerate wind power deployment, as delivery currently risks falling short despite cost competitiveness.

The amount of progress made in five years of the European Green Deal should inspire confidence in what can be achieved by 2030. A faster roll out of clean flexibility, grid infrastructure and electrification will be key to sustaining clean power growth. Solar continues to be the fastest growing EU power source, but more storage and demand flexibility is needed to sustain growth and for consumers to reap the full benefits of abundant solar. After a challenging few years for the wind power sector, additions are set to grow, but not by enough to hit EU targets. Closing this gap will require continued policy implementation and political support, such that the rate of additions between now and 2030 is more than double that of recent years.

The EU has much to gain from accelerating its electricity transition: a clean electrified future, powered by wind and solar, will enhance energy security and bring down energy costs for all consumers.



“Fossil fuels are losing their grip on EU energy. At the start of the European Green Deal in 2019, few thought the EU’s energy transition could be where it is today; wind and solar are pushing coal to the margins and forcing gas into structural decline. While the EU's electricity transition has moved faster than anyone expected in the last five years, further progress cannot be taken for granted. Delivery needs to be accelerated particularly in the wind sector, which has faced unique challenges and a widening delivery gap. However, the achievements of the past five years should instil confidence that, with continued drive and commitment, challenges can be overcome and a more secure energy future be achieved.”

Dr Chris Rosslowe
Senior Energy Analyst,
Ember

"The EU is striding closer towards a clean energy future powered by homegrown wind and solar. This new energy system will reduce the bloc’s vulnerability to fossil price shocks, tackle the climate crisis and deliver affordable energy for its households and companies. Timely policy action that sustains wind and solar growth, accelerates the deployment of clean flexibility and promotes electrification, will help to secure the future of EU competitiveness."

Dr Beatrice Petrovich
Senior Energy Analyst, Ember

Introduction

Continuing transition to clean power is key to competitiveness

The EU power sector transition made crucial progress in 2024, with momentum sustained despite economic headwinds and political upheavals. The new EU political leadership has been clear that the future of European competitiveness is through reduced fossil fuel dependency.

The transformation of the European power sector faced many potential stumbling blocks in 2024. Inflation remained above historic levels - creating challenging conditions for investment - and many national and European elections bred concerns that the transition to clean energy would lose support. On the contrary, progress continued at pace.

The strategic, economic and social case for the energy transition in Europe is clearer than ever. While the worst of the energy crisis might be over, Europe's ongoing dependence on fossil energy leaves it vulnerable to global shocks in an increasingly volatile world. European citizens - still suffering high energy prices caused by Russian aggression in Ukraine - are increasingly feeling the impacts of the climate crisis, from record summer heatwaves to extreme flooding. Not only are renewables addressing these problems by reducing emissions, they are the cheapest solutions available and are overwhelmingly popular.

As political attention shifts to Europe's industrial and economic performance, some may argue for sustainability to be deprioritised. Conversely, the report by former European Central Bank President Mario Draghi on the future of European competitiveness concludes the best route is through reduced fossil fuel dependency, confirming that industrial policy must be rooted in the energy transition. The return of President Trump to the White House and the likely US retreat from clean energy leadership presents a clear opportunity for the EU to step up.

In this context, it is welcome to see continued commitment to the European Green Deal from the new EU Commission, as citizens and businesses stand to benefit from a faster transition. This report outlines what happened in EU electricity in 2024, the progress made during five years of the European Green Deal and key priorities to unlock further advances.

Chapter 1: 2024 at a glance

The EU power sector in 2024

Fossil power declined again in 2024, despite increases in electricity demand and EU power exports. A record year of solar growth contributed most to fossil decline, lifting solar above coal for the first time. Fossil gas power fell for the fifth year running, and was lower than wind power for a second year. Solar growth and a recovery in hydropower meant renewables accounted for nearly half (47%) of EU power generation and clean sources reached 71%, both record highs.

Solar reaches record highs while nuclear and hydro bounce back

Solar was the fastest growing EU power source in 2024, with generation 22% (+54 TWh) higher than 2023. This increase was due to a record amount of new capacity additions (66 GW), and despite slightly lower solar irradiance compared to 2023. Solar was therefore the single biggest driver of reduced fossil power in 2024. It provided 11% of EU electricity (304 TWh), overtaking coal (269 TWh) for the first year ever.

Wind power generation remained similar to 2023 levels at 17% of EU power (477 TWh). Additions of wind capacity continued, but were offset by less favourable wind conditions. Even so, wind remained the second largest source of EU power behind nuclear, widening its lead over gas (established in 2023). Wind and solar together reached a record share of 29% of the EU's power mix in 2024. This helped push renewables to nearly half (47%) of total EU electricity generation.

The EU's power sector became cleaner in 2024

	2023 Electricity generation (TWh) Share of generation (%)	2024 Electricity generation (TWh) Share of generation (%)	Change 2023-2024 Generation (TWh) Percentage change (%)
Total renewables	1208 TWh **44.8%**	1300 TWh **47.4%**	92 TWh **7.6%** ▲
- Solar	250 TWh **9.3%**	304 TWh **11.1%**	54 TWh **21.7%** ▲
- Wind	470 TWh **17.4%**	477 TWh **17.4%**	7 TWh **1.5%** ▲
- Hydro	330 TWh **12.2%**	362 TWh **13.2%**	32 TWh **9.8%** ▲
- Bioenergy	152 TWh **5.6%**	150 TWh **5.5%**	-2 TWh **-1.3%** ▼
- Other renewables*	7 TWh **0.3%**	7 TWh **0.3%**	0 TWh **4%** ▲
Nuclear	620 TWh **23%**	649 TWh **23.7%**	29 TWh **4.7%** ▲
Total fossil	868 TWh **32.2%**	793 TWh **28.9%**	-75 TWh **-8.7%** ▼
- Coal	319 TWh **11.8%**	269 TWh **9.8%**	-50 TWh **-15.7%** ▼
- Gas	456 TWh **16.9%**	430 TWh **15.7%**	-26 TWh **-5.6%** ▼
- Other fossil**	93 TWh **3.5%**	94 TWh **3.4%**	0 TWh **0.3%** ▲
Net imports	-2 TWh	-17 TWh	-15 TWh
Electricity demand	2694 TWh	2725 TWh	31 TWh **1.2%** ▲

Source: Yearly electricity data, Ember
*'Other renewables' generation includes geothermal, tidal and wave generation. **'Other fossil' generation includes generation from oil and petroleum products, as well as manufactured gases and waste.

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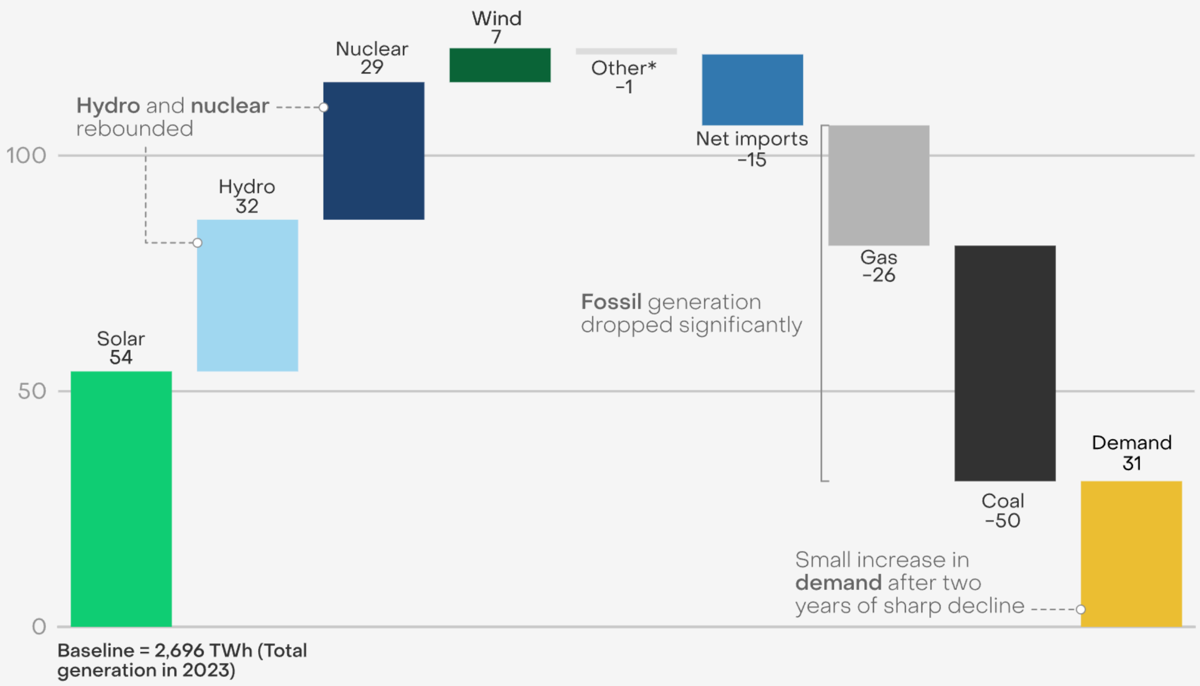
Hydro and nuclear generation increased by 32 TWh (+10%) and 29 TWh (+5%) respectively, reaching shares of 13% and 24%, completing rebounds from their 2022 lows and pushing clean sources to a record 71% of the EU power mix. Hydro generation benefited from above average rainfall patterns across most of Europe, despite droughts in southeast Europe. The increased nuclear output can largely be explained by fewer outages in France.

Solar power growth - and a hydro and nuclear rebound - dramatically reduced the EU's coal and gas generation in 2024

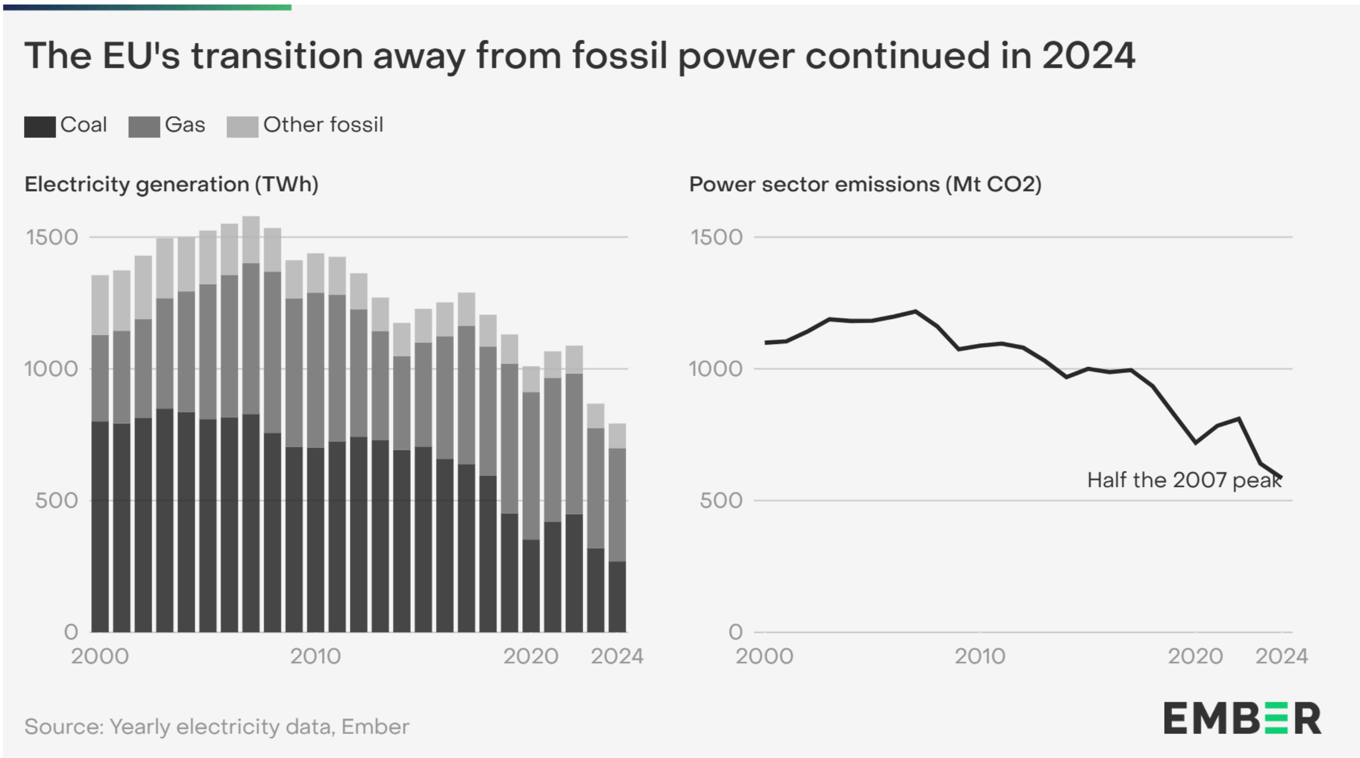
Annual change in electricity generation, 2023-2024 (TWh)



Source: Yearly electricity data, Ember
*Other includes biomass, other renewables and other fossil

Fossil power falls to a historic low across the EU

In 2024, EU fossil generation declined by 75 TWh (-9%) compared to 2023, falling to its lowest level for more than forty years (793 TWh). While not as large as the record fossil collapse between 2022 and 2023, the fall happened despite a small rise in power demand of 31 TWh (+1%) and an increase in net exports to non-EU countries (totalling +15 TWh, with notable increases of +11 TWh to the UK and +4 TWh to Ukraine).



Coal and gas power fell by 16% and 6% respectively, compared to 2023. This caused EU power sector emissions to fall by 9% to an estimated 585 million tonnes of CO2, less than half their 2007 peak.

Coal generation fell to below 10% (9.8%) of EU power (269 TWh) for the first time in decades. It decreased in 16 of the 17 countries that still used it in 2024, and is now marginal or absent in most systems, making up less than 5% of the electricity mix in 16 Member States. The EU's remaining coal power is highly concentrated in just two countries, Germany (39%) and Poland (34%), but even they saw coal generation fall by 17% and 8% respectively year-on-year.

Gas generation declined for the fifth consecutive year, falling to 16% of EU power (430 TWh). Its decline was also widespread, occurring in 14 of the 26 countries with gas power, including three of the top four gas burning EU countries: Italy (-2%), Spain (-19%) and the Netherlands (-5%).

Small increase in demand after two years of sharp decline

In contrast to the previous two years, which saw sharp declines in EU power demand, an increase of 31 TWh (+1%) was observed in 2024. While small, the recovery was consistent across the EU, seen in 22 out of 27 Member States, and it occurred in every quarter. Germany was a notable exception, with demand remaining almost the same as 2023, still 11% below 2019 levels. Total EU power demand remained low compared to pre-crisis levels (5% lower than 2019). It is too early to say whether this year's rebound marks a new era of increasing power demand, which is expected due to growth in electrification, data centres, air conditioning and more.

Chapter 2: Five years of progress

The European Green Deal delivered benefits beyond emissions reduction

2024 marks five years since the start of the European Green Deal, the EU’s landmark energy and climate policy package. Since its launch, wind and solar have surged, taking renewables to nearly half of EU electricity in 2024 and reducing dependency on coal and gas. In half a decade, the EU has made enough progress to prove that a deep transformation of the power sector is achievable, while also reducing an expensive fossil import bill.

In December 2019, the launch of the European Green Deal introduced key policies to spur the EU’s clean electricity transition. In 2022, in response to Russia's invasion of Ukraine and fossil price shocks, the EU further strengthened the bloc’s targets for wind and solar growth with the REPowerEU policy package.

These EU initiatives have contributed to a deep transformation of the bloc’s electricity sector. In 2019, renewables provided a third (34%, 979 TWh) of EU electricity, while fossil fuels provided 39% (1,130 TWh). By the end of 2024, renewables advanced to nearly half the EU mix (47%, 1,300 TWh), as fossil power fell to a historic low of 29% (793 TWh).

Between 2019 and 2024, the surge of renewable power was widespread across the bloc. In this time, the number of countries where renewables produce more electricity than fossil fuels rose from 12 to 20.

As a result of its power sector transformation, the EU has cemented its position as a leader in clean power. The emissions intensity of EU electricity generation fell 26% over the last five years, to 213 gCO2 per kWh. This was a steeper decline than other major economies, such as the US, where the emissions intensity fell by 13% over the same period, to 361 gCO2 per kWh in 2024.

Wind and solar displaced coal and gas

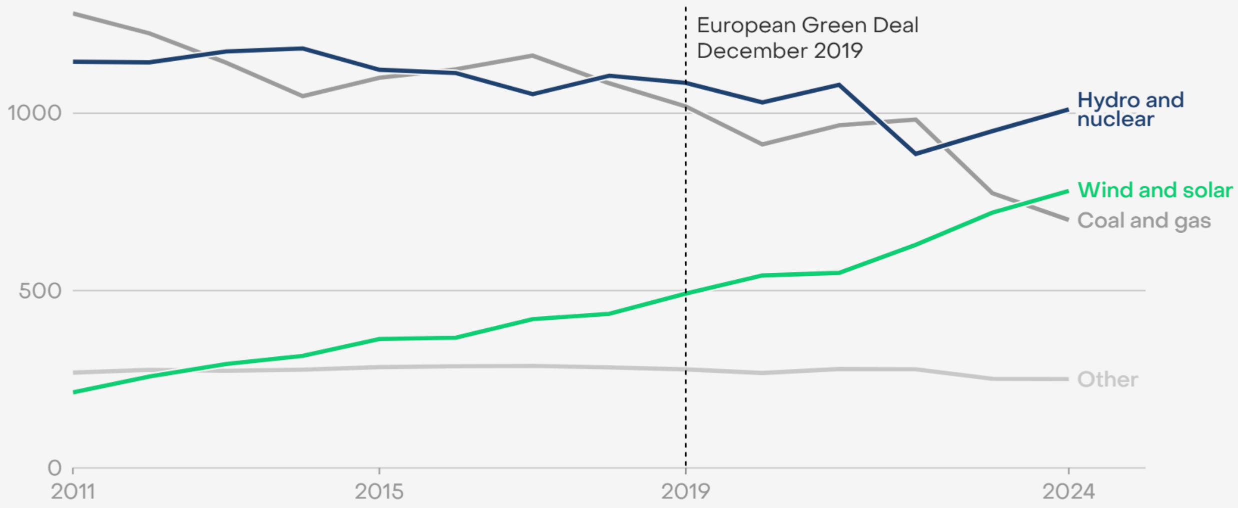
The surge of renewable power in the EU was driven by the meteoric rise of homegrown wind and solar. From 2019 to 2024, wind and solar's share of the EU electricity mix increased from 17% to 29%. Solar generation increased by 179 TWh (+144%) in this period, an amount equivalent to the annual production of over 50 coal power plants, and almost tripled its share of EU generation from 4% in 2019 to 11% in 2024. Wind generation increased by 110 TWh (+30%) over the same period, reaching a 17% share of EU electricity in 2024, up from 13% in 2019.

The consistent growth of wind and solar distinguishes them from the other main sources of clean power in the EU. While installed solar capacity almost tripled from 120 GW in 2019 to 338 GW in 2024 and wind capacity grew by 37% from 169 GW to 231 GW over the same period, hydropower capacity remained flat at 130 GW and the nuclear fleet actually decreased from 110 GW to 96 GW. Over the past five years, nuclear and hydro generation fluctuated due to weather conditions and outages.

Since the launch of the European Green Deal, rising wind and solar has driven a decline in fossil generation. Wind and solar installed in the past five years have cumulatively avoided 15% of fossil generation (736 TWh) over the period (see Methodology). This is equivalent to around 460 million tonnes of CO2, roughly the same as power sector emissions produced by Italy since 2019.

Since the European Green Deal, wind and solar growth has driven a decline in EU coal and gas

Electricity generation (TWh)



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

Green Deal cut the EU's fossil import bill

Beyond reducing emissions, growth in wind and solar spurred on by the European Green Deal has delivered huge benefits to the EU through reduced energy costs and enhanced security.

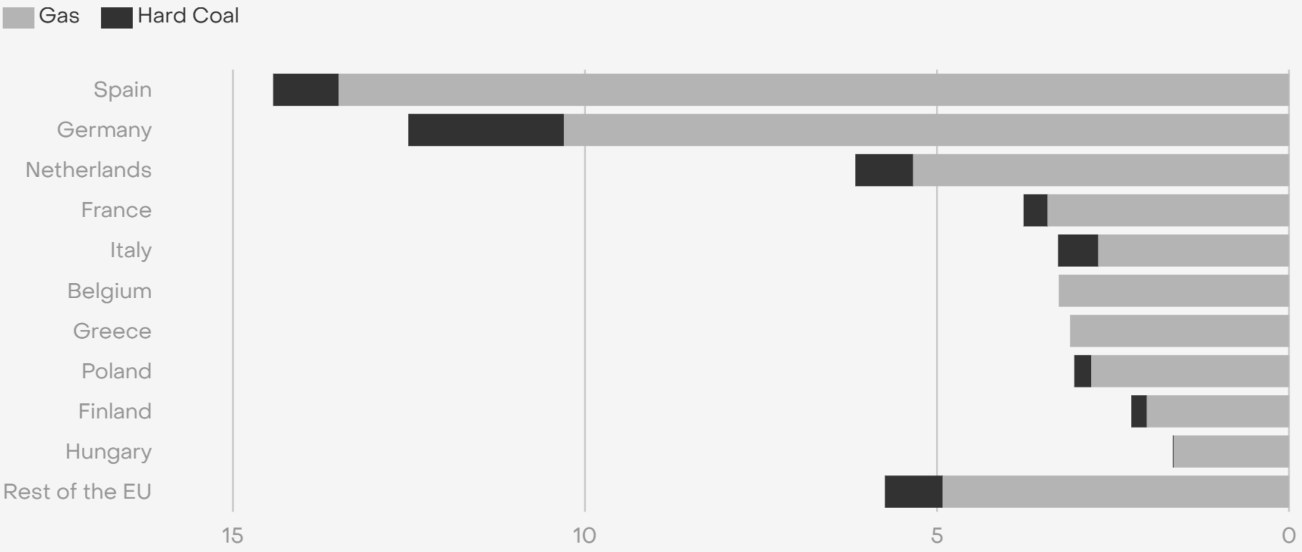
Without wind and solar capacity additions over the first five years of the European Green Deal, the EU would have spent an additional €59 billion on fossil fuel imports for power generation: €53 billion for fossil gas and €6 billion for hard coal.

The total avoided gas imports of approximately 92 billion cubic metres is equivalent to around 18% of gas consumed in the power sector in the EU since the end of 2019. The avoided coal imports of 55 million tonnes is equivalent to 23% of hard coal consumed in the EU power sector in that same period.

In 2024 alone, without wind and solar installed since the previous year, EU power sector gas and coal consumption would have both been 11% higher.

Growth in wind and solar power since the Green Deal has saved the EU €59bn from avoided fossil fuel imports

Avoided fossil fuel cost due to added wind and solar, 2019 - 2024 (€ billion)



Sources: Ember hourly generation data, Solar Power Europe, WindEurope, Montel
Assuming 50% efficiency for gas plant and 40% efficiency for coal. Uses Day Ahead TTF gas price where country exchange not available, and front month API2 for coal

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Coal nearing the end

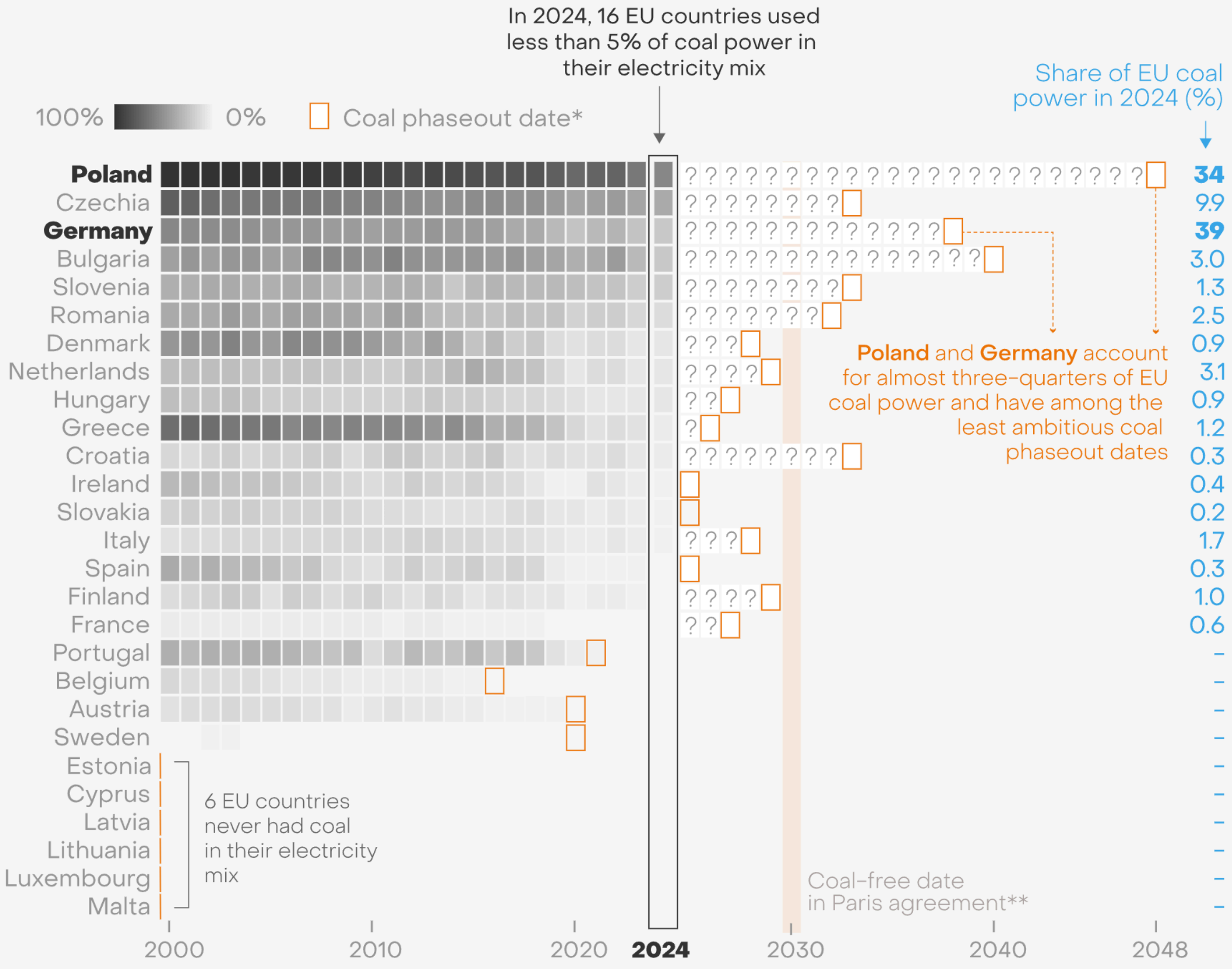
Over the first five years of the European Green Deal, the importance of coal in the EU power mix fell significantly: from 16% of the EU power mix in 2019 to less than 10% five years later. The steep falls in coal power over the last two years cancelled out the temporary upticks in 2021 and 2022 resulting from the gas crisis. Over the past five years, Austria, Sweden and Portugal phased out coal from their electricity mix. In 2024, coal provided less than 5% of power generation in 16 countries, ten of which had no operating coal power plants.

This is a change from 2019, when the dirtiest fuel provided less than 5% of power generation in 12 countries and seven were coal-free.

A new wave of coal plant closures is imminent: another 11 EU countries have announced a complete phaseout of coal from their electricity mix within the next five years. This means that only seven countries will still be using coal by 2030, with at least 34 GW of the remaining 101 GW of operating coal plants closing by that date.

EU coal power is on its way out

Countries ranked by coal share of electricity generation mix in 2024 (%)



Source: Yearly electricity data, Ember, Beyond Fossil Fuels · *Represents announced rather than actual
**To be in line with the UN Paris Climate Agreement, EU countries need to be coal power free by 2030 at the latest

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Five years of declining gas power

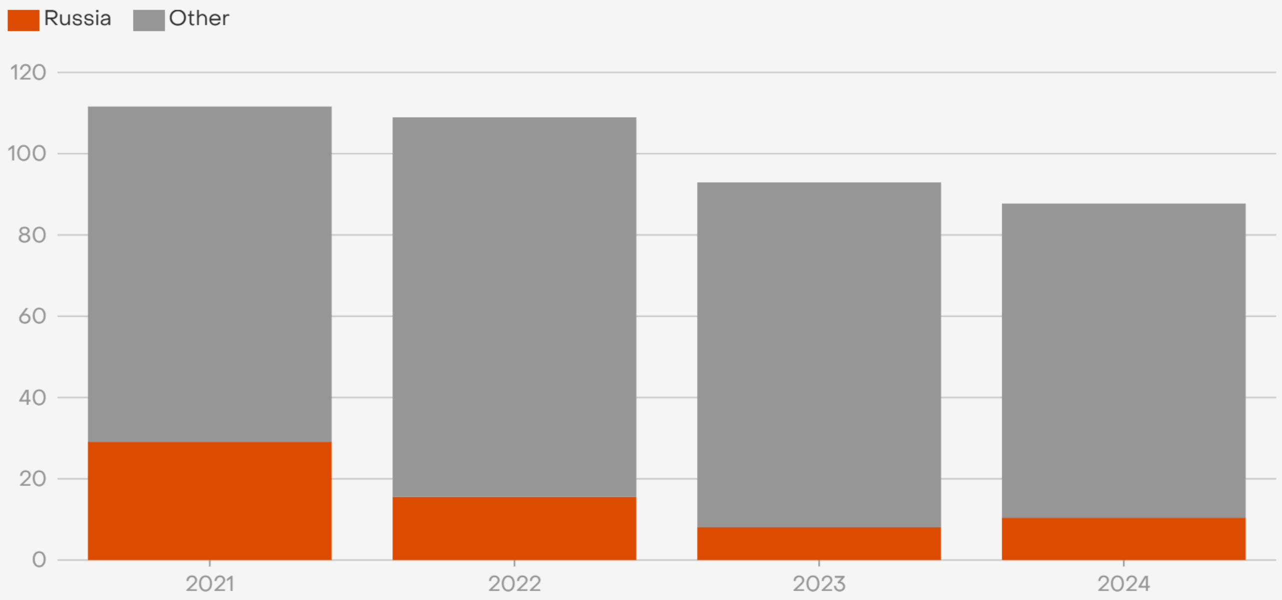
Since the start of the European Green Deal, gas power has been consistently declining. The decline was widespread, with gas decreasing its share in the mix of 19 out of 27 EU Member States between 2019 and 2024. In 2019, fossil gas provided 20% of EU power (569 TWh) and was the second-largest source of EU electricity after nuclear. By 2024, gas had fallen by a quarter, dropping into third place with a share of 16% (430 TWh).

The decline of gas power has been a major factor in reducing EU gas consumption since the energy crisis, and reducing the EU's dependency on Russian energy. Total EU gas demand fell by 20% in the past five years, with about a third of this decline occurring in the power sector. In 2024, overall gas demand is expected to have remained almost stable, as reduced gas burning for power offset a recovery in the industrial sector (see Methodology).

Despite this progress, Russian gas still accounted for 14% of total EU gas consumption in 2024 (down from around 50% in 2019). In fact, gas imports from Russia (including pipeline and liquefied natural gas) increased by 18% in 2024, from 38 bcm in 2023 to 45 bcm, mainly due to increased imports into Italy (+4 bcm), Czechia (+2 bcm), and France (+1.7 bcm) (see Methodology). The power sector alone consumed approximately 88 bcm of gas in 2024. Of this, approximately 10 bcm (12%) was from Russia, providing an estimated €4 bn in revenue.

EU gas power is in decline but imports from Russia increased in 2024

Gas consumption in the power sector, by origin (bcm)



Source: Ember (yearly generation), CREA (gas imports), Eurostat · Power sector gas consumption assumes 50% plant efficiency. Russian fraction calculated from CREA country-level pipeline gas and LNG import data and Eurostat import dependency

In an effort to bring Russian gas imports to zero, the EU has not only been reducing gas consumption, but also diversifying gas sources. This led to more reliance on imports of liquefied natural gas (LNG), which accounted for 38% of imports in 2024, up from 22% in 2019. This reliance is only likely to deepen as Russian gas exports to Europe via Ukraine stopped on the 1st of January 2025.

Continuing to reduce EU gas demand in all sectors - including power - will deliver further strategic, economic and climate benefits. It will minimise the exposure of households and companies to the inherent volatility and price shocks of the global LNG market. Additionally, it will avoid negative climate impacts, as burning US LNG is as polluting as burning coal. Finally, it is fully aligned with the EU's security objective to end reliance on Russian energy.

Chapter 3: Solar's meteoric growth continues

Clean flexibility will light the way for further solar success

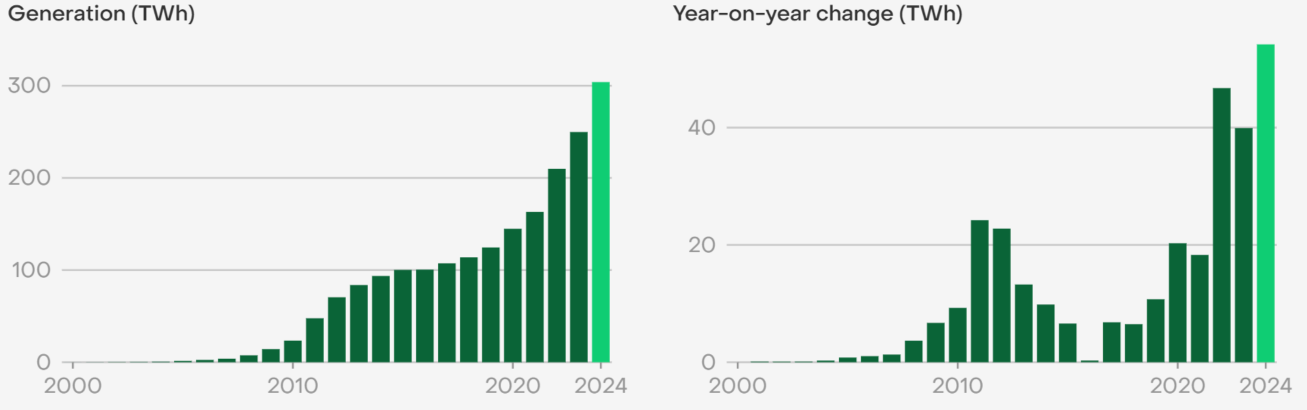
The EU's solar success story continued in 2024, as the bloc saw a record annual increase in solar generation. An accelerated rollout of batteries and smart electrification will be key to cost-effectively sustaining solar's impressive growth.

In 2024, solar grew in every EU country, delivering good progress towards 2030 targets. Sustaining that growth requires an accelerated rollout of clean flexibility, which will also help lower electricity bills for consumers. Solutions such as batteries and smart electrification are already mature and ready to deploy, but require policy action to reach their full potential.

Another record year for solar

2024 marked a record annual increase in solar generation, up 54 TWh (+22%) compared to 2023, when solar generation had already increased by 40 TWh compared to 2022. 2024 was also a record year for annual capacity additions: the EU solar fleet grew by 66 GW, equal to over 450,000 panels added per day (see Methodology), and 4% more than the 63 GW of additions in 2023.

2024 was another record year for EU solar power generation



Source: Yearly electricity data, Ember

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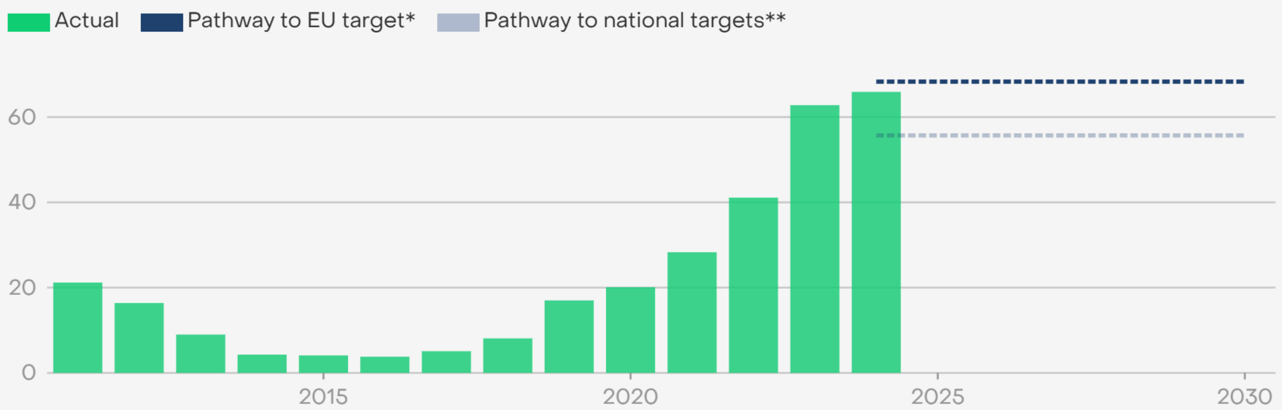
The rate of growth seen in 2024 is already above what the latest national targets would require, highlighting a disconnect between the rapid pace of on-the-ground market trends and the slow response of governments in updating their targets. Installed solar capacity reached 338 GW in 2024 and, if the current pace is sustained, the EU remains on track to meet the interim REPowerEU solar target of 400 GW total installed capacity by 2025. Furthermore, maintaining the current pace of growth would bring the EU solar target of 750 GW by 2030 within reach.

Solar power growth already outpaces national targets but must be sustained to achieve EU 2030 targets

Annual solar capacity additions in the EU (GW)



Source: Ember NECP tracker, Solar Power Europe · Pathway assumes constant annual solar additions starting from the 2023 installed base and reaching the corresponding target for cumulative installed capacity in 2030. *Based on RePowerEU 2030 target **Based on the sum of targets in the latest 2024 NECPs

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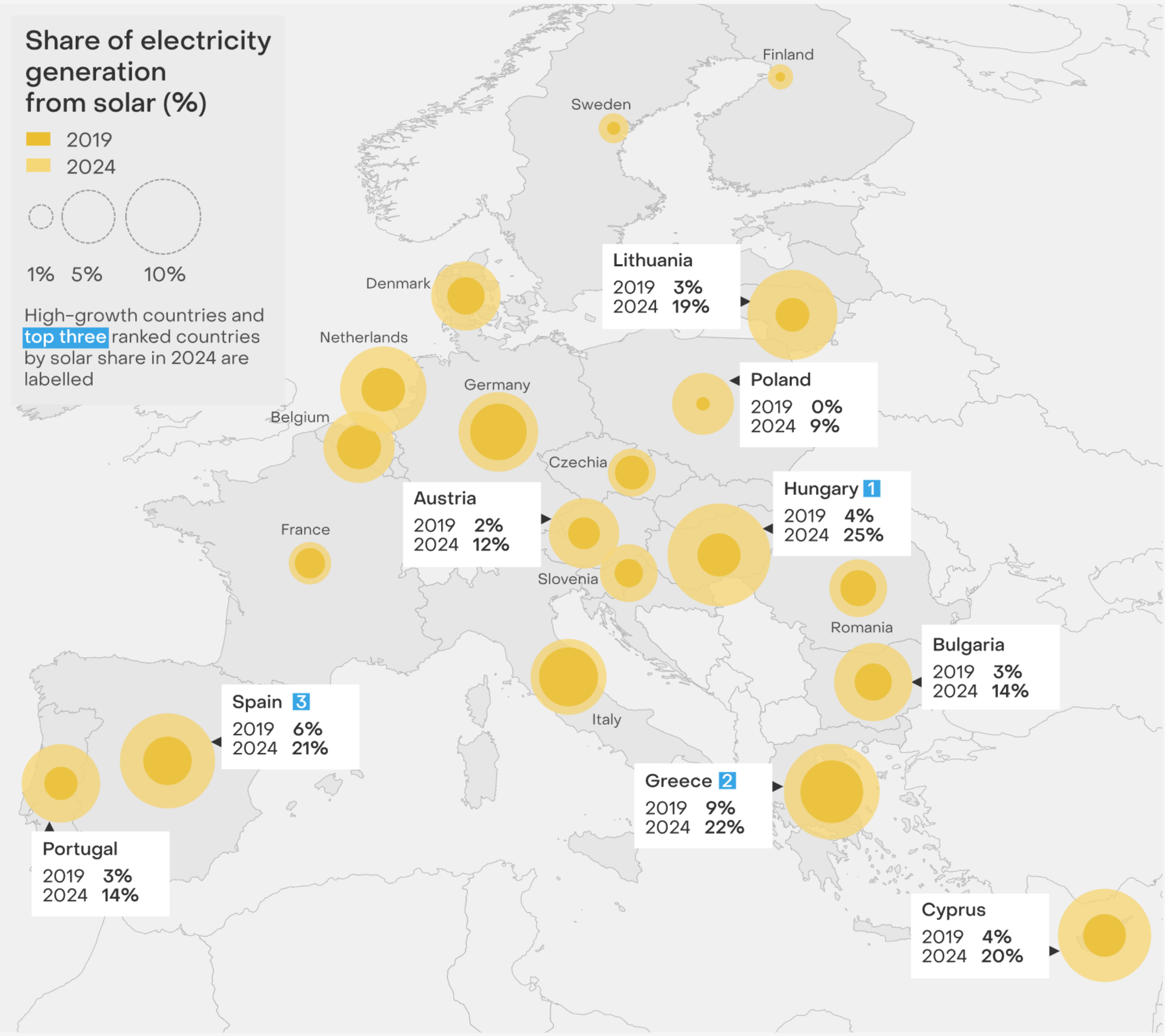
Solar is growing in every country

In 2024, all EU countries saw growth in both solar generation and installed capacity compared to the year before. 16 EU countries generated more than 10% of their electricity from solar in 2024, three more than in 2023. Innovative solutions are also emerging for solar beyond roofs and fields: solar on balconies boomed in Germany and policymakers are becoming aware of the vast unlocked potential for agri-PV.

Solar power is growing in every EU country



Source: Yearly electricity data, Ember
Countries with solar generation below 1 TWh were excluded from this graphic (Croatia, Ireland, Estonia, Latvia, Luxembourg, Malta, Slovakia). Natural Earth Boundaries, Centroids by Gavin Rehkemper.

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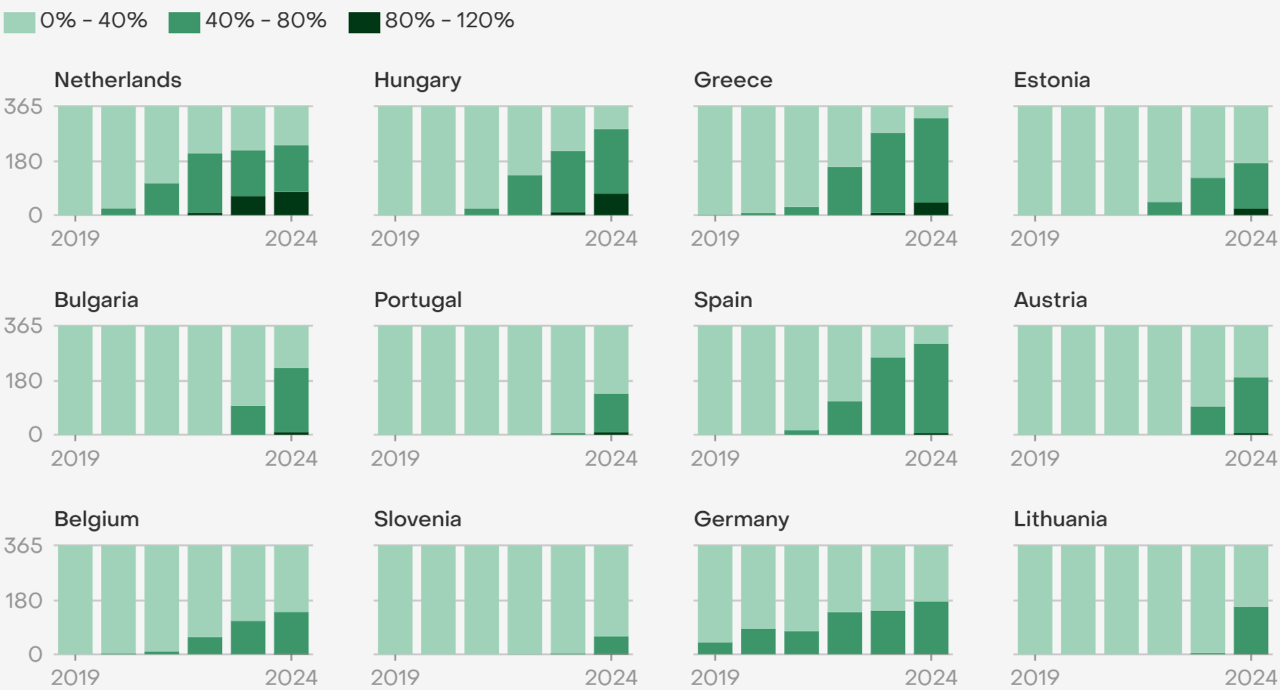
Days with plentiful solar increase in many EU countries

At its peak production hours, solar is getting close to exceeding demand in the top-solar countries. In 12 EU countries, solar generation met 80% or more of power demand in at least one hour in 2024. In the Netherlands and Hungary, more than 70 days in 2024 saw solar meeting more than 80% of the country's total demand at its peak production hour. This is a significant jump from 2023, particularly for Hungary, where the peak solar generation met more than 80% of domestic demand in only 10 days in 2023. Hours with abundant solar generation present a valuable opportunity to further reduce reliance on expensive fossil power, if solar growth is coupled with batteries, smart electrification, expanded grids and other clean flexibility solutions. Batteries, in particular, can shift abundant and cheap solar power beyond sunny hours to the evening demand peaks and replace expensive fossil power in power system balancing. Most of the clean flexibility tools are already deployable.

During its best hour of the day, solar already meets a high share of power demand in many EU countries

Number of days per year by the highest hourly share of electricity demand met by solar power



Source: Hourly electricity data, Ember (includes all EU countries except Malta)
EU countries where solar met more than 80% of demand at its peak generation hour. Countries are sorted by number of hours when solar met more than 80% of the electricity demand in 2024.

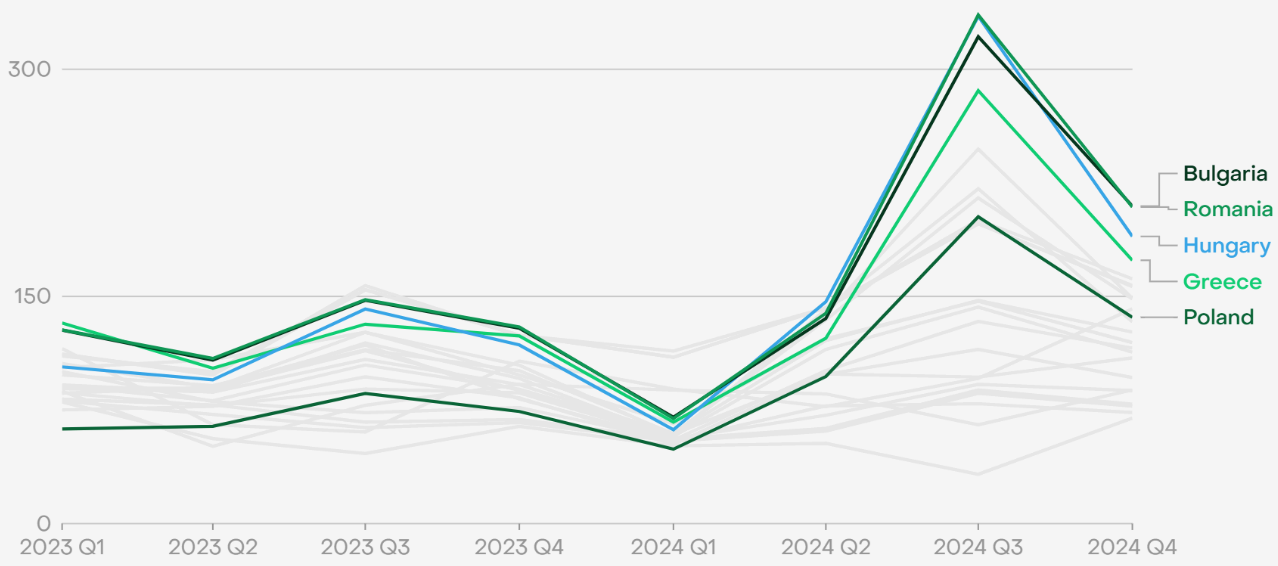
Clean flexibility will sustain solar growth and bring benefits

In 2024, plentiful solar contributed to lower power prices in the central hours of the day. At times, the lack of demand for abundant solar electricity pushed hourly power prices to zero or even below. Negative or zero price hours became more common in 2024 compared to 2023 (4% of hours on average across the EU versus 2% in 2023) and happened virtually everywhere in the EU.

Intraday price spreads widened as well, amplified by the [high costs of fossil power generation ramping up in the evening.] In 2024, across the large majority of EU countries, the difference between the minimum and the maximum power price within the day was higher compared to 2023, particularly in the summer. In Q3 2024, 18 EU countries saw average intraday price spreads increasing by at least 10% compared to the same quarter in 2023. In five countries (Bulgaria, Greece, Hungary, Poland and Romania), average price spreads in Q3 2024 doubled compared to the same quarter in 2023 and were above €200/MWh.

Large and widening intraday price spreads are an opportunity for batteries and other clean flexibility solutions

Average price spread by quarter, 2023-2024 (€/MWh)



Source: ENTSO-E
Spreads refer to the difference between the maximum and minimum day-ahead electricity prices within a day. Cyprus, Malta, Luxembourg excluded from this graphic due to lack of price data.

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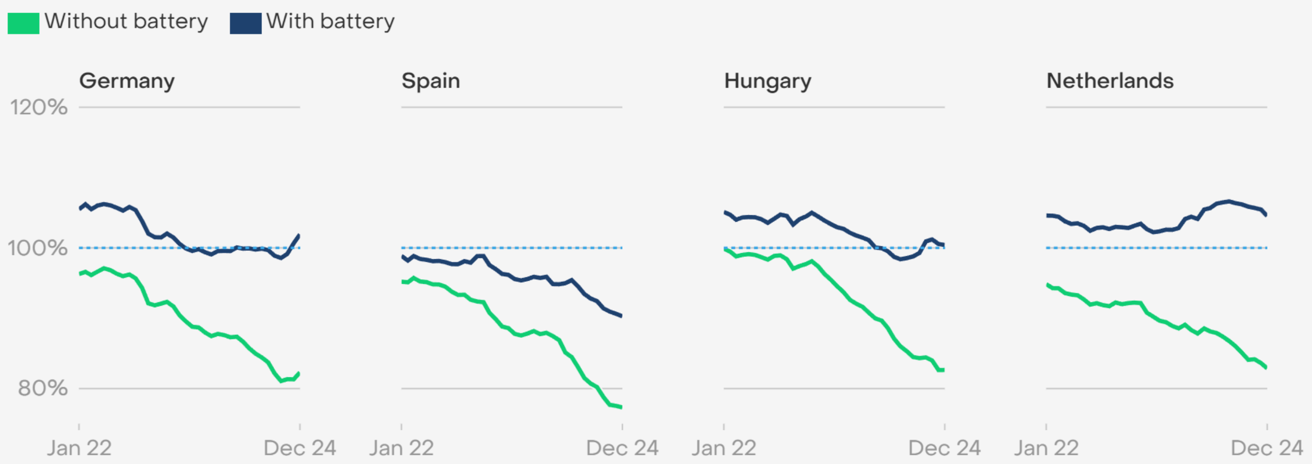
The business case for clean flexibility strengthens

Negative prices and increased spreads signal a business case for more clean flexibility options. Consumers could save money by shifting demand to periods of abundant solar generation and low prices (via smart electrification). Market participants could gain additional revenues by shifting solar across time (via storage) or space (via grids). Battery operators, for example, can earn revenues from buying power when prices are lower at midday and selling when prices are higher during the evening demand peak.

A readily available solution is a battery co-located with a solar plant. This gives solar power producers more control over the prices they receive and helps them avoid selling for low prices in the middle of the day. Battery storage co-located with solar plants is set to become an industry standard in the years to come. This is because it improves the business case for solar while keeping solar electricity competitive against fossil generation. In fact, a combination of grid-scale battery and utility solar can now produce electricity more cheaply than existing coal or gas power plants, according to a recent study of generation costs in Germany.

Battery storage enhances the value of solar electricity

Price captured by a typical solar asset relative to the average price of electricity (%)



Source: Hourly electricity data, Ember
The lines represent solar capture rates and reflect the market value of solar energy when sold on the day-ahead market, with and without a co-located battery. Battery model is for a 90 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. For full details, see Methodology (European Electricity Review 2025)

An improved policy framework for clean flexibility is needed

The deployment of batteries has been growing rapidly in recent years: EU installed battery capacity doubled to 16 GW in 2023, up from 8 GW in 2022. However, capacity is concentrated in a small number of countries, with 70% of the existing batteries located in Germany and Italy as of the end of 2023. Improving market access and removing barriers - such as double grid charging and restrictive requirements for participation in capacity markets and grid services - can unlock further private investments in battery storage across the EU.

Additionally, demand flexibility and smart electrification can help consumers reduce their bills. Flexible electricity use is gaining traction: the number of smart energy tariffs and services available for European energy consumers has almost tripled in the last three years. However, barriers to demand flexibility still exist. For example, smart meters are critical for giving consumers real-time control over their energy use, but in ten EU countries fewer than 30% of households have access to them, and six countries have a smart meter rollout below 10%. Furthermore, the majority of EU power consumers are on fixed-price contracts, hindering their opportunity to access the cheapest electricity.

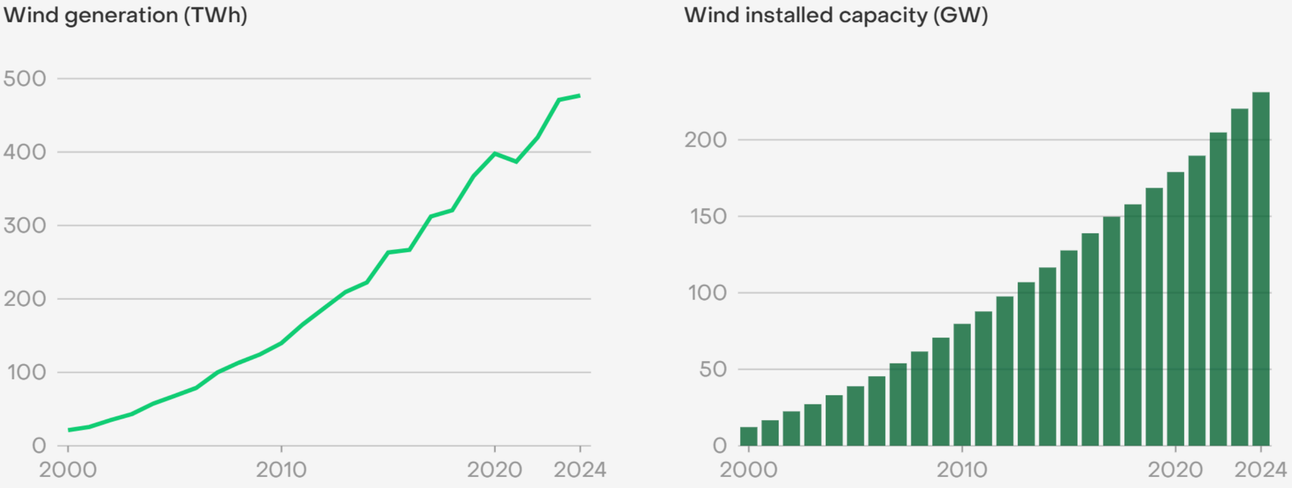
Grids and cross-border interconnectors are also key providers of clean flexibility. National targets that better reflect the rapid growth of solar would help in planning the EU's grid expansion and modernisation, thereby optimising an effective solution for sharing abundant solar within and between countries.

Wind growth set to accelerate as obstacles are tackled

Wind capacity additions have been held back in the last few years by a combination of global macroeconomic challenges and domestic policy barriers. However, wind remains cost competitive with fossil power, and recent policy changes are starting to show results, with turbine orders, auction volumes and permitting rates all increasing.

Wind generation grew by 7 TWh year-on-year in 2024 to reach 477 TWh. This growth is lower than the average 30 TWh year-on-year increase seen between 2019 and 2023. While capacity additions continued in 2024, wind conditions were less favourable than in 2023, leading to lower than expected generation.

The EU's wind capacity and generation remain on an upwards trend



Sources: WindEurope (installed capacity), Ember (yearly generation data)

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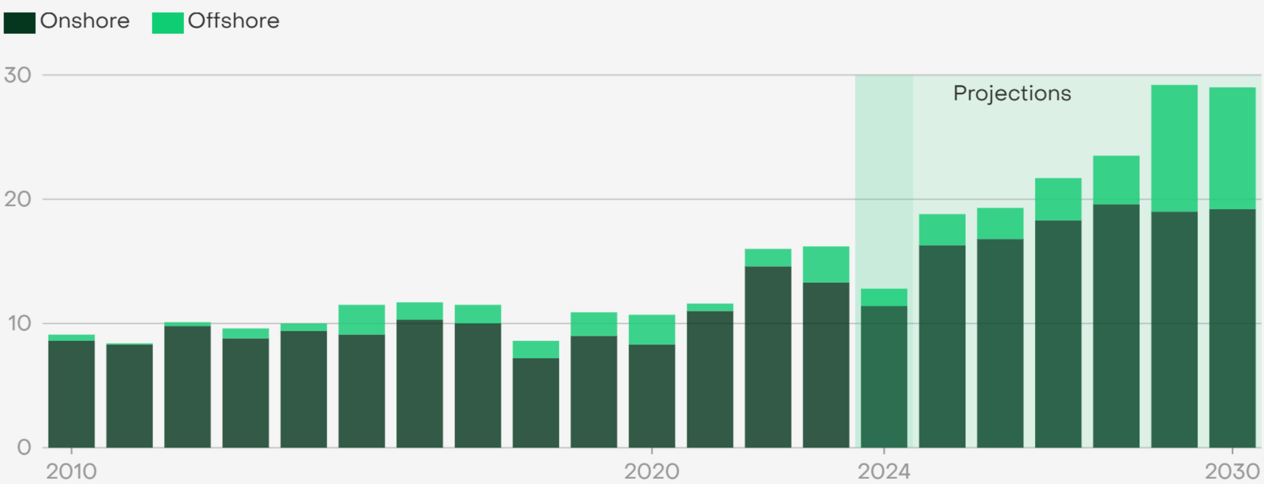
Several factors suggest that wind generation is likely to resume its rising trend. Annual capacity additions are [expected to increase](#) over the next five years, rising from an [estimated](#) 13 GW in 2024 to nearly 30 GW by 2030. Furthermore, offshore wind, which produces more electricity per GW than onshore installations, is expected to make up a progressively larger share of new capacity.

EU wind power additions are set to expand, especially offshore

Annual wind capacity additions, gross (GW)



Source: WindEurope · Projection represents WindEurope's expectation as of September 2024. Additions in 2024 are estimated (as of January 2025).

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Wind remains cost competitive, despite inflationary pressures

Globally, high inflation and supply chain problems - caused primarily by the Covid-19 pandemic and Russian aggression in Ukraine - have created challenges for the wind industry. These factors have disproportionately impacted wind due to long project lead times and relatively high upfront investment needs. It is partly for this reason that wind capacity additions have remained similar year-on-year, rather than accelerating quickly like solar.

Macroeconomic challenges have interrupted cost declines in wind power

The levelised costs of onshore and offshore wind power in Europe fell by 68% and 60% respectively between 2010 and 2021. The challenging economic environment of recent years interrupted this trend, with costs broadly plateauing since 2021.

In Europe, the price of wind turbines has increased by approximately 10% since 2021 (based on Vestas and Nordex average turbine prices) but the majority of this occurred between 2021 and 2022, with prices remaining flat in 2024 compared to 2023. Additionally, the cost of capital in the energy sector increased in 2024 (to 6.6% WACC from 6% in 2022/23), but by less than the previous annual rise (5.1% to 6%). These cost increases have counteracted the economic benefits of continued technological improvements. In Germany, for example, the levelised cost of energy (LCOE) for onshore wind rose slightly from €39-83/MWh in 2021 to €43-92/MWh in 2024. Onshore wind auction prices have also increased, with the EU average rising from €47.6/MWh (2024€ 55.7/MWh) in 2021 to €76/MWh in 2024.

By contrast, in the offshore sector, a steeper learning curve and continued improvements in capacity factors have allowed cost declines to continue. The latest LCOE estimate for Germany in 2024 is €55-103/MWh, lower than the pre-crisis level of €73-121/MWh (2021).

Wind is still cheaper than fossil power

Despite this mixed picture for deployment costs, wind remains competitive against fossil gas generation, the typical price-setter on European wholesale power markets.

The price of gas on European markets (Dutch Title Transfer Facility) has grown steadily throughout 2024, starting the year at around €30/MWh and ending at around €50/MWh, well above the pre-crisis norm of €20/MWh. Accordingly, the average short-run marginal cost of EU gas power across 2024 was an estimated €96/MWh, reaching a high of around €125/MWh in December. This remains above the typical cost of both onshore and offshore wind in the EU in 2024.

Continued deployment of wind power would, therefore, have an important role to play in reducing electricity prices in the EU even in the absence of further cost reductions. However, after a disruptive few years, the cost of wind is expected to start falling again as supply chains recover, inflation eases and technology advancements continue. Some indicators of recovery are already visible. Turbine prices were raised after most European wind manufacturers posted losses in 2022, but their financial positions have significantly recovered since. This recovery, plus increased competition from Chinese suppliers, is likely to put downward pressure on prices. Furthermore, the price of steel - the single biggest material costs for a wind turbine - has fallen from its record high in 2022.

Forecasts of LCOE confirm falling cost expectations, with onshore and offshore wind (in Germany) expected to fall to €39-84/MWh and €53-98/MWh respectively by 2035.

Policy obstacles still exist but changes are having an impact

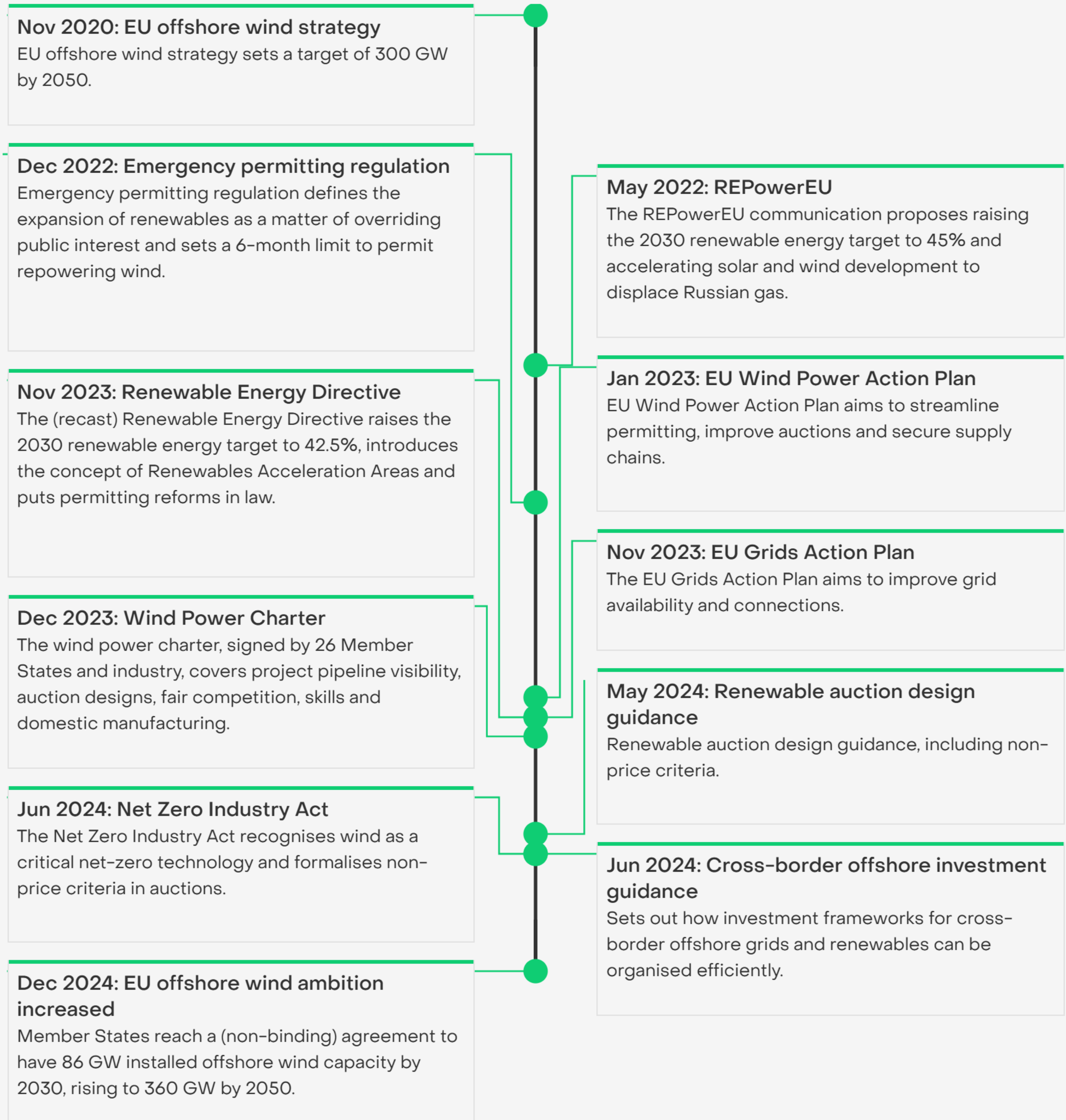
In addition to macroeconomic issues, some of wind's problems are made in Europe. It has become clear that processes at EU and national level for developing grids, permitting new projects and managing grid connections were inadequate for the pace of the energy transition.

Suboptimal support schemes and restrictive planning rules at the national level have also limited opportunities for growth. Offshore wind auctions in Lithuania and Denmark failed due to poor design. Sweden refused offshore wind developments on security grounds. Barriers exist onshore as well, with countries such as Poland continuing to enforce excessive minimum distance rules.

In recognition of such challenges in the wind sector, many policy actions have been taken at the EU level to accelerate deployment, especially since the gas crisis. For example, permitting times in the EU for onshore wind in 2022 averaged 6 years, while new rules aim to reduce them to 2 years. These interventions will take time to achieve their full impact, but there are already some signs of improvement.

Several EU policies in recent years aim to boost wind power

Summary of major EU policies relevant to wind power since the launch of the EU Green Deal (2019)



Source: Ember's compilation based on PIB, Mercom India

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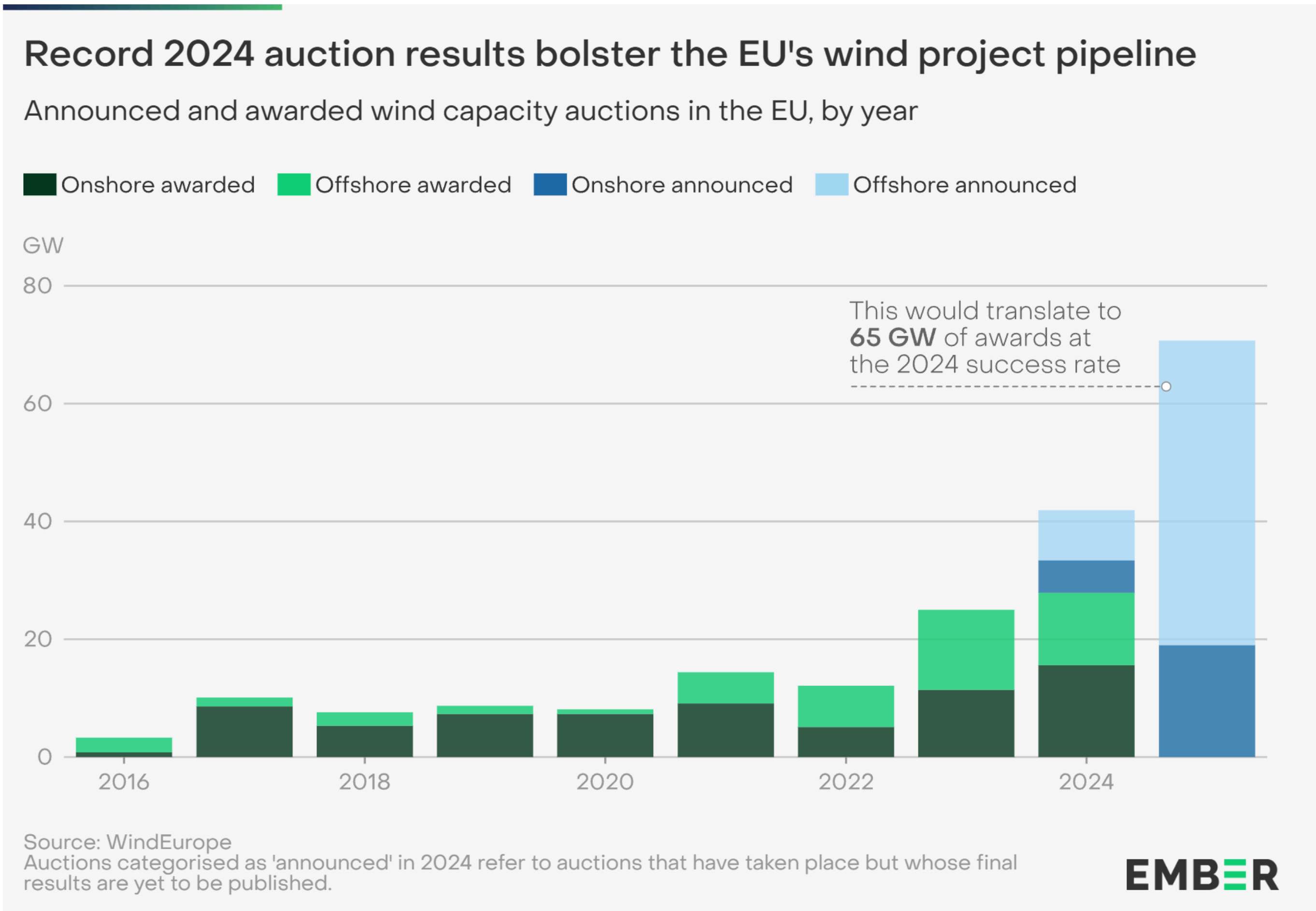
A strengthening project pipeline

Compared to previous years, 2024 saw increased levels of wind farm permitting, more turbine orders and record levels of capacity up for auction.

Permitting rates were higher in H1 2024 compared to H1 2023 in most markets with available data. While the vast majority of Member States have yet to fully implement EU permitting reforms, Germany has made more progress than most. Consequently, approvals reached 12 GW in 2024, up by 60% compared with 2023, and more than the rest of the EU combined.

Wind turbine orders also recovered across the EU in 2024, totalling 13.1 GW from January to September, 40% higher than the same period in 2023, and the second highest ever.

Auctions awarded a record 28 GW of capacity across the EU in 2024, with Germany alone awarding 19 GW. Auctions already announced for 2025 amount to a potential 71 GW. If the average success rate of auctions in 2024 was repeated, auctions in 2025 would deliver 65 GW of new capacity. This means auctions in 2024 and 2025 could cover 45% of the further additions needed for a REPowerEU target of 440 GW (see Methodology).

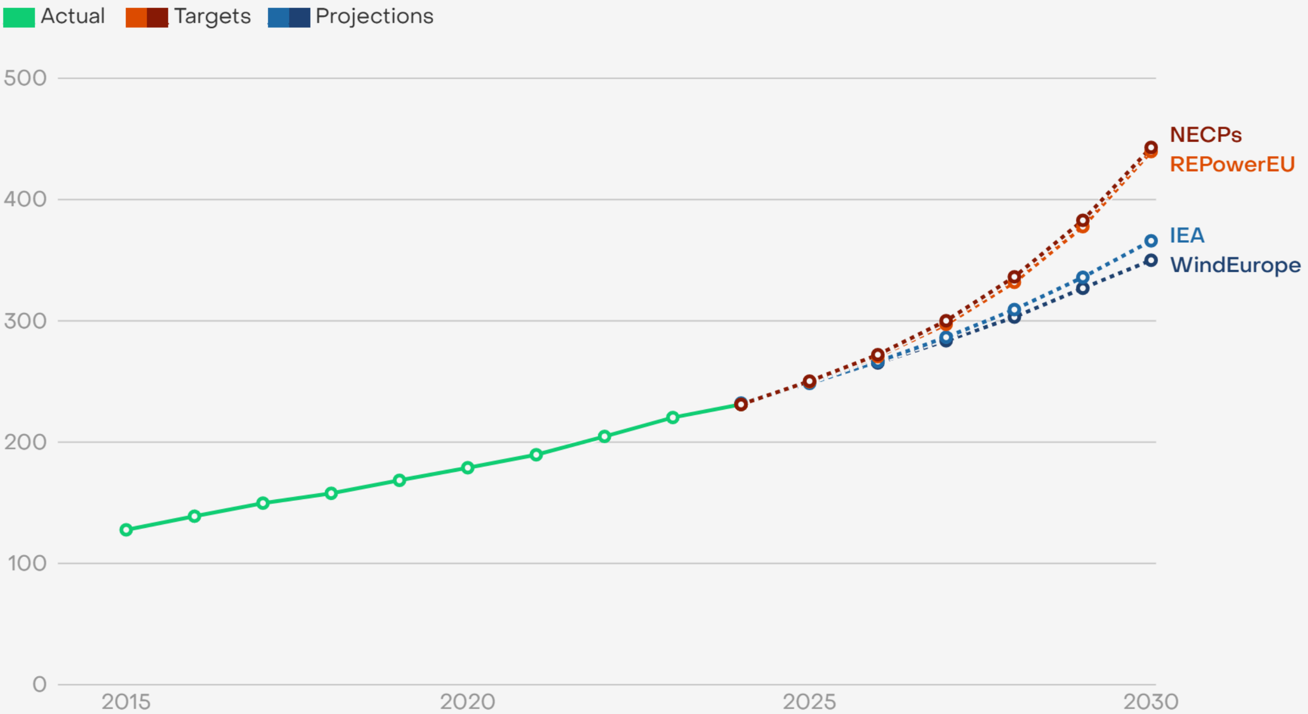


Further policy effort needed

While higher growth is on the horizon, the delays in recent years have created a widening delivery gap between market forecasts and EU ambition. Current outlooks from WindEurope and the IEA predict average annual wind additions of 19-22 GW (net) between 2025 and 2030. However, an average of 34 GW is required to hit EU targets and deliver Member State plans for 2030. The delivery gap is biggest in the offshore sector, where several governments have lowered their 2030 ambitions and forecasts due to project delays.

Wind outlooks still fall short of national and EU targets

Total installed EU wind capacity (GW)



Source: WindEurope, European Commission, IEA · WindEurope projections from September 2024. IEA 'Main case' from October 2024. Projection to 2030 REPowerEU and NECP targets assumes additions grow with constant CAGR.

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Timely implementation and enforcement of the existing policy framework is the first step to closing the delivery gap. For onshore wind, permitting reforms and updated grid connection processes will be key. For offshore wind, it is critical to have auction designs that provide attractive incentives, and an overall approach that maximises supply chain certainty.

Several files promised by the incoming European Commission could further improve the prospects for wind power. The Electrification Action Plan should outline a vision for smart electricity demand growth, boosting the investment case for clean power. Both the pathway to get off Russian energy, and the 2040 climate target, should clearly signal a strong future role for wind power.

Building on the momentum of the EU's electricity transition in the next five years

Policies that sustain wind and solar growth, clean flexibility and electrification are needed to deliver energy security and competitiveness for generations to come.

The European Green Deal has delivered impressive progress in just five years. The new EU Commission can use its next landmark policy package – the Clean Industrial Deal – to build on the momentum of the EU's electricity transition over the next five years and continue to deliver benefits for households and businesses alike.

There are compelling reasons to accelerate cleaning up the EU power sector. Wind and solar growth can drive down energy prices and lower dependence on expensive and risky fossil fuel imports, especially from Russia. Renewable energies are overwhelmingly popular with European citizens. As part of the Clean Industrial Deal, the EU has the opportunity to secure the skilled workers and value chain for the clean technologies that are set to dominate the future of energy markets.

With global markets becoming increasingly competitive, the EU needs to put the following priority actions on top of the policy agenda in 2025:

- The roadmap to ending Russian energy imports and the 2040 climate target proposal should clearly signal the pivotal contribution of wind power;
- Continued support should be provided to the European wind industry, including through cross-border investments;
- Permitting reforms for renewables need to be implemented, following already established examples;
- Renewables auctions with improved designs need to be executed on time, which is essential to guarantee the necessary pace of wind deployment;
- National governments need to finalise spatial energy plans and remove overly restrictive minimum distance rules for wind farms;
- The Electrification Action Plan should enable smart electrification that helps consumers reduce their bills and improves the business case for renewables;
- Existing electricity market rules need to be implemented to improve market access and remove barriers to accelerated deployment of clean flexibility, with a focus on battery storage and demand-side flexibility;
- The existing grid policy framework, including anticipatory grid investments, should be implemented without delay, ideally through a dedicated task force;
- A one-stop-shop for grids should be considered at the EU level, which would streamline access to finance for grid investments, enabling beneficial regional connectivity.

Methodology

Generation, imports and demand

Annual data from 1990 to 2023 is gross generation, published primarily by Eurostat with wind generation data from IRENA. 2024 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 2023 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: ENTSO-E, Eurostat, E-Control GmbH
- 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 provided by Green Collective
- Italy: Bioenergy and solar from Terna; other fuels from ENTSO-E; flow data from Terna
- Latvia: solar from AST; other fuels from 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 data from EnergieOpwek; hourly data from the nationaal energie dashboard from 2021 onwards, pre-2021 data is 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

Wind installed capacity data

Actual and projected installed wind capacity is based on the data provided by Wind Europe in Wind energy in Europe: 2023 Statistics and the outlook for 2024-2030. Updates to expected gross 2024 additions by country were published in their autumn update and where these differed to the previous forecast gross additions, this difference was applied to expected net additions to calculate installed 2024 total capacity. This report also takes into account the estimated gross wind capacity additions for the EU as a whole, published January 2025.

Wind auction data

The basis of the wind capacity auction data is Wind Europe. For 2024 and 2025 Ember supplemented this with awarded and announced capacity auctions from national agencies in charge of the tendering process. The average strike price is calculated as the capacity-weighted strike price in EUR/MWh. Offshore refers to both floating and fixed-foundation offshore wind. The total auctioned capacity for 2024 may still increase, as results from some auctions, particularly those scheduled for December, are yet to be announced. Auctions with tender applications extending into 2025 are categorised under 2025.

Solar installed capacity data

Capacity numbers presented are in units of direct current (DC, gross output). Due to the lack of transparency on this issue in national reporting, not all capacity data in national energy and climate plans can be guaranteed to be in units of DC.

As part of the REPowerEU plan, EU solar strategy aims to bring online over 320 GWac of solar photovoltaic by 2025 (more than doubling compared to 2020) and almost 600 GWac by 2030. Those official numbers refer to units of alternating current (AC) and have been converted to units of direct current (GWdc) by multiplying by 1.25.

The source used for solar capacity data is SolarPower Europe.

Annual capacity additions translated in number of panels added per day, assuming an average panel size of 400 W.

The source for national solar targets is Ember's Live EU NECP Tracker.

Behind the meter solar

We implemented adjustments for behind the meter solar not accounted in official statistics for six countries (Austria, Croatia, Portugal, Spain, Slovenia, Romania), affecting 2022-2024.

Gas demand and imports

EU total gas demand: 2019-2023 based on Eurostat; 2024 calculated based on IEA forecast for 2023/2024 year on year change (-2%) and Eurostat data for 2023.

Share of Russian gas in EU power sector's gas demand: gas import data by departure and destination country provided by the Centre for Research on Energy and Clean Air (CREA) was used to calculate Russian share of imports. This was scaled to share of consumption using country import dependencies derived from Eurostat gas consumption and production data. Import dependencies for 2024 were taken from 2023 due to Eurostat reporting lag. The percentage of Russian gas burnt for power generation is assumed to be the same as the percentage of Russian gas in total consumption per country. This percentage is then applied to country gas in power demand and values summed across the EU to get the share of Russian gas in EU gas in power demand.

The LNG share in EU gas imports was calculated using Bruegel's gas import tracker.

Avoided fossil fuel import costs

This method estimates avoided fossil fuel import costs due to added wind and solar capacities between two chosen years. For each fuel (onshore wind, offshore wind and solar), additional capacity is defined on a monthly basis as the difference between installed capacity in a given month, compared to the same month in an earlier reference year. Monthly capacity data from various country sources is available for Belgium, Denmark, Finland, France, Germany, Poland, Portugal and Spain. Where monthly capacity data is not available, a linear interpolation is performed across the year in question. Projected installed wind capacities for the end of 2024 are taken from WindEurope's Autumn 2024 report as this is the latest country-level information available. Solar yearly capacities come from SolarPower Europe's EU Market Outlook 2024-2028.

This approach provides a scaling factor for each month of the year of interest, which is then applied to actual hourly generation data to estimate the volume of generation from new additions of each technology. It is assumed that if the new wind and solar hadn't been installed, the resulting generation gap would have been filled with another fuel. To determine which fuel would have replaced it, the following steps are applied, in order, to each hour of generation data:

- If fossil generation accounts for <5 % of hourly generation, it is assumed that extra wind and solar did not displace fossil, as it is likely other clean sources or imports - lower in the merit order than fossil - would have produced instead
- If fossil generation is within 5% of its yearly minimum, it is assumed that additional wind and solar did not displace fossil, which is assumed to be operating at a minimum 'must run' level. This takes into account, for example, combined heat and power plants which must often run at minimum capacities.
- If a country has no coal or gas capacity (eg Cyprus), all additional wind and solar is assumed to have replaced 'other fossil'
- Short run marginal costs (SRMCs) for gas and hard coal are then used to determine which fuel would be setting the marginal price. It is assumed throughout that lignite is cheaper than hard coal and gas and would therefore not be the marginal price setter.
- If gas is the most expensive SRMC and gas generation is not zero in the given hour, it is assumed that gas is the marginal price setter and therefore has been displaced by added wind and solar capacity in that hour. The same logic applies to hard coal if it has a higher SRMC than gas.
- If gas is the most expensive SRMC but is not generating in the given hour, it is assumed that hard coal (so the second most expensive technology) would be displaced, and vice versa.

- In both points above, an installed capacity check is made to ensure there is sufficient hard coal or gas capacity available such that it could have generated more in the absence of the added wind and solar. Capacities are taken from GEM's coal and gas trackers. In the rare case there is insufficient capacity for one of these fuels, the gap is made up using the other, or if there is insufficient of either, then 'other fossil' is used.

The above steps are applied, and summed over the hours of the year, to calculate the amount of hard coal and gas generation avoided by new wind and solar capacities added between a historical reference year (e.g., 2019) and a chosen year of interest (e.g., 2024).

To estimate the share of this avoided gas and hard coal generation that would have used imported fossil fuels, the avoided generation values are multiplied by gas and hard coal import dependencies per country per year. Import dependencies are derived from Eurostat data, so values are not available for 2024 due to data reporting lags. To fill this gap, values are carried over from 2023, which represents a conservative approach as indigenous production is generally in decline across the EU.

To calculate avoided fossil fuel import costs, the avoided gas and hard coal generation in TWh are first divided by assumed plant efficiencies of 50% (Higher Heating Value) for gas and 40% for hard coal to estimate the volume of fuel avoided, and this value then multiplied by respective fuel costs. These are taken from day ahead TTF prices for gas, unless specific country market data is available, and daily front month API2 prices for hard coal.

Avoided gas imports are converted from TWh to bcm using a calorific value of 35.17 MJ/m3. Avoided coal is converted from TWh to million tonnes by multiplying by 0.122.

To calculate total avoided fossil fuel import costs thanks to wind and solar added since the start of the Green Deal, the above methodology is applied to each year from 2020 up to 2024 inclusive, using the historical reference year of 2019. Malta is excluded from this calculation due to a lack of data.

Solar capture rates calculations

Solar capture rates reflect the market value of solar energy when sold on the day-ahead market. Solar capture prices are the average prices that a solar generating unit earns for each kWh sold to the market, determined by its hourly production profile and the hourly spot power prices over a specific period. They are calculated using hourly day-ahead prices from ENTSO-E and hourly generation data as described above. Our model shows the one-year rolling average to give a better understanding of the long term development of solar capture rates. A marginal price-taking solar with a co-located battery storage unit is modelled with the following assumptions:

- 90 MW AC solar array with output based on national generation data
- 60 MW AC battery with 1 hr (60 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 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 battery storage.

Power price data

Wholesale electricity prices are average day-ahead spot prices per MWh sold per time period, cleaned and sourced from ENTSO-E. These are the prices paid to electricity generators, and are not the same as retail electricity prices or total costs to end users.

Within-day power price spreads refer to the difference between the maximum and minimum day-ahead electricity prices within a day. Price spreads not computed for Cyprus, Malta, Luxembourg due to lack of reliable price data.

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Lead authors
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