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Electric Insights Quarterly

Authors:

Dr Iain Staffell, Professor Richard Green, Professor Tim Green, and Dr Nathan Johnson
Imperial College London

Dr Malte Jansen
University of Sussex

Professor Rob Gross
UK Energy Research Centre

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Electric Insights was established by Drax to help inform and enlighten the debate on Britain's electricity. Since 2016 it has been delivered independently by a team of academics at Imperial College London using data courtesy of Elexon, National Grid and Sheffield Solar.

1. Introduction

2023 marked a return towards normality for Britain's power system. Wholesale electricity prices continued falling back towards their levels from before Europe's energy crisis, and imports from the continent resumed after a brief hiatus. This pushed down generation from gas by one-fifth, allowing carbon emissions to get back onto their trajectory towards net zero. Article 2 recaps the year.

A major government announcement came in January. Britain's first negative emissions power station received planning consent, allowing Drax to install carbon capture and storage onto two units of its biomass power station. Article 3 looks at why the UK is looking to take the lead on this technology, and what it means for the next phase of the road to net zero.

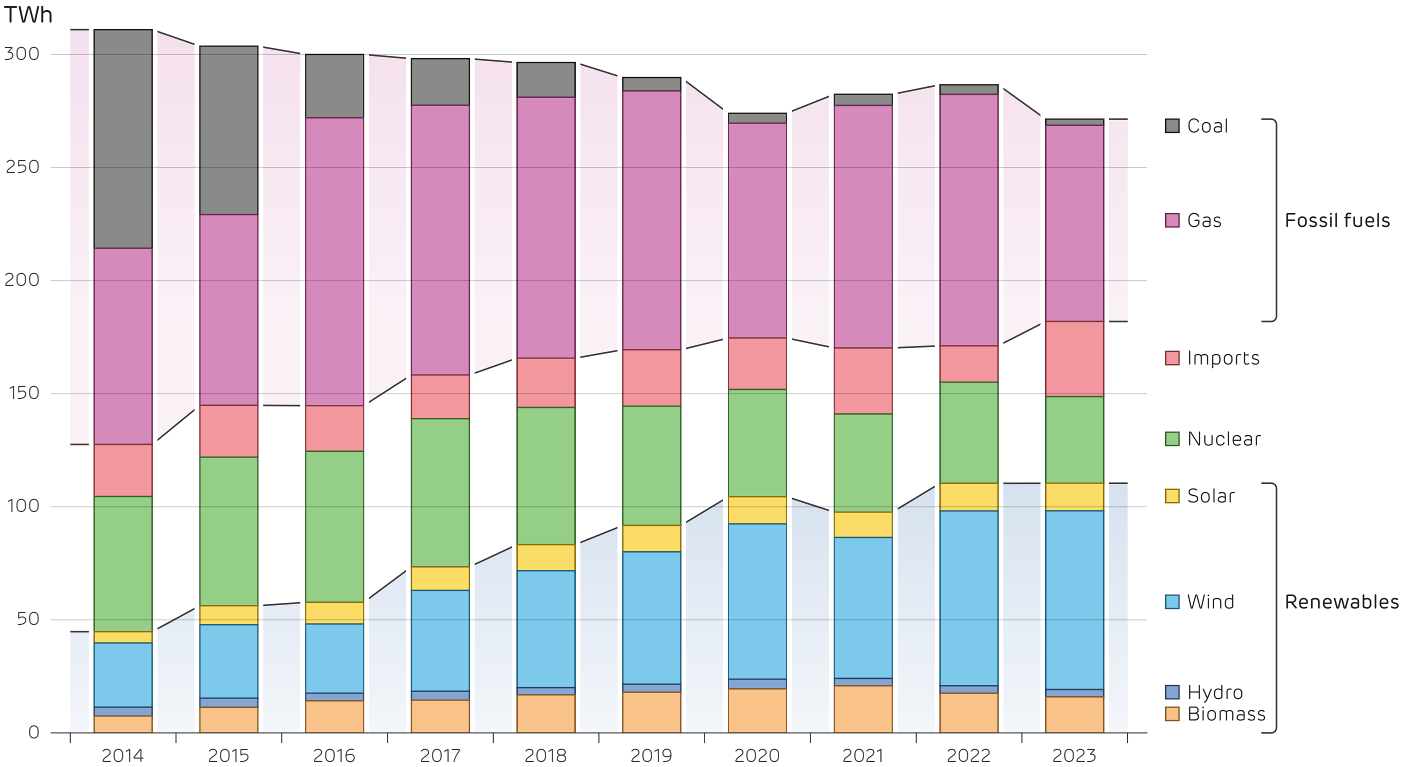
December provided several positive developments for the UK's wind industry. After the last round of the CFD auctions attracted no offshore wind bids, the Government raised the next auction's price cap to £100 / MWh (advertised as £73/MWh in 2012 terms). Ørsted announced the go-ahead for Hornsea 3, a 2.4 GW wind farm in the North Sea (enough to power over 3 million homes).

Britain's wind farms also had a record-breaking month in December, and over Quarter 4 of the year, wind was the largest source of electricity in Britain for only the second time, supplying a record 35% of demand.

More renewables mean more volatility for the power system. Negative electricity prices are on the rise across Europe, and the number in Britain has tripled over the past year. Article 4 explains how negative power prices are driven by excess renewable output combined with a lack of flexibility, and what we can do about them.

One solution is to increase Britain's connectivity to other markets. Article 5 reports on the Viking Link, the country's first interconnector with Denmark, which started operating in December. This should add more flexibility to the grid and should help to reduce electricity prices further in the coming years.

The changing annual electricity generation mix over the last ten years



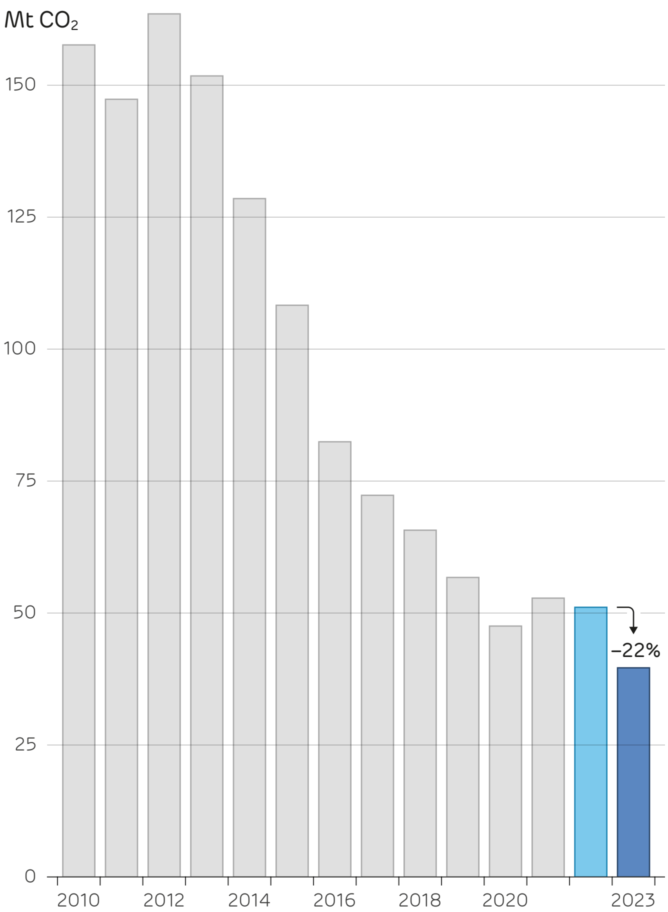
2. Britain's electricity system in 2023

2023 was the cleanest year ever for electricity production in Britain. Emissions from the power sector fell by 22% compared to 2022, the largest decline in seven years. This was driven by less fossil fuel being burnt, with their share of electricity demand fell to an all-time low of just 33%.

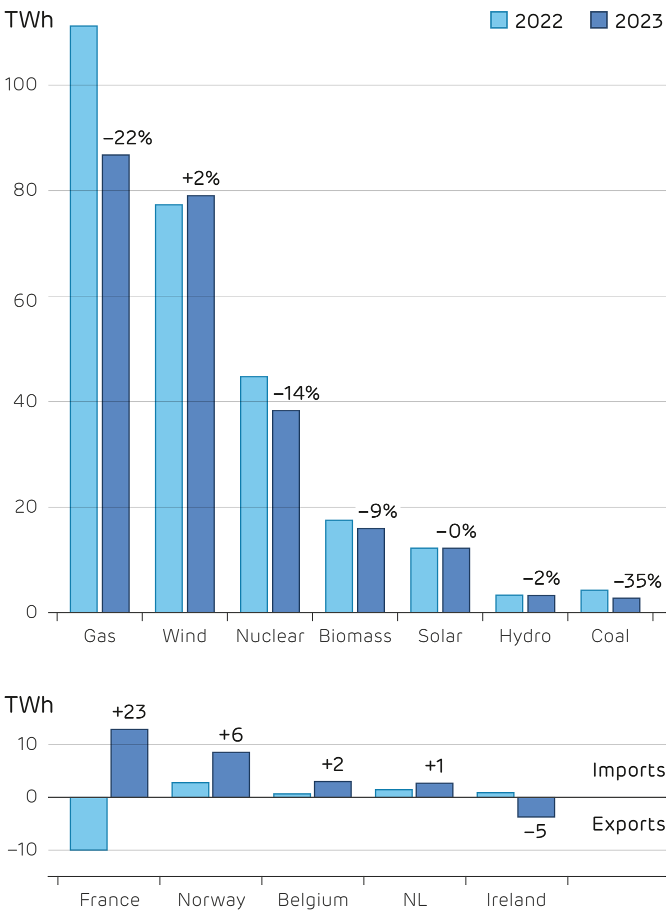
Gas power generation fell by a fifth, in part because demand was lower (by 5 TWh) but mostly because Britain switched from exporting (4 TWh in 2022) to importing (24 TWh in 2023) from its neighbours. Coal output also fell to just 3 TWh – or 1% of Britain's electricity, making it the smallest source of generation on the power system for the first time ever. By October, the UK's last coal power station will permanently shut.

Much of the change is due to increased electricity generation in France. Last year the French nuclear fleet suffered widespread outages, meaning France had to import from Britain and its other neighbours. Now that many of these reactors are back online, France is once again exporting to the rest of the continent. The same cannot be said for Britain's nuclear fleet. Output fell by 14% last year, to its lowest since 1982.

Annual carbon emissions from electricity generation since 2010



The annual electricity generation and trade mix in 2023 compared to 2022

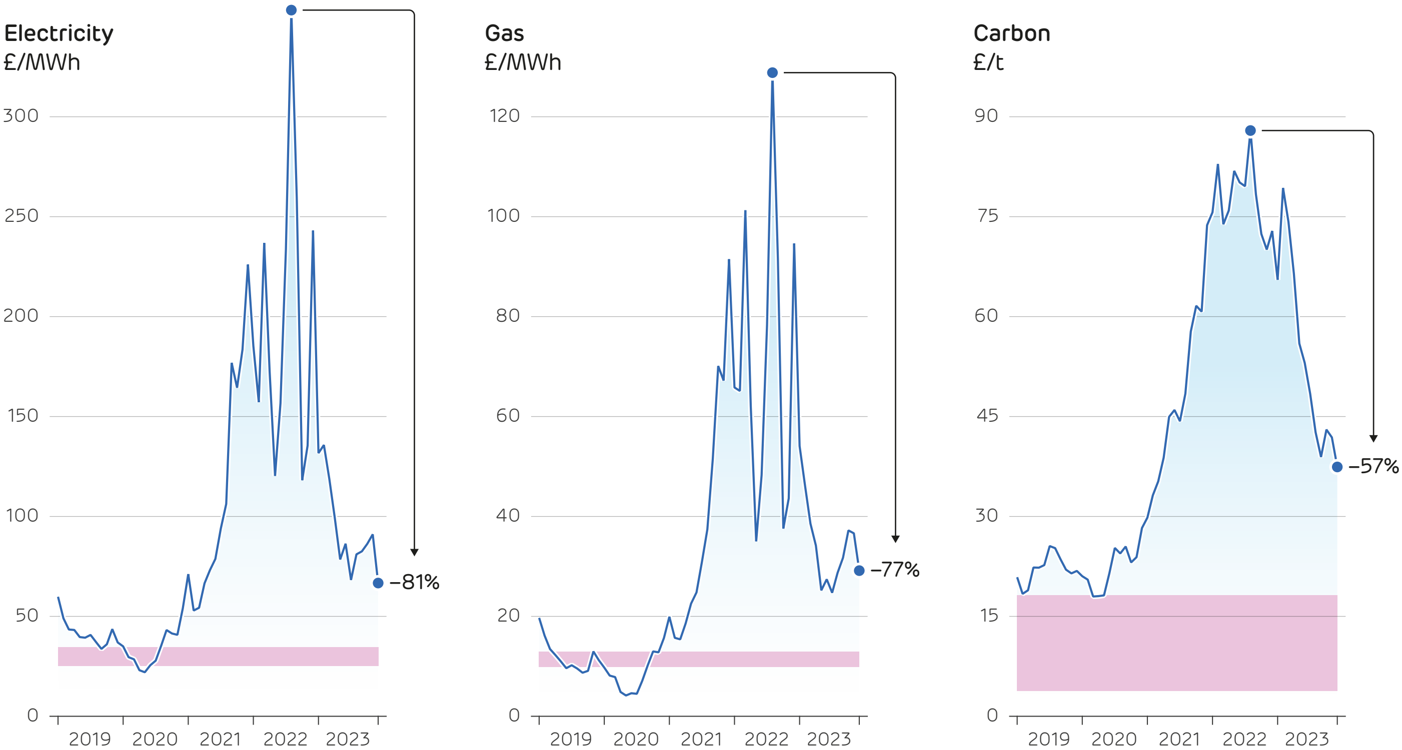


The cost of living crisis made 2023 a tough year for many. Much of the pressure on households and businesses came from the rise in energy prices during 2021-22. However, wholesale electricity prices have fallen 80% since their peak in August 2022, from £353/MWh to £66/MWh in December 2023.

This has only just started translating into consumer bill reductions. Ofgem's current energy price cap puts the average household bill for gas and electricity at £160 per month, only 23% lower than people were paying one year ago at the height of the crisis. This fall is masked by the effect of the Government's energy price guarantee. Without that, average bills would have risen to over £350 per month, and so bills have effectively fallen 55% from their peak. Cornwall Insight predicts that average household bills will fall this year, by 16% in April, and a further 8% in July, to reach £125 per month in the summer. The average bill during 2019-20 was just shy of £100 per month, so energy markets will finally be almost back to normal.

Looking ahead to 2024, analysts forecast that wholesale prices will continue falling as the gas market continues to correct itself, which will mean further reductions to household bills going into 2025. However, there is plenty to be uncertain about, with war in Europe and the Middle East potentially disrupting fuel shipments, continued delays to the Hinkley Point C nuclear reactor, and elections on both sides of the Atlantic – all of which could have profound implications for UK energy prices.

Monthly average wholesale prices for electricity, natural gas and carbon dioxide emissions in the UK. Pink bands show the average range of prices during the 2010s for context.



3. Carbon Dioxide Removal: getting back to Net Zero

The Planning Inspectorate has recently given consent to Drax Power (publisher of this report) to install carbon capture equipment at two of its biomass-burning generators in Yorkshire. This would turn them into the world's first large-scale power station capable of removing carbon dioxide (CO_2) from the atmosphere. But what are 'carbon dioxide removal' and 'negative emissions' technologies, and why are they needed?

Net Zero Emissions

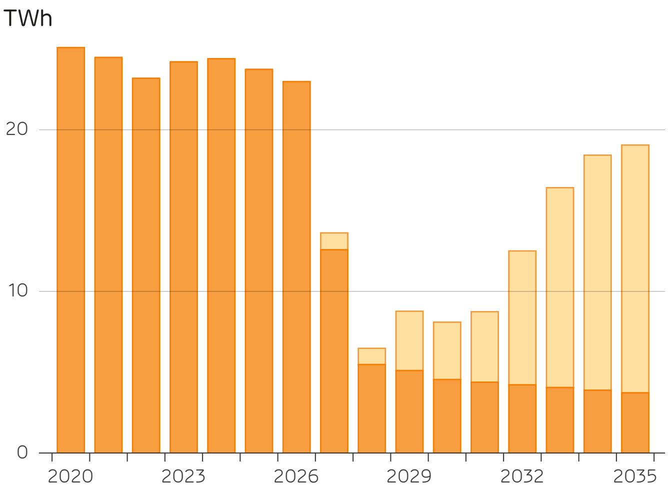
At present, the UK and other countries are trying to reduce emissions of CO_2 and other greenhouse gases to slow the rate of global warming. With more greenhouse gases in the atmosphere, more energy gets trapped within it, which causes temperatures to rise. To stop further increases in the earth's temperature, we must completely stop adding greenhouse gases to the atmosphere. We can do so either by reducing emissions all the way to zero, or by reducing them most of the way and then offsetting any remaining emissions using carbon dioxide removal. This approach is known as reaching 'Net Zero' emissions.

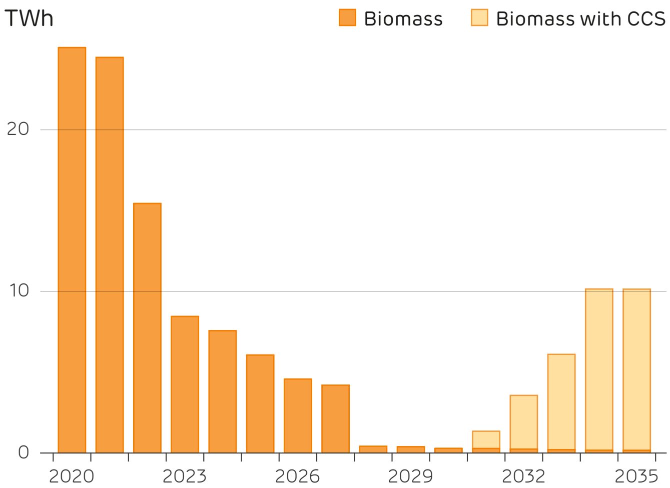
For some activities, such as long-haul air travel and heavy industry, the technological solutions for decarbonising may prove impractical or prohibitively expensive. The Net Zero approach lets us still emit some greenhouse gases from these activities, so long as they are offset by removing an equivalent amount from the atmosphere.

Some worry that technologies like Carbon capture and storage (CCS) are a distraction from the task of reducing emissions from burning fossil fuels. Efforts to avoid and reduce emissions first should indeed take priority – but we are now at the point where "keeping to 1.5°C is simply not possible without the use of carbon capture and storage".

The Climate Change Committee's scenarios for the UK envisage our power system eliminating almost all its remaining emissions in the next decade using a combination of CCS, nuclear and renewable generation. Their approach decarbonises electricity fastest and furthest – going beyond zero into net negative emissions ten years from now. This is because it is much easier to replace or retrofit a relatively small number of stationary power stations than millions of widely dispersed heating systems and motor vehicles, for technological, organisational and (sometimes) political reasons.

Scenarios for the development of biomass electricity generation over the coming decade, with and without CCS.
Left shows the central pathway from the Climate Change Committee's Sixth Carbon Budget.
Right shows the median pathway across National Grid's Future Energy Scenarios.





Carbon Dioxide Removal

Carbon dioxide removal can take many different forms. Some approaches aim to increase the amount of CO_2 taken up by the earth's natural carbon sinks, often by growing (or re-growing) forests. Others increase carbon take-up in the soil, or more controversially 'seeding' the oceans with nutrients to increase the amount of CO_2 that plant life there can absorb.

The Drax plan to combine Biomass Energy with Carbon Capture and Storage (known as BECCS) is a technological approach to carbon dioxide removal. Another is Direct Air Capture (DAC), which sucks CO_2 directly out of the atmosphere using CCS technology. However, because CO_2 concentrations are so much lower in the atmosphere than in a power station exhaust flue, it is more difficult to separate, and so the cost is likely to be significantly higher.

CCS technology applied to a power station stops 95–98% of its CO_2 emissions reaching the atmosphere. CCS can turn a gas-fired power station into a low-emission power source, but adding CCS to a biomass power station turns it into a carbon-negative power source. As the CO_2 absorbed by growing the fuel becomes permanently sequestered, this reduces the amount of atmospheric CO_2 over the life cycle of the biomass, resulting in the overall process being net carbon negative while producing renewable electricity.

Electricity from Biomass

Electricity generated by burning sustainably-sourced biomass is deemed low carbon by the UK government and international carbon accounting rules. Although CO_2 is released from combustion in current biomass power stations, those carbon molecules were (relatively) recently in the earth's atmosphere before being stored in growing biomass. This type of carbon is part of the 'biogenic' carbon cycle: the natural process of plants absorbing CO_2 via photosynthesis and releasing it via respiration. This is also known as the 'fast' carbon cycle, as carbon circulates through it relatively quickly. This contrasts with emissions from burning fossil fuels, which unlocks carbon that was last in the atmosphere millions of years ago.

In addition to biogenic carbon, there are emissions from the harvesting, processing and transportation of biomass. For Electric Insights, we follow UK legislation in assuming these electric creation activities put the carbon intensity of biomass electricity at 121 gCO_2/kWh – 70% lower than from natural gas and 87% lower than from coal.

Companies which generate electricity from biomass and BECCS, such as Drax and Ørsted, must follow strict sustainability guidelines for the use of biomass. The Government's Biomass Strategy outlines a priority use framework that evaluates where biomass would be most sustainably and efficiently used across sectors, accounting for the four principles of sustainability, air quality, the circular economy and resource efficiency, and ability to support the UK's 2050 Net Zero target.

Global need for BECCS

Large-scale carbon removal, including from BECCS, is widely regarded as being critical to stabilising the global climate. The Intergovernmental Panel on Climate Change (IPCC) suggests that the world will need to remove between 0.5 and 9.5 billion tonnes of carbon dioxide annually via BECCS by 2050 to stay on course to limit global warming to below 1.5°C target.

Governments around the world have been increasingly adopting policies which are supportive of carbon dioxide removals and BECCS. These include the US Inflation Reduction Act, the EU Renewable Energy Directive and the UK's 'Powering Up Britain' energy security, Net Zero strategy, and Biomass Strategy.

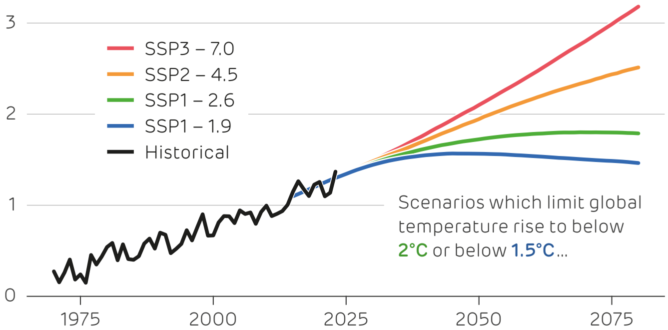
Both biomass combustion and carbon capture are mature technologies, but the combination of these together would be a world first. This means that building the world's first large-scale BECCS power station will require hefty up-front investment – estimated at around £2 billion. It will also increase ongoing operating costs as the energy cost to capture CO_2 reduces the amount of electricity it can send to the grid. This has led to criticism of the plans to go ahead with BECCS, suggesting it will add to consumer bills.

However, if the UK is to meet its legally-binding commitment to Net Zero emissions, the cost of BECCS should not be compared to renewable electricity, which reduces but does not actively remove carbon emissions. Instead, it will need to be compared to the wider alternatives, such as eliminating emissions from the most difficult sectors, such as aviation and heavy industry.

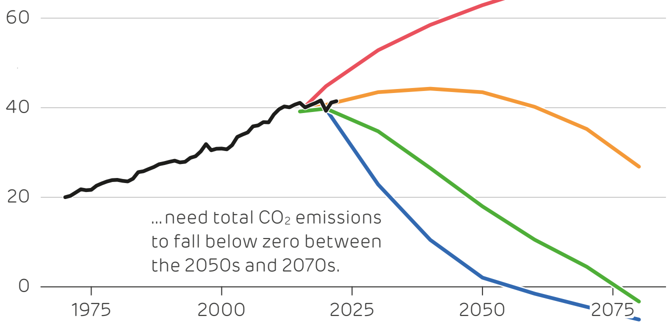
Given the catastrophic costs of allowing climate change to escalate, and the difficulty of eliminating emissions across the entire economy, carbon dioxide removal could prove a very wise investment.

IPCC scenarios for global warming and the role of BECCS over the next fifty years.
Data from the IPCC, IIASA, and Our World in Data. The coloured lines represent four of the many scenarios modelled by the IPCC, which consider a range of 'shared socioeconomic pathways' (SSPs) and levels of radiative forcings from 1.9 to 7.0 W/m².

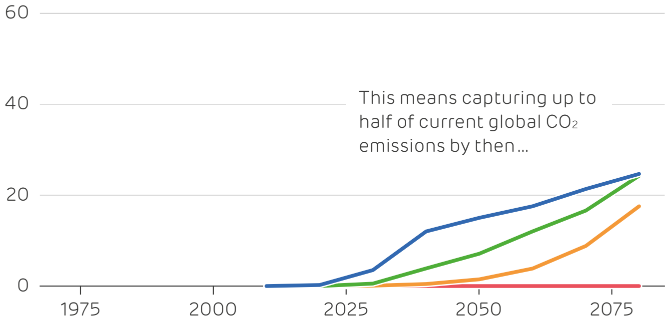
Global temperature rise above pre-industrial times
°C



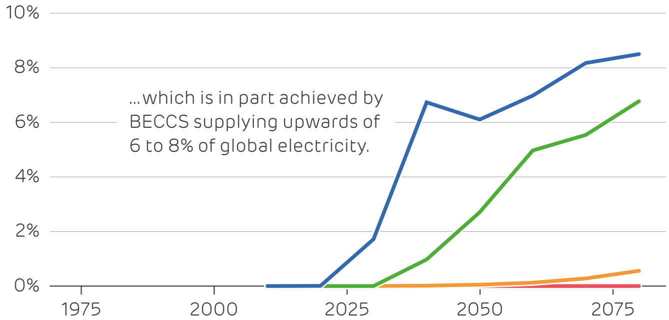
Global carbon emissions
Gt CO_2



Global carbon captured
Gt CO_2



Share of global electricity from BECCS
%



4. The rise of negative power prices

Britain experienced a record-breaking 214 hours of negative power prices during 2023, averaging more than half an hour a day. Their frequency has more than tripled from the year before, and this coincides with the highest ever payouts for wind farms not to generate (so called curtailment payments), which exceeded £300 million in 2023.

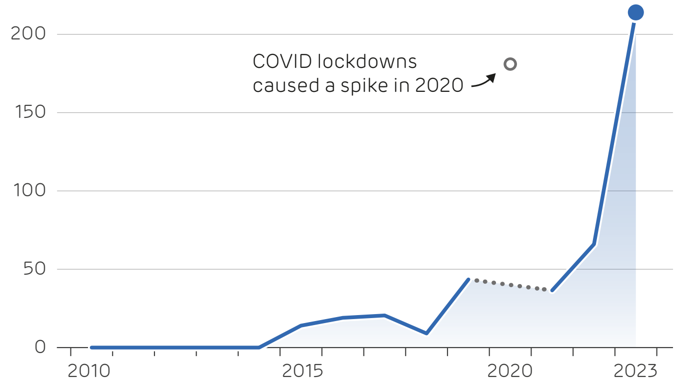
Negative power prices are not just on the rise in Britain, they are becoming commonplace throughout Europe. In the Netherlands and Nordic countries, on average 1 hour in every 24 had prices of zero or below. Britain saw Europe's 8th largest number negative price hours in 2023, with prices averaging –£16/MWh during those hours.

Negative prices – paying customers instead of charging them for your product – suggests that what you're selling is a waste that must be got rid of. For example, shops pay to have their refuse collected, which could be seen as selling it for a negative price.

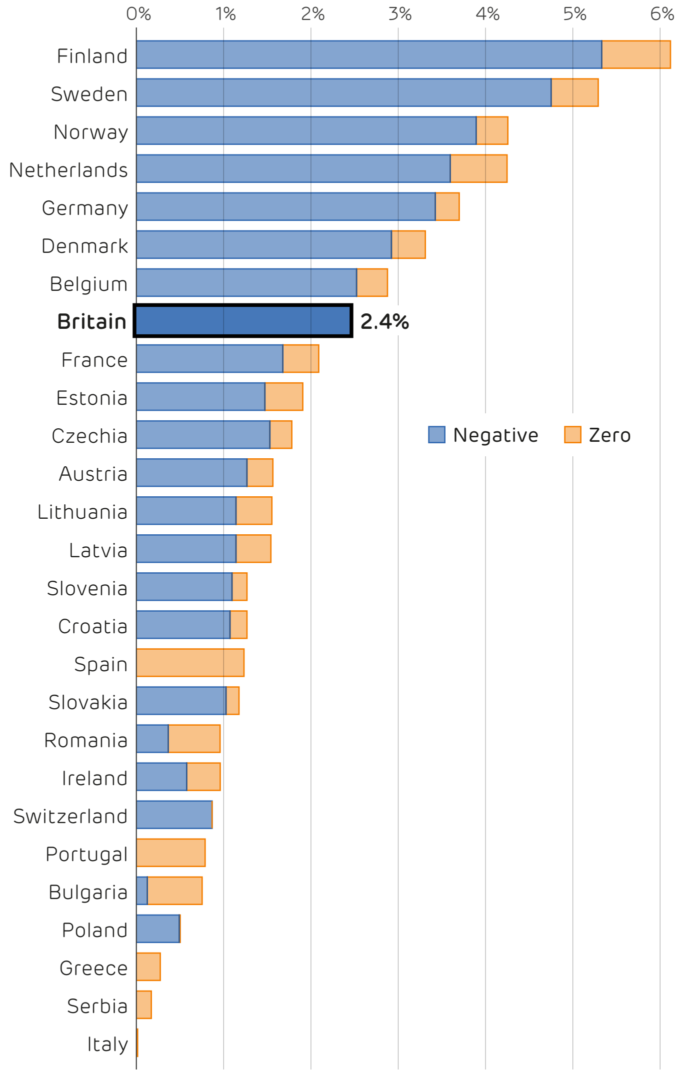
So, why might electricity be treated as a waste product for some of the year? This can be explained by the peculiar nature of electricity as a commodity, and the design of renewable policies. Firstly, electricity is not like other products: supply and demand must balance exactly at all times. If too much is produced (because it is windy and sunny) then the excess must be exported, stored, or shut off to avoid making the electricity system unstable.

Britain now has 44 GW of wind and solar capacity, and a minimum electricity demand of just 17 GW. Add to this the 6 GW of inflexible nuclear reactors and oversupply is a very real possibility. At times of oversupply, price needs to fall to persuade flexible generators to reduce output, interconnectors to export, storage systems to charge up, or customers to use more electricity. One reason prices go negative rather than fall to zero is due to the support schemes in place for wind farms. Some older farms earn 'ROC' subsidies, worth around £50 for every MWh sold. This means it is still profitable for these farms to sell power even at prices down to –£50 (or thereabouts). Only when prices fall below what they could have earned from ROCs will they be willing to shut off. Negative prices can also be caused by generators lacking flexibility: for example, nuclear power stations take several days to shut down and restart, so they may be willing to pay more flexible generators to shut off for short periods of time.

The number of hours with negative electricity prices in Britain each year



The share of hours in 2023 with zero or negative power prices across European markets



Negative prices go hand in hand with the curtailment of wind farms. Britain's wind farms lost 5% of their output to curtailment in 2023, some 4.3 TWh (enough to power 1.5 million houses). Constraint payments for shutting farms off reached £300 million in 2023, which adds nearly £4/MWh to the cost of wind generation.

How do we fix the issue of negative prices, and should we?

To adapt a common refrain among traders: 'the cure for negative prices is negative prices' – the market will adjust in ways that reduce the impact of negative prices. Taking this view, negative prices are no bad thing, they are a signal for developers to build more flexible technologies that rely on large price differentials. This could include large-scale energy storage which can use these times to charge, more interconnectors to export excess electricity abroad, or ways for people and industries to shift the timing of their consumption such as National Grid's Demand Flexibility Service. As the share of electric vehicles increases, there may be greater scope for individual households to shift their demand by a few hours, or even days. This can benefit households, as cars can be charged when prices are lower, and the wider system, as these will be times when power supply is lower carbon.

As more of these solutions come online, the mismatch between supply and demand will shrink, and with it the incidence of negative prices. The goal posts are always moving though, and if the development of new flexibility sources does not keep pace with new wind and solar farms, we should expect price volatility to continue growing in future.

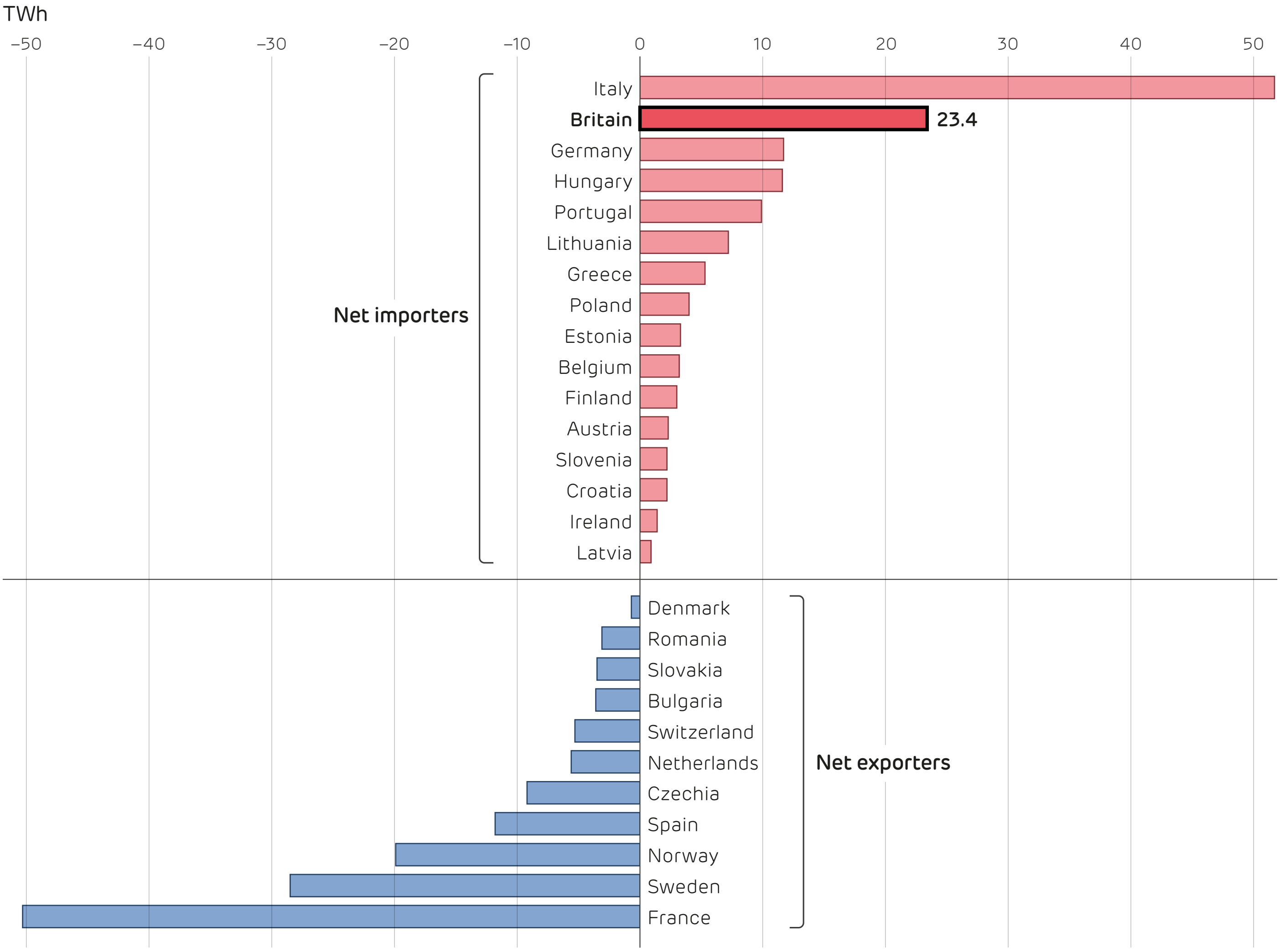
5. World's longest subsea power cable connects Britain to Denmark

On December the 29th the Viking Link went online, enabling Britain to begin trading electricity with Denmark. The Viking Link is the world's longest undersea power cable, spanning 760 km across the North Sea to connect Lincolnshire to southern Jutland in Denmark. It will transmit up to 0.8 GW of power until upgrades to Denmark's transmission grid unlock its full capacity of 1.4 GW.

Denmark is comparable to Scotland in terms of population, with 5.9 million versus 5.5 million people. Wind is by far its largest source of generation, supplying almost two-thirds of electricity. This is enabled by a well-connected grid, with large interconnections to neighbouring Norway, Sweden and Germany.

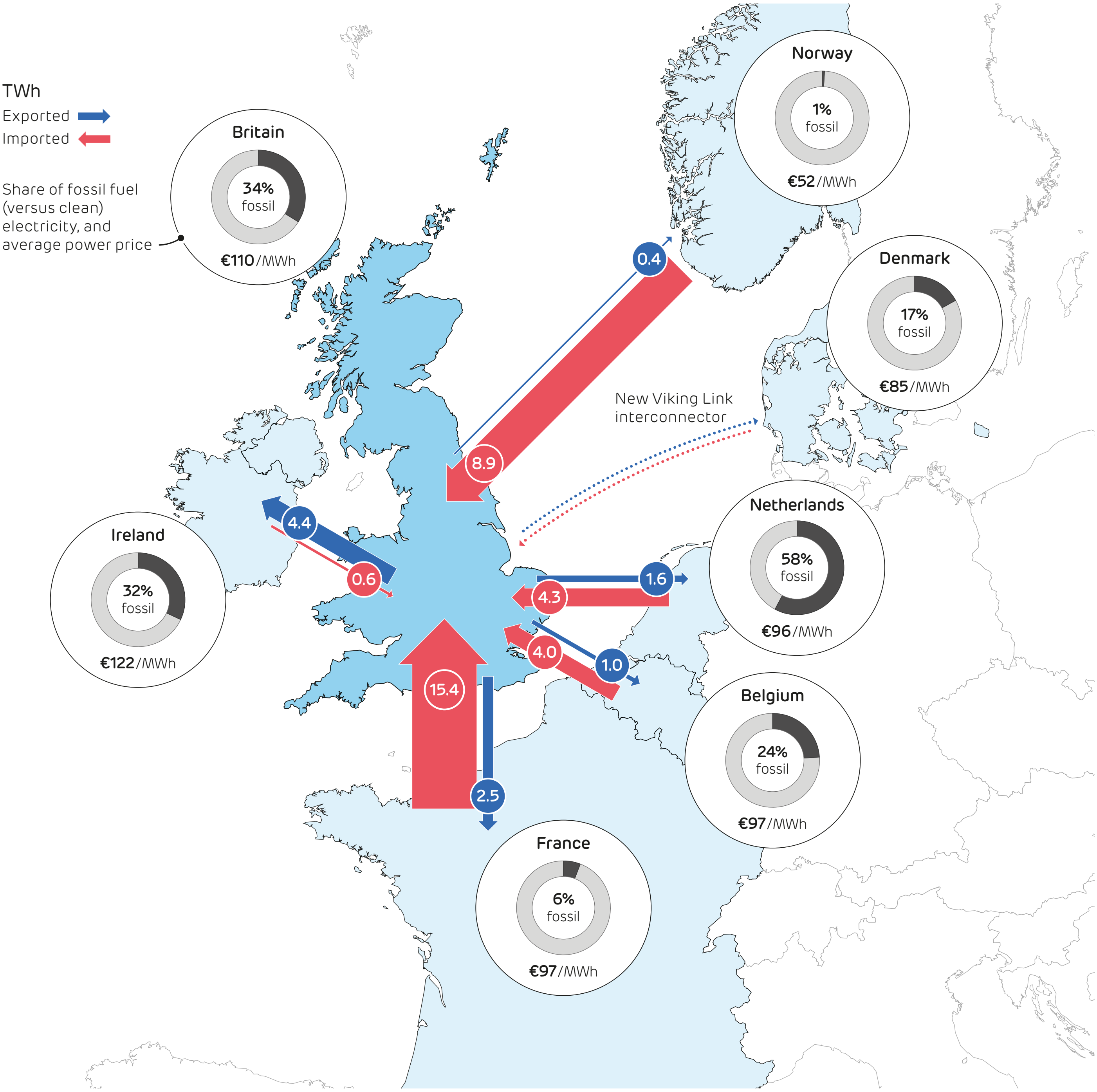
In its first days, the Viking Link sent an average of 660 MW to Britain, with us importing every hour since it went live. Britain already has the 2nd largest trade deficit for electricity across Europe. It imported 33 TWh and exported 10 TWh during 2023, giving a 23 TWh net shortfall of generation – second only to Italy.

Net trade of electricity between European countries in 2023



This new interconnector stands to further increase our reliance on foreign imports. However, it is expected to save UK consumers around £50 million per year by increasing access to cheaper power sources abroad. Last year, Danish electricity prices averaged £20/MWh lower than in Britain. The link should also benefit Britain's renewables by giving more options to export when output is high.

Electricity trade between Britain and neighbouring markets during 2023



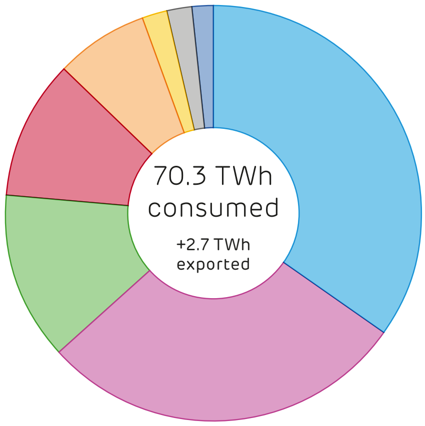
6. Capacity and production statistics

Wind power had a record-breaking quarter, producing more than 25 TWh of electricity over the last three months of 2023. This made it the largest source of electricity over the quarter, supplying more than a third of the country's demand.

In contrast, gas fell to its lowest share since 2015, squeezed out by more imports and less exports (so less need for power supply), and more generation from biomass and wind. Gas-fired electricity production was down by 24% compared to the same quarter the previous year.

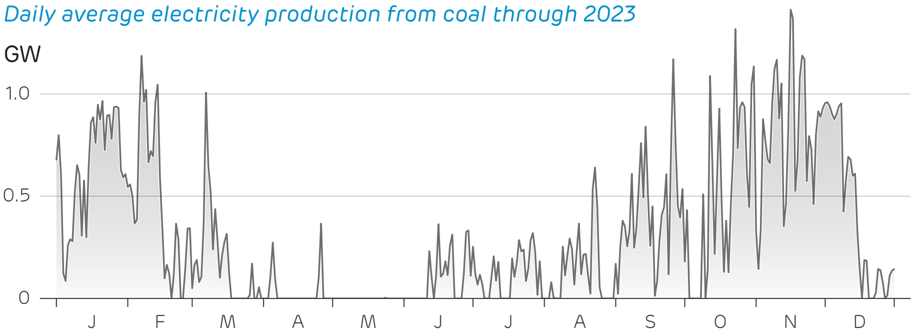
Coal bucked its annual downwards trend, producing one-third more in Quarter 4 compared to the year before. The country's last coal plant ran almost continuously since summer, a far cry from the start of this decade which saw whole months with zero coal output.

Britain's electricity supply mix in the fourth quarter of 2023



	Share of the mix
Wind	35.0%
Gas	28.4%
Nuclear	13.2%
Imports	10.7%
Biomass	7.4%
Solar	2.0%
Coal	1.8%
Hydro	1.6%

Daily average electricity production from coal through 2023



Installed capacity and electricity produced by each technology [1,2]

	Installed Capacity (GW)		Energy Output (TWh)		Utilisation / Capacity Factor	
	2023 Q4	Annual change	2023 Q4	Annual change	Average	Maximum
Nuclear	6.4	–1.0 (–14%)	9.6	–1.0 (–9%)	69%	83%
Biomass	3.8	~	5.4	+1.5 (+37%)	64%	100%
Hydro	1.2	~	1.2	+0.0 (+4%)	47%	100%
Wind	29.0	+2.0 (+7%)	25.5	+0.8 (+3%)	41%	77%
– of which Onshore	14.4	+0.7 (+5%)	10.4	+0.8 (+9%)	33%	63%
– of which Offshore	14.6	+1.3 (+9%)	15.1	–0.1 (–0%)	49%	82%
Solar	15.4	+1.3 (+9%)	1.5	+0.0 (+2%)	4%	54%
Gas	27.7	~	20.7	–6.6 (–24%)	34%	94%
Coal	1.8	–2.0 (–52%)	1.2	+0.3 (+33%)	31%	90%
Imports	8.4	+1.0 (+14%)	7.6	+3.3 (+77%)	42%	87%
Exports			2.6	–2.9 (–53%)	14%	71%
Storage discharge	3.1	~	0.5	+0.1 (+32%)	8%	75%
Storage recharge			0.6	+0.2 (+50%)	8%	52%

1 Other sources give different values because of the types of plant they consider. For example, BEIS Energy Trends records an additional 0.7 GW of hydro, 0.6 GW of biomass and 3 GW of waste-to-energy plants. These plants and their output are not visible to the electricity transmission system and so cannot be reported on here.
2 We include an estimate of the installed capacity of smaller storage devices which are not monitored by the electricity market operator.

7. Power system records

Britain's power system saw a range of new extremes, breaking annual records on several fronts. 2023 saw:

- **The highest ever renewables share:** over two-fifths of annual demand met by wind, biomass, solar and hydro.
- **The highest ever wind generation:** over 9 GW averaged across the year.
- **The highest share of imports:** over 12% of electricity consumed in Britain.
- **The lowest electricity demand since 1987:** falling below 30 GW averaged over the year.
- **The lowest share of fossil fuels in the generation mix:** below one-third for the first time ever.
- **The lowest ever carbon emissions:** falling below 150 g/kWh. Britain's electricity was cleaner than ever during the final quarter of the year, reaching a new monthly minimum of 131 g/kWh in October, and then breaking this record again with 124 g/kWh during December.

The tables below look over the past fourteen years (2009 to 2023) and report the record output and share of electricity generation, plus sustained averages over a day, a month and a calendar year. Cells highlighted in blue are records that were broken in the fourth quarter of 2023, or annual records broken in 2023. Each number links to the date it occurred on the Electric Insights website, so these records can be explored visually.

Wind – Maximum

	Output (MW)	Share (%)
Instantaneous	21,929	69.4%
Daily average	20,877	60.9%
Month average	14,525	40.4%
Year average	9,022	28.9%

Solar – Maximum

	Output (MW)	Share (%)
Instantaneous	9,830	34.8%
Daily average	3,480	13.9%
Month average	2,651	10.0%
Year average	1,397	4.5%

Biomass – Maximum

	Output (MW)	Share (%)
Instantaneous	3,831	16.8%
Daily average	3,316	12.9%
Month average	2,849	8.8%
Year average	2,216	7.1%

All Renewables – Maximum

	Output (MW)	Share (%)
Instantaneous	27,915	77.3%
Daily average	24,262	68.3%
Month average	18,334	51.0%
Year average	12,610	40.4%

	Gross demand	
	Maximum (MW)	Minimum (MW)
Instantaneous	60,070	16,934
Daily average	49,203	23,297
Month average	45,003	26,081
Year average	37,736	29,910

	Demand (net of wind and solar)	
	Maximum (MW)	Minimum (MW)
Instantaneous	59,563	3,365
Daily average	48,823	7,848
Month average	43,767	16,253
Year average	36,579	19,491

	Day ahead wholesale price	
	Maximum (£/MWh)	Minimum (£/MWh)
Instantaneous	1,983.66	–77.29
Daily average	666.90	–11.35
Month average	353.36	22.03
Year average	198.16	33.88

	Carbon intensity	
	Maximum (g/kWh)	Minimum (g/kWh)
Instantaneous	704	15
Daily average	633	40
Month average	591	124
Year average	508	148

	All low carbon – Maximum	
	Output (MW)	Share (%)
Instantaneous	35,172	93.4%
Daily average	30,305	88.0%
Month average	23,754	66.3%
Year average	18,451	59.2%

	All low carbon – Minimum	
	Output (MW)	Share (%)
Instantaneous	3,395	8.3%
Daily average	5,007	10.8%
Month average	6,885	16.7%
Year average	8,412	21.6%

	All fossil fuels – Maximum	
	Output (MW)	Share (%)
Instantaneous	49,307	88.0%
Daily average	43,085	86.4%
Month average	36,466	81.2%
Year average	29,709	76.3%

	All fossil fuels – Minimum	
	Output (MW)	Share (%)
Instantaneous	1,495	4.1%
Daily average	2,502	7.5%
Month average	7,382	24.3%
Year average	10,234	32.8%

	Nuclear – Maximum	
	Output (MW)	Share (%)
Instantaneous	9,342	42.8%
Daily average	9,320	32.0%
Month average	8,649	26.5%
Year average	7,604	22.0%

	Nuclear – Minimum	
	Output (MW)	Share (%)
Instantaneous	2,065	5.6%
Daily average	2,238	6.9%
Month average	3,563	10.5%
Year average	4,372	14.0%

Coal – Maximum

	Output (MW)	Share (%)
Instantaneous	26,044	61.4%
Daily average	24,589	52.0%
Month average	20,746	48.0%
Year average	15,628	42.0%

Coal – Minimum

	Output (MW)	Share (%)
Instantaneous	0	0.0%
Daily average	0	0.0%
Month average	0	0.0%
Year average	315	1.0%

Gas – Maximum

	Output (MW)	Share (%)
Instantaneous	27,131	72.6%
Daily average	24,210	62.2%
Month average	20,828	54.8%
Year average	17,930	46.0%

Gas – Minimum

	Output (MW)	Share (%)
Instantaneous	1,403	4.1%
Daily average	2,444	7.5%
Month average	6,775	19.9%
Year average	9,159	24.6%

Imports – Maximum

	Output (MW)	Share (%)
Instantaneous	8,055	34.4%
Daily average	6,942	26.9%
Month average	5,100	18.2%
Year average	3,792	12.2%

Exports – Maximum

	Output (MW)	Share (%)
Instantaneous	–5,662	–23.7%
Daily average	–4,763	–14.1%
Month average	–3,098	–9.8%
Year average	–731	–5.8%

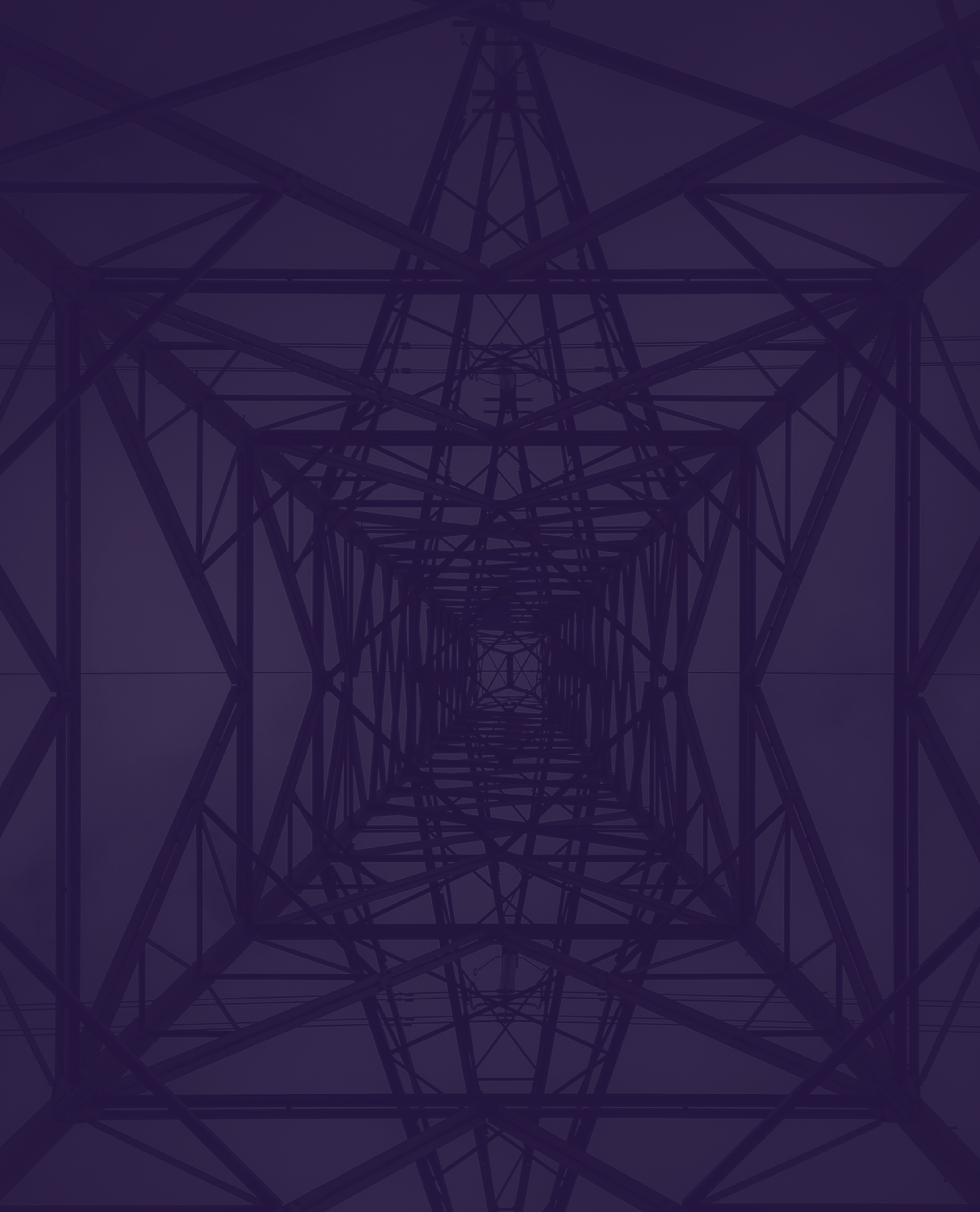
Pumped storage – Maximum[3]

	Output (MW)	Share (%)
Instantaneous	2,660	7.9%
Daily average	409	1.2%

Pumped storage – Minimum[3]

	Output (MW)	Share (%)
Instantaneous	–2,782	–10.8%
Daily average	–622	–1.7%

3 Note that Britain has no inter-seasonal electricity storage, so we only report on half-hourly and daily records. Elexon and National Grid only report the output of large pumped hydro storage plants. The operation of battery, flywheel and other storage sites is not publicly available.



Drax Group plc
Drax Power Station, Selby, North Yorkshire, YO8 8PH
www.drax.com
@DraxGroup

Imperial Consultants
58 Prince's Gate, Exhibition Road, London, SW7 2PG
www.imperial-consultants.co.uk
@ConsultImperial