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Electric Insights Quarterly

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Contents

Electric Insights was established by Drax to help inform and enlighten the debate on Britain's electricity. It is delivered independently by a team of academics from Imperial College London. Data courtesy of Elexon, National Grid and Sheffield Solar.

Headlines

There is a new groundswell of support for tackling the global environmental crisis head on and reducing carbon emissions to — or even below — zero. School strikes for climate, led by Greta Thunberg, have become a global movement in a matter of months. David Attenborough's Climate Change: The Facts was the BBC's first documentary in over a decade to cover "Earth's greatest threat in over 1000 years". Extinction Rebellion closed parts of London for a week to protest against inaction over climate change. MPs have made history by passing the world's first declaration of an "environmental and climate change emergency".

The UK is in a position of strength. It is again a top performer in PWC's Low Carbon Economy Index, and was ranked #2 at COP24 for transforming its energy system. Much of this is due to progress in the electricity sector, but as the quick win of phasing out coal nears completion, further decarbonisation is slowing and the UK risks missing its carbon targets for 2025 and beyond.

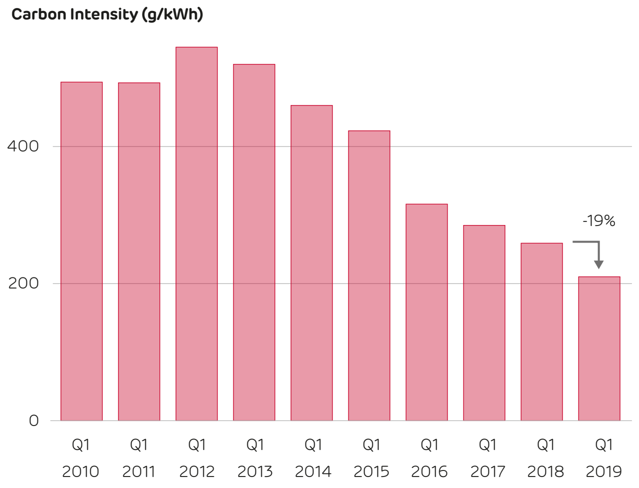
The Committee on Climate Change spells out what is required in its landmark report on achieving net-zero emissions by 2050. Britain must redouble its commitment to renewables: despite costs falling dramatically, less new capacity is being built than at any time since 2010, and the UK has continued to fall in the EY Renewable Energy Country Attractiveness Index. Britain's power system should continue to lead the way on emissions cuts, rapidly heading towards zero in the 2020s. This must then be followed by rolling out bioenergy with CCS, hydrogen, and smart new tools to improve flexibility. The electricity sector should then expand to provide clean heating and transportation by ramping up the market for electric vehicles (which are around 3% of new sales today) and electric heat pumps (around 1% of new home heating systems).

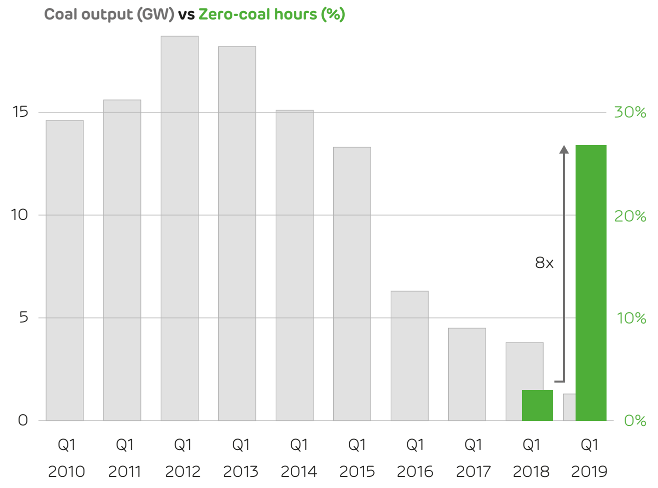
This quarter, Electric Insights looks at how low Britain's power system can go, in terms of fossil fuels and carbon emissions, because of the key limiting factor: how much controllable generation we need. National Grid ESO's Head of National Control discusses their roadmap for operating a zero carbon system in 2025. Our second article looks at what to do when the wind doesn't blow. The three main options: interconnection, storage and conventional fuels all have roles to play in balancing out lulls in wind output.

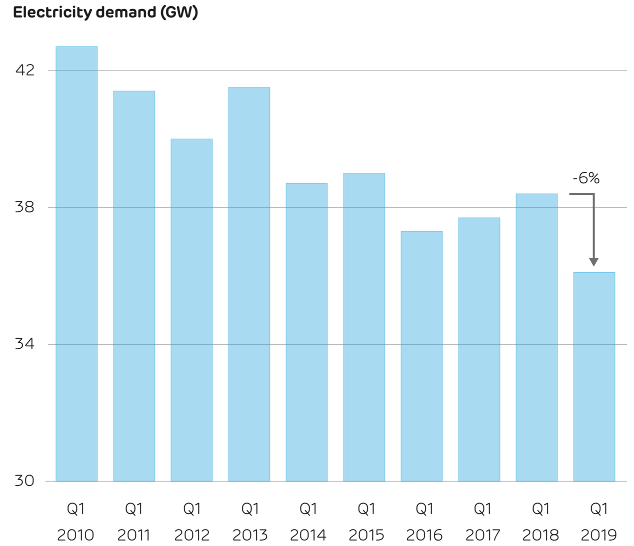
Britain's interconnection received a boost as the Nemo link to Belgium opened at the end of January. This pushed imports to record highs, and meant that more than a tenth of our electricity was produced abroad for the first time ever. We take a look at our neighbouring power systems and where Britain's imports come from.

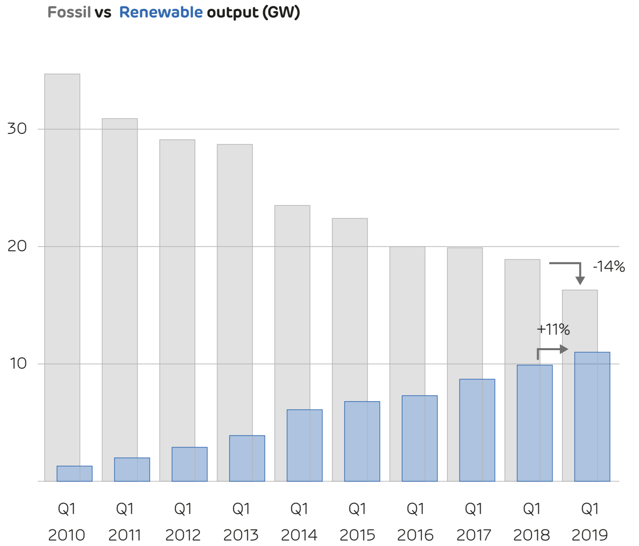
The three months to March saw large changes in the power system from Q1 2018. The capacity and production statistics reveal that the mild winter kept demand low, coal output fell by two-thirds, and interconnectors saw the highest running hours of any technology. Finally, following on from last quarter's article, Electric Insights now includes a quarterly update on all of Britain's power system records. This quarter, 22 of the records we cover were toppled.

Comparison of the first quarter of 2019 to previous years









1. How low can we go?

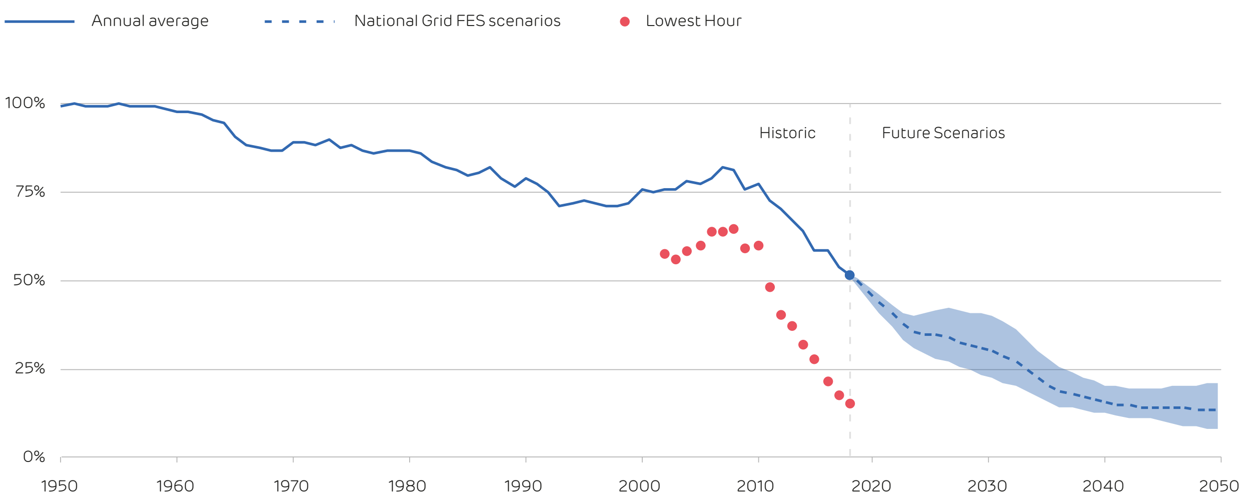
Just how low can Britain's power system go in terms of fossil fuels and carbon emissions? Does Britain's geography necessitate a minimum amount of dispatchable, flexible and thermal power on the system? Being an island, it is more expensive for us to build electrical links to other countries, than it is for example Germany to build them across its land borders. Similarly, our lack of mountains means that pumped hydro is never going to provide weeks or months of storage. Britain faces more challenges than most in this area, but that does not dampen the ambition for zero carbon electricity.

Last month National Grid ESO announced it will be ready to operate a zero-carbon electricity system by 2025. This would mean that as more renewables and nuclear power come online, the power system can be operated safely and securely at times when they are able to supply all demand. With over 43 GW of wind, solar and nuclear capacity already installed and demand averaging 35 GW last year, this situation is already a real possibility.

Wind, solar and nuclear have provided up to 88.5% of Britain's electricity at one moment in time. What prevents them going further? The current solution is instead to curtail (or waste) some renewable generation and bring on flexible fossil generators (coal and gas) to keep the system stable. This sends power prices negative and increases emissions, as happened for six hours straight on a sunny, windy day in March. The key problem is that the grid needs many services to run safely: reserve, inertia, frequency response and voltage support to name a few; and these are currently provided by flexible and dispatchable technologies.

All of Britain's electricity came from flexible and controllable sources (coal, oil, gas and hydro) until the world's first commercial nuclear reactor opened at Calder Hall in 1956. Over the next four decades this share gradually moved down to 75% as nuclear came into the mix.[1] As shown below, the last ten years have seen a greater change than the previous fifty – this year is set to be the first when less than half of the country's electricity comes from fully dispatchable sources.

The share of generation from fossil fuels, biomass and hydro [2]



1 Note that Britain's older gas-cooled nuclear reactors are not flexible and cannot reduce output to follow load. Newer water-cooled reactors such as the EPR being built at Hinkley Point C should have similar flexibility to other conventional power plants.
2 Thermal power stations (coal, oil, gas and biomass) and hydro are the technologies which can provide the full set of system services at present.

The share of controllable generation has fallen by 3% per year over the last decade. National Grid's Future Energy Scenarios sees this trend continuing into the mid-2020s, as Britain sources more of its electricity from wind and solar, and imports more from abroad. The share of fully-dispatchable British electricity generation may fall to just one quarter in as little as ten years, before settling at between 8% and 21% in the 2040s.

As always, year-round averages do not tell the whole story, and it is the hour-to-hour variation which matters with electricity. Since 2016 the power system has seen periods with less than a quarter of electricity coming from conventional sources (as shown by the red circles). Last year on an August night, a low of 15% was reached, with just 2.4 GW being produced from fossil fuels. The question now is how to squeeze out this last couple of gigawatts of fossil fuels?

This will require a radical departure from the traditional ways of planning, analysing and operating power systems. National Grid ESO has set out a roadmap for achieving this over the next five years: from defining new services and regional requirements to them, building new markets for these services, allowing more technologies into these markets,[3] increasing the deployment of storage, and using AI to improve the forecasting tools for wind and solar power.

Other system operators at the forefront of renewables integration are trialling their own approaches. Australia uses mandates: new wind and solar farms must install their own technical solutions (such as flywheels) to provide system services. California has opted for central regulation: their grid operator decides how much storage (or other flexible solutions) to build and then runs these much like the transmission wires. National Grid ESO is instead taking the market-led approach: defining the need for services and creating the marketplaces for trading them. Their aim is to allow companies to innovate and compete to find out how these services can then be delivered most efficiently.

Of course, running a traditionally fossil-fuelled power system at zero carbon on average will be much more difficult than running it for half an hour at a time. Ultimately, the aim is not just to cope with single periods. Having the tools and systems in place to run for a single hour at zero carbon will mean the grid is ready and capable to run for longer. Britain quickly moved from seeing the first ever zero-coal hour to having the first day, first weekend, and most recently a whole week without coal. In five years' time we could well be repeating the same exciting process, but with zero fossil fuels, and zero carbon. To quote Fintan Slye, director of National Grid ESO, "Operating a zero-carbon electricity system in 2025 is a major stepping stone to the full decarbonisation of the entire electricity system".

3 For example, allowing wind and solar to provide reserve and response services from 2020.

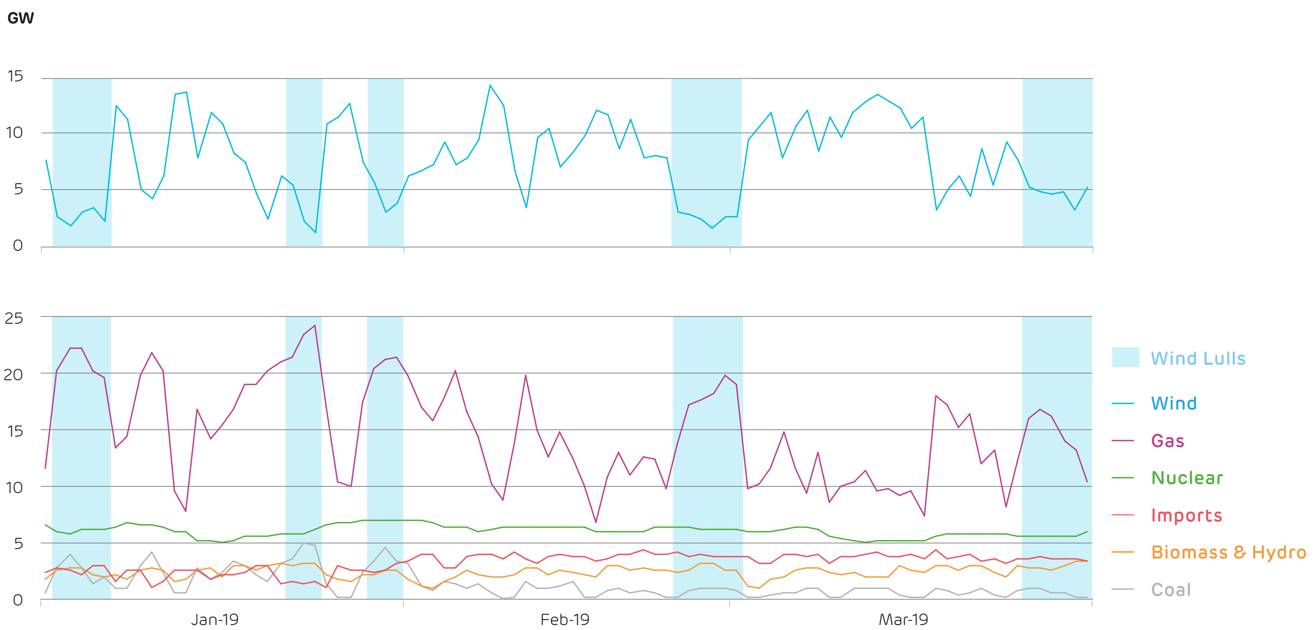
2. What to do when the wind doesn't blow?

Some call it intermittency, some call it variability; the simple fact is we cannot control the wind. Britain's wind farm output swings widely from one week to the next, caused by high- and low-pressure weather systems passing over the country.

Wind output can vary from 2 GW one day to 12 GW the next,[1] and Britain can experience long lulls in wind output. For example, the mini heatwave at the end of February saw a 6-day long collapse in wind output. So, how can Britain balance out the variability that wind power brings?

From the chart below it is clear that gas is the main source of flexibility at the moment. We have sufficient capacity, and it is sufficiently flexible to ramp up or down by 10+ GW when needed. Nuclear output is stable over the course of the year, only varying due to maintenance. Coal provides extra balancing during the coldest weather (when gas prices are higher), but at most it flexed up and down by 5 GW (daily average) during January. Hydro and biomass also provide flexibility, but together they are dwarfed by the swings in wind power. Finally, interconnectors ought to provide flexibility, but at the moment it is more profitable to import at full power regardless of what the wind is doing.

Daily average output from wind farms (top) and other generating technologies (below) over the first three months of 2019



1 For example on January 7th and 8th or January 24th and 25th.

Britain has around 20 GW of wind capacity today, but National Grid and BEIS expect this could double to 40 GW in as little as seven years.[2] Doubling the current levels of volatility at a time when coal capacity is retiring will test the whole electricity system, and likely require new sources of flexibility. Three key options are available to us: (1) more interconnection, (2) energy storage, (3) new fuels such as hydrogen, or (4) using existing fuels to back up wind farms.

Further interconnection could help, but weather systems cover large areas, meaning wind speeds tend to be correlated. Research has shown that countries across Northern Europe tend to experience high or low wind output at the same time.

Balancing the wind with energy storage would need radically different technologies to those we have today. Britain's pumped hydro storage plants usually operate on a daily cycle, charging up overnight and discharging during the day (although they are increasingly used to provide rapid response to grid fluctuations). Lithium ion batteries are for even shorter durations, typically holding less than 4 hours of charge, rather than the several days needed to balance out wind lulls. Electric vehicles, homes and offices could provide a large new source of flexibility in the near future, through vehicle-to-grid (V2G) and demand-side response (DSR).

Hydrogen has the potential to offer large-scale energy storage, as it could use the UK's geological formations to provide weeks, or even months, of backup. Hydrogen could be produced from excess renewable power at times of surplus, or from natural gas with carbon capture. Hydrogen sorely needs technological scale-up and cost reductions to become a competitive option, but hydrogen could prove pivotal in the UK meeting its economy-wide carbon reduction targets by offering zero-emission heating for homes and powering long distance and heavy goods vehicles.

Sticking to the present day, fossil fuels provide an almost-ideal counterbalance. They have a high energy density, are easy to store, and we already have the infrastructure in place to transport and use them. However, in a carbon-constrained world, we cannot continue indefinitely using unabated coal or gas to backup renewables. Biomass is an alternative, but we only have 3.2 GW today, and this is not expected to grow significantly over the coming decades. Ultimately, a mix of all these solutions will likely be the best route forwards.

2 National Grid Future Energy Scenarios and BEIS Energy and Emissions Projections.

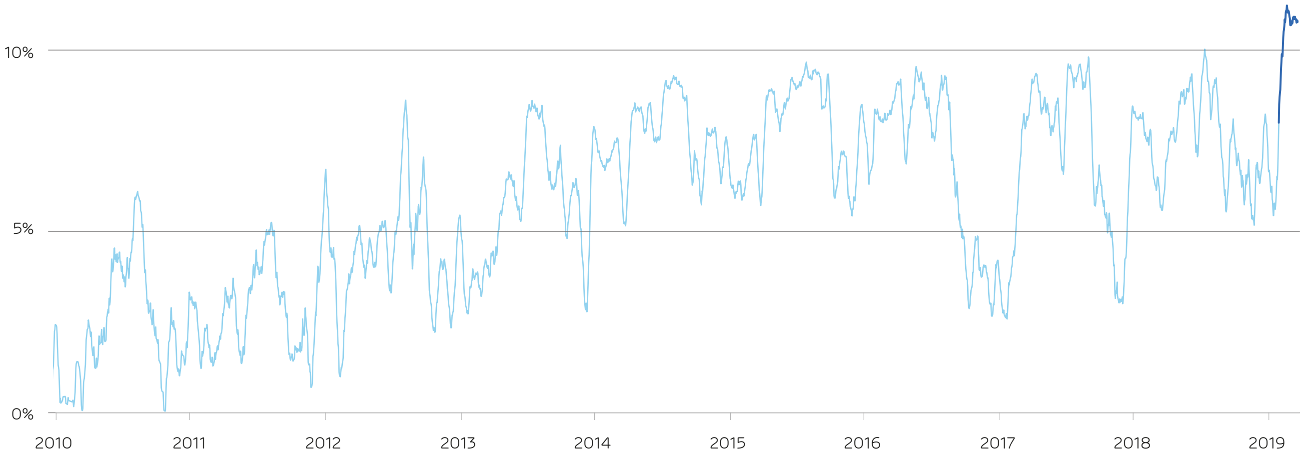
3. 10% of electricity now generated abroad

A new interconnector to Belgium has pushed British electricity imports to record highs. At the start of this year, the £600m Nemo link between Kent and Zeebrugge in Belgium came online. It adds 1 GW – or 25% – to Britain's connections with neighbouring countries. The link has imported power to Britain every day it has been in operation, exploiting the price differential between electricity markets on either side of the channel.

Averaged over the first three months of 2019, power was almost £10/MWh cheaper to buy on the continent. Electricity traded at £52/MWh in Britain, while in Belgium it was just £42.70/MWh. Belgium has the lowest natural gas prices in Europe, and their power stations pay £16 per tonne less for carbon emissions than their counterparts in Britain. This helps to explain why Britain exported to Belgium for only 2.5 hours out of the 2 months the link has been running.

As a result, Britain has fallen below 90% self-sufficiency for electricity generation for the first time ever. In February and March, a tenth of Britain's electricity has been imported from Europe, with 2.3% coming from Belgium. While this is record levels for electricity, it is low compared to other forms of energy. Britain imports around half of its crude oil and two-thirds of its natural gas (primarily from Norway).[1] Despite our heritage as a coal-mining country, now 80% of the coal we burn is imported, primarily from Russia and the US. Domestic coal mining fell to 2.6 million tonnes last year, the lowest level since records began.[1]

The share of Britain's electricity that is imported each week.
The darker line shows the time since the Belgian interconnector came online.



1 Source: BEIS Energy Trends.

4. Where do Britain's imports come from?

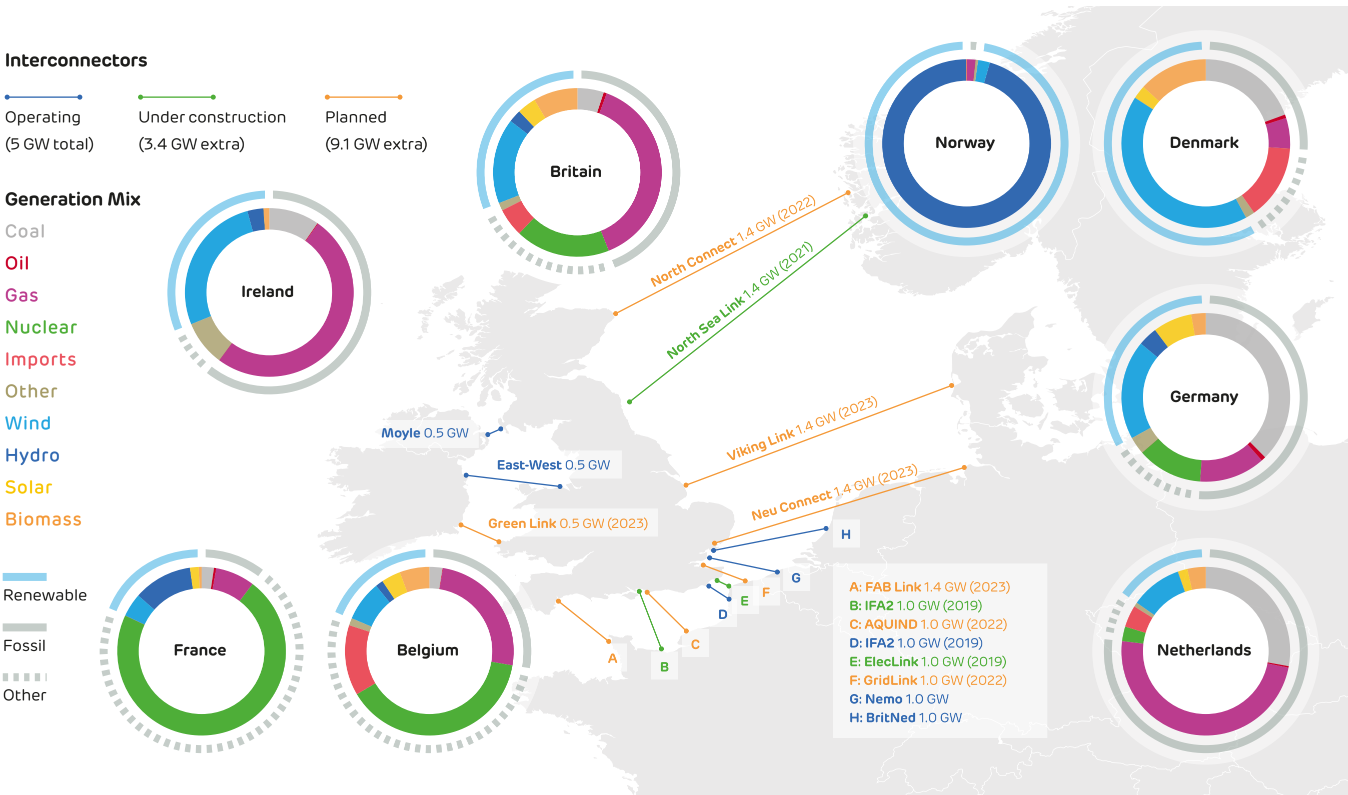
As Britain's electricity imports are on the rise, we look at how our neighbouring countries generate their electricity. Europe's electricity mix is diverse, ranging from fully-renewable through to heavy reliance on coal and gas. The graphic below details where our imported electricity comes from – mapping the current and proposed interconnectors to Britain, and the makeup of each of our neighbours' power systems.

Britain currently have five interconnectors: 2 GW to France, 0.5 GW each to Northern Ireland and the Republic of Ireland, and 1 GW each to the Netherlands and Belgium. The British and Irish power systems trade back and forth on a roughly equal footing, but the other links primarily export to us. The share of power coming from each country is mainly governed by the size of their links. Around half of Britain's imports came from France, and a quarter each from Belgium and the Netherlands.

Imports from Belgium are mostly nuclear and gas, and are similar in their carbon content to British electricity (183 g/kWh in Belgium versus 227 g/kWh here, averaged over 2017–18). Belgian electricity is much cleaner than imports from the Netherlands or Ireland, which primarily burn gas and coal. France is our cleanest connected neighbour, with 90% of their electricity coming from nuclear and renewables.

More links to France and Ireland are in the pipeline, followed by longer cables to Norway, Denmark and Germany. Norway has one of the cleanest electricity systems in the world, as their abundant mountain ranges mean they run on 95% hydro power. Denmark and Germany are renowned for their large shares of wind power, but these are backed up almost exclusively by coal, or its even dirtier cousin, lignite.

Map of the UK's current and planned interconnectors, with pie charts showing the grid mix in Britain and neighbouring countries [1]



1 Grid mix is the average over 2017–18. Source: Eurostat

5. Capacity and production statistics

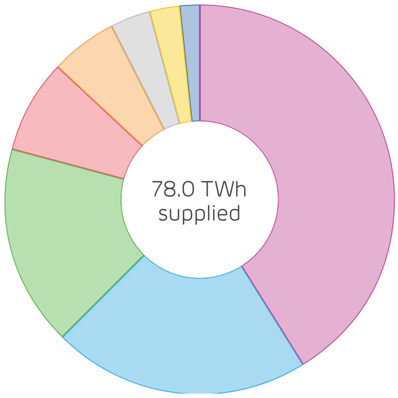
This quarter saw some significant changes from the first three months of 2018. Winter was particularly mild, with average temperatures 2°C higher than last year, meaning demand was down by 6%. Nuclear output is 16% lower than last year as five reactors are down for maintenance, including two extended outages due to cracks being found.

Coal output was also down by two-thirds, and no coal was burnt for electricity for 581 hours over the quarter (27% of the time). Zero-coal hours have shot up from 0 in Q1 2017, and just 71 in Q1 2018. As we predicted last quarter, Britain's solar panels have now beaten coal over the past 12 months – supplying 1.3 GW on average versus 1.1 GW. The warm sunny spells meant we saw midday periods when solar was the second largest source of electricity during February.

Power prices fell by almost a third from £61/MWh at the end of last year to £43/MWh in March. Lower fuel prices, and high wind output helped to suppress prices, even though the price of carbon emissions rose to a 10-year high.

Outages meant Britain's nuclear reactors only ran at 64% of nominal capacity. In comparison, Britain's interconnectors were the most heavily utilised technology, averaging 71%. Britain imported an average of 3.75 GW during February and March, and at no point did imports fall below 1.4 GW.

Britain's electricity supply mix in the first quarter of 2019



	% of mix
Gas	41.3%
Wind	21.2%
Nuclear	16.8%
Imports	7.9%
Biomass	5.3%
Coal	3.6%
Solar	2.5%
Hydro	1.4%

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

	Installed Capacity (GW) 2019 Q1	Annual change	Energy Output (TWh) 2019 Q1	Annual change	Utilisation / Capacity Factor	
					Average	Maximum
Nuclear	9.5	~	13.1	−2.5 (−16%)	64%	74%
Biomass	3.2	+0.6 (+24%)	4.1	+0.9 (+29%)	61%	98%
Hydro	1.1	~	1.1	+0.3 (+30%)	48%	94%
Wind	20.8	+1.1 (+6%)	16.5	+1.0 (+6%)	38%	76%
Solar	12.9	+0.1 (+1%)	1.9	+0.3 (+17%)	7%	66%
Gas	28.1	+0.4 (+1%)	32.2	−0.4 (−1%)	54%	98%
Coal	10.5	−0.6 (−6%)	2.8	−5.3 (−65%)	13%	72%
Imports	5.0	+1.0 (+25%)	7.1	+1.1 (+19%)	71%	97%
Exports			0.8	+0.2 (+43%)	8%	60%
Storage discharge	4.2	+0.9 (+29%)	0.5	−0.2 (−25%)	8%	70%
Storage recharge			0.6	−0.2 (−26%)	10%	64%

1 Other statistical 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 small 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. Britain's storage capacity is made up of 2.9 GW of pumped hydro storage, 0.6 GW of lithium-ion batteries, 0.4 GW of flywheels and 0.3 GW of compressed air.

6. Britain's power system records

This year we have begun keeping track of all the record highs and lows on Britain's power system. The tables below look over the past decade (2009 to 2019) and report the record output and share of electricity generation, plus sustained averages over a day, a month and a calendar year.[1] Cells highlighted in blue are records that were broken in the first quarter of 2019. Each record links to the date it occurred on the Electric Insights website, allowing the data to be explored visually.

Wind - Maximum	Output (MW)	Share (%)
Instantaneous	15324	49.7%
Daily average	14209	41.5%
Month average	8403	24.0%
Year average	5901	17.3%

Solar - Maximum	Output (MW)	Share (%)
Instantaneous	9390	29.0%
Daily average	3386	12.0%
Month average	2464	8.1%
Year average	1319	3.9%

Biomass - Maximum	Output (MW)	Share (%)
Instantaneous	3171	12.8%
Daily average	3094	9.7%
Month average	2361	7.1%
Year average	1921	5.6%

All Renewables - Maximum	Output (MW)	Share (%)
Instantaneous	22440	60.9%
Daily average	16749	49.4%
Month average	12188	35.0%
Year average	9507	27.9%

Nuclear - Maximum	Output (MW)	Share (%)
Instantaneous	9342	42.8%
Daily average	9320	32.0%
Month average	8649	26.5%
Year average	7604	22.0%

All low carbon - Maximum	Output (MW)	Share (%)
Instantaneous	30107	88.0%
Daily average	24800	76.3%
Month average	19714	60.7%
Year average	17902	52.4%

Wind power broke several records this quarter, exceeding 15.3 GW on Sunday February 8th, and generating almost half of Britain's electricity on Friday January 13th. Biomass also had a record day, supplying just shy of a tenth of Britain's electricity on Sunday March 31st. Monthly generation from all low carbon sources (renewables, nuclear and French imports) came close to averaging 20 GW during March.

1 The annual records relate to calendar years, so cover the period of 2009 to 2018.

Imports - Maximum

	Output (MW)	Share (%)
Instantaneous	6319	16.8%
Daily average	4344	12.9%
Month average	3748	10.6%
Year average	2630	7.5%

Exports - Maximum

	Output (MW)	Share (%)
Instantaneous	–3870	–9.9%
Daily average	–2748	–6.1%
Month average	–1690	–3.8%
Year average	–731	–1.9%

Pumped storage - Maximum [2]

	Output (MW)	Share (%)
Instantaneous	2660	6.0%
Daily average	259	0.7%

Pumped storage – Minimum

	Output (MW)	Share (%)
Instantaneous	–2782	–10.8%
Daily average	–622	–1.7%

All records for electricity imports were broken as the Nemo interconnector began operation (except the highest year, which was 2018). The greater connectivity meant one export record was also broken – with Britain exporting almost 10% of its generation, beating the previous record of 9.3% that has stood since 2011.

Coal - Maximum

	Output (MW)	Share (%)
Instantaneous	26044	61.4%
Daily average	24589	52.0%
Month average	20746	48.0%
Year average	15628	42.0%

Coal - Minimum

	Output (MW)	Share (%)
Instantaneous	0	0.0%
Daily average	0	0.0%
Month average	193	0.6%
Year average	1757	5.1%

Gas - Maximum

	Output (MW)	Share (%)
Instantaneous	27131	66.3%
Daily average	24210	59.6%
Month average	20828	54.8%
Year average	17930	46.0%

Gas - Minimum

	Output (MW)	Share (%)
Instantaneous	1556	4.9%
Daily average	3071	9.5%
Month average	6775	19.9%
Year average	9159	24.6%

All fossil fuels - Maximum

	Output (MW)	Share (%)
Instantaneous	49307	88.0%
Daily average	43085	86.4%
Month average	36466	81.2%
Year average	29709	76.3%

All fossil fuels - Minimum

	Output (MW)	Share (%)
Instantaneous	2421	10.5%
Daily average	5079	18.9%
Month average	11102	35.9%
Year average	14951	43.8%

2 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.

While fossil fuels are generally on the decline in Britain, gas-fired power stations hit new record outputs on Thursday January 24th, as freezing weather and low wind speeds coincided. Gas power stations produced more than 27 GW for the first time ever, and more than 24 GW averaged over the whole day.

Gross demand	Maximum (MW)	Minimum (MW)
Instantaneous	60070	18320
Daily average	49203	24704
Month average	45003	29598
Year average	37736	33525

Demand (net of wind and solar)	Maximum (MW)	Minimum (MW)
Instantaneous	59563	9852
Daily average	48823	16341
Month average	43767	22477
Year average	36579	26305

Day ahead wholesale price	Maximum (£/MWh)	Minimum (£/MWh)
Instantaneous	792.21	-45.70
Daily average	197.45	0.00
Month average	63.17	30.83
Year average	56.82	36.91

Carbon intensity	Maximum (g/kWh)	Minimum (g/kWh)
Instantaneous	704	56
Daily average	633	104
Month average	591	180
Year average	508	217

March this year had the cleanest electricity mix on record, with 36% renewables and 17% nuclear versus just 38% fossil fuels. Carbon emissions were 3 g/kWh lower than the previous record from August 2018.

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