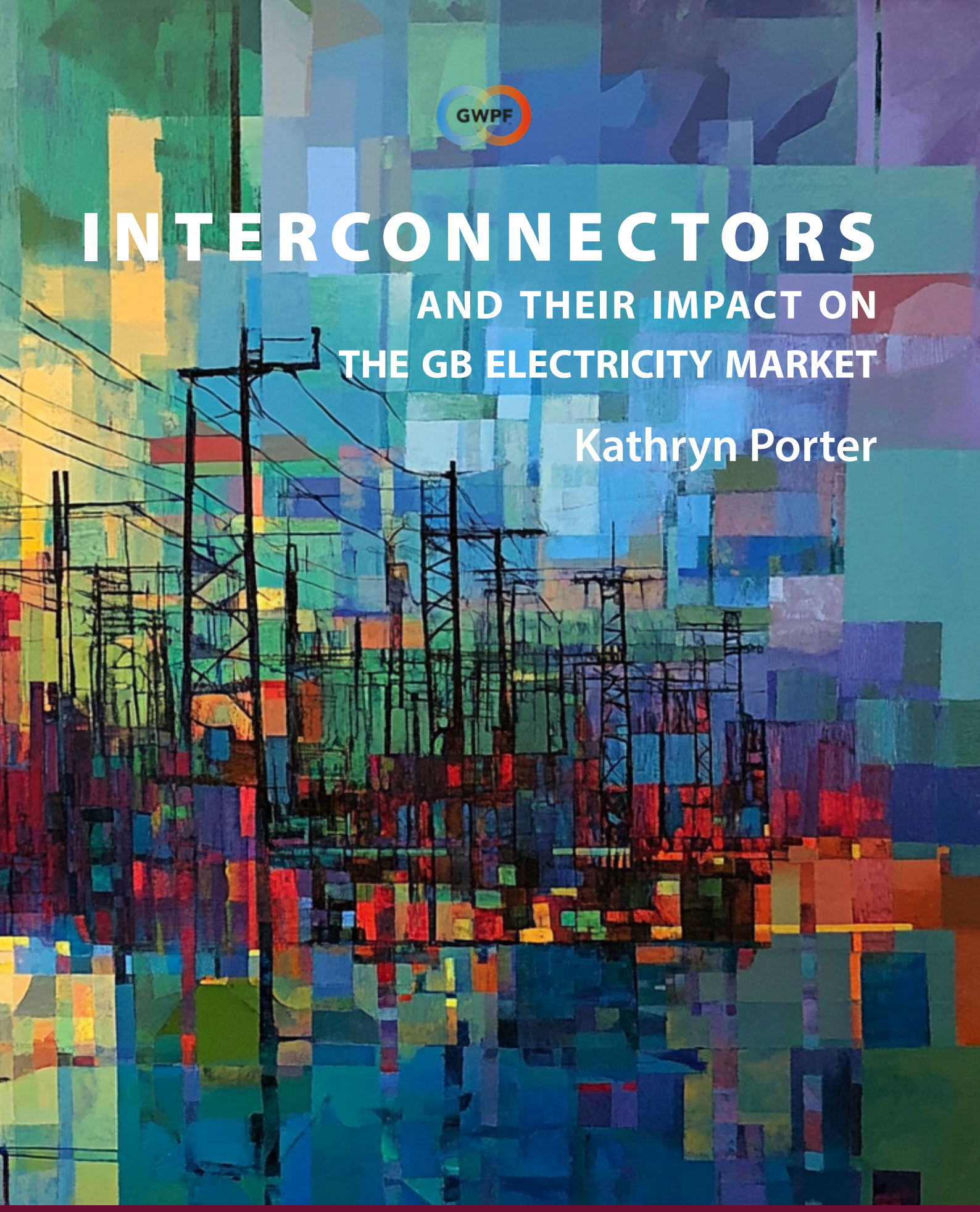

INTERCONNECTORS

AND THEIR IMPACT ON THE GB ELECTRICITY MARKET

Kathryn Porter

The Global Warming Policy Foundation
Briefing 71

Interconnectors and their Impact on the GB Electricity Market

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Briefing 71, The Global Warming Policy Foundation

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About the author

Kathryn Porter is an independent energy consultant, with broad experience of the energy and finance sectors in both leadership and technical roles. She has specific expertise in the utilities, oil and gas sectors, with finance experience spanning equities and equity derivatives, debt capital markets, M&A, loans, and risk management.

Currently running her own consulting business, Watt-Logic, Kathryn advises clients across the energy value chain on the opportunities and risks arising from the energy transition. This includes analysis of investment opportunities in generation and storage, devising procurement and risk management strategies for buyers of gas and electricity, advising on commercial contracts, such as offtake and power purchase agreements, and helping clients to understand the impact of regulatory and market change on their businesses. Kathryn has also acted as an expert on a matter relating to cross-border energy trading.

Before starting her business, Kathryn held various energy structuring and hedging roles at Centrica, Société Générale, EDF Trading, and at Barclays Capital, where she moved into commodities after starting in a fixed income role. Prior to this she worked in the Capital Markets & Advisory division at Commerzbank and in the financial services audit practice at Deloitte.

Kathryn holds a Master's degree in physics from the University of Exeter and an MBA from London Business School. She is a Chartered Fellow of the Chartered Institute for Securities and Investments and is a member of the Institute of Directors. She is an associate member of the Executive Council for the All-Party Parliamentary Group for Energy Studies.

Executive summary

The GB electricity market has become increasingly reliant on interconnection with other markets. In its 2023 Future Energy Scenarios[1], National Grid ESO (NG ESO), the electricity system operator said:

> 'To manage dunkelflaute[2] periods, dispatchable thermal power plants (gas and/or hydrogen), depending on the scenario and year, are likely to be required. A combination of LDES (e.g. Compressed Air Energy Storage (CAES), Liquid Air Energy Storage (LAES), Pumped Hydro Storage (PHS)) and interconnectors will be required to manage the network during these periods.'

In other words, interconnectors are seen as key to managing periods of low wind output in an electricity system increasingly dependent on intermittent renewable generation. But what if the markets at the other end of those interconnectors are also experiencing dunkelflaute conditions? As most of them (with the exception of Norway) have similar weather to the UK, and (with the exceptions of Norway and France) share similar wind-led decarbonisation strategies, can we really rely on interconnectors to ensure security of supply? And what about the effects of energy nationalism, which has been increasing since the war in Ukraine? Can we rely on countries being willing to export at all times when GB needs to import?

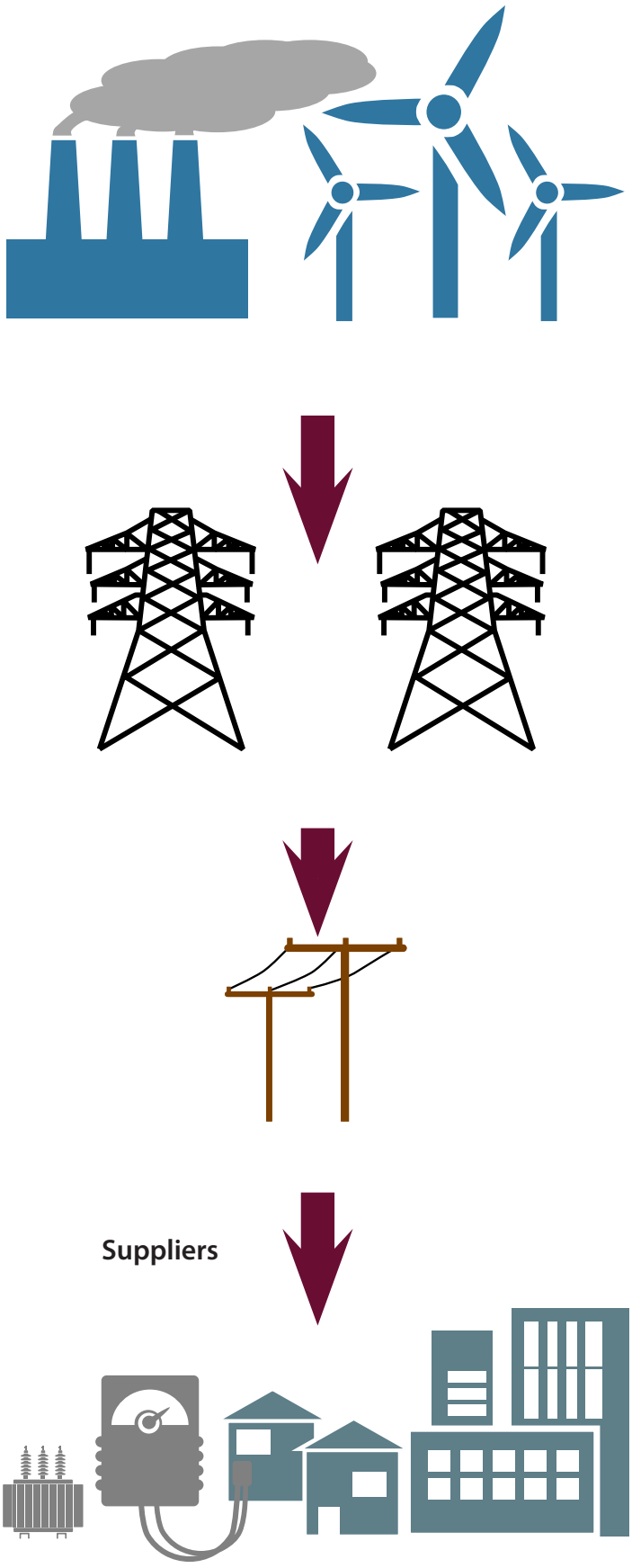
Cross-border electricity trading allows resources to be used more efficiently across wide regions, but they tend to increase prices in exporting countries while lowering prices for importers, which may be unpopular in nations that export more than they import (such as Norway). Britain generally has higher electricity prices than its neighbours and is therefore typically an importer of electricity, so it benefits from (slightly) reduced power prices. However, analysis of historic interconnector behaviour indicates that quite often we import when we don't need to, and export when GB demand is high and imports would be preferable. In addition, the rules governing the behaviour of interconnectors do not guarantee they will import to Britain during times of electricity shortages – they could even export instead.

Some countries, in particular Norway, are expressing doubts about their commitment to trading electricity, and have passed laws allowing them to suspend exports under certain conditions. They are also considering imposing export taxes in order to prevent domestic prices rising too much, which may reduce the availability of exports. Other countries may take a similar stance if they face electricity shortages. However, with weather conditions highly correlated across northern Europe and with many countries there relying on wind power, it is increasingly likely that national grids will face simultaneous shortages, and be unwilling to export. There have also been well-publicised acts of sabotage against cross-border gas pipelines, raising concerns over the security of all energy infrastructure.

All of this suggests that while interconnectors may benefit Britain under normal market conditions, they may not deliver at times they are needed the most, and that relying on them could be a risky strategy.

[1] https://www.nationalgrideso.com/document/283101/download

[2] 'Dunkelflaute' is a German term which means 'dark lull'. It describes a Dunkelflaute is a meteorological phenomenon when there is little to no solar and wind power generation due to unfavourable weather conditions - see https://capital.com/dunkelflaute-what-is-definition



Generation
Electricity is generated by power stations and windfarms etc.

Transmission system
Electricity from power stations is moved over long distances over the high-voltage transmission system.

Local distribution grids
Transformers step the voltage down for it to be carried over lower-voltage distribution networks.

End consumers
Ultimately, it is delivered to end-consumers (homes and businesses).

Figure 1: The UK electricity system

Background

The electricity industry is made up of four functions: generation, transmission, distribution and supply (Figure 1). Both generation and transmission are highly capital intensive and transmission is a natural monopoly.

The electricity system or 'grid' comprises the electricity substations, transformers, and power lines that connect electricity producers and consumers. This is normally divided into two distinct sections: the high-voltage transmission network and the lower-voltage distribution networks. Large sources of generation (power stations) and demand (large industrial users such as factories) connect directly to the transmission network, while other users (small generators and consumers such as houses and businesses) connect to the local distribution network.

Once produced, electricity travels along the grid infrastructure following the path of least resistance, at roughly the speed of light. As electricity is transmitted, energy is lost due to heating of the wires and other factors. These are known as 'line losses', and can be reduced by moving the electricity at higher voltages. This is why there is a distinction between the transmission, which uses high voltages to minimise line losses, and the local distribution networks, which use the lower voltages closer to those required by consumers.

Most transmission lines are high-voltage three-phase alternating current (AC), but over very long distances (more than 600–900 km[3]), line losses can be significant. For this reason, high-voltage direct current (HVDC) technology is used for very long-distance transmission, particularly in submarine power cables. Interconnectors are high-voltage cables that connect the electricity systems of neighbouring countries (or states in the case of the US) to one another. Interconnectors allow electricity to be traded between countries, with flows typically moving from the lower- to the higher-priced market.

National Grid ESO (NG ESO), the GB transmission system operator, say of interconnectors:[4]

> By sharing excess power, we can ensure renewable energy isn't wasted, and constraint payments[5] are minimised. For example, when weather conditions mean supplies from UK wind farms and solar are lower, we can draw on carbon-free sources of electricity through the interconnectors. On windy or very sunny days in Britain, excess renewable energy can be sent via an interconnector to neighbouring countries. By connecting Great Britain to broader and more diverse sources of energy, interconnectors can help overcome operability issues, which lowers costs to consumers.

Great Britain's electricity network is linked to networks in several other countries, including France, Norway, Netherlands, Belgium, and Ireland, via interconnectors that allow electricity to be traded and shared. These interconnectors currently have a total capacity of 8.4 GW and more are being built, potentially adding 16 GW by 2035. NG ESO modelling found that interconnectors will remain an important source of energy into GB in periods of highest need, and those imports are mostly expected to grow in absolute terms during periods of system stress.

Rules governing the behaviour of interconnectors

The contribution of interconnectors to GB energy security is laid out in the Capacity Market, a mechanism by which providers of electricity supply (including generators, batteries and interconnectors) agree to provide electricity during times of system stress (shortages), in exchange for guaranteed payments. Each contract holder must meet annual availability tests and must be available to provide the agreed electricity if NG ESO, the electricity system operator, declares that a system

3 https://www.cencepower.com/blog-posts/hvdc-transmission-systems

4 https://www.nationalgrideso.com/news/interconnectors-role-transitioning-net-zero

5 'Constraint payments' are payments made to renewable generators when they are unable to generate because of grid constraints. Many renewable generators receive subsidies which guarantee the price of the electricity they sell. These subsidies are necessary to allow them to borrow the money needed to pay for the cost of building the generation plant, and the payments are used to service the debt. If the generator is asked not to generate because there is not enough capacity on the power lines to deliver the electricity to consumers, they do not receive these subsidy payments, and are therefore paid a 'constraint payment' instead.

stress event is occurring.

The Capacity Market was introduced in recognition of the impact of intermittent renewable generation, such as wind and solar power, could have on energy security, for example when it is not windy or sunny other sources of electricity will be needed. At the moment, most capacity procured through the Capacity Market is gas-fired generation, but other forms of non-intermittent generation such as nuclear power, and non-generating sources of electricity such as batteries and interconnectors are also eligible. Some other European countries also operate capacity markets; these are similar but not identical to that operating in Britain.

Under Capacity Market rules, interconnectors only need to be operational during times of system stress – they do not need to be importing, and there are no mechanisms to force imports if the capacity has been sold to market participants for the purposes of exporting (although exports can be stopped). If the markets at each end of the cable have simultaneous system stress, then technically, there would be price competition between them to secure imports, but in reality, it is expected that system operators would intervene to float the cable, meaning power would not flow in either direction.

> Interconnector analysis has always been challenging. Firstly, because of their nature: they are transmission links but inject energy resources into the GB network like generators. Secondly, because an assessment of their contribution under stress events is quite hypothetical as there is an absence of sufficient historical evidence on flows under stress. As a consequence, the resource contribution and derating factor analysis is essentially model-based.
>
> Panel of Technical Experts: Report on the National Grid ESO Electricity Capacity Report 2023

The overall expected availability of interconnectors is captured in the Capacity Market de-rating factors. Each type of electricity source in the Capacity Market is awarded a 'de-rating factor', which represents the proportion of its nameplate capacity that it is expected to produce at any time. For example, a power station with a de-rating factor of 87% would be expected to generate 87 MW for every 100 MW of installed capacity. In the case of interconnectors, this reflects the amount of electricity it is expected to import and the ratio of imports to exports, as well as the likely availability of the interconnectors – for example, times when they are offline due to maintenance or faults.

The de-rating factors determined by the Government[6] in 2023 (Table 1) suggest that two thirds of available interconnector capacity would be available in a time of system stress, which is less than NG ESO[7] and the Panel of Technical Experts[8] (PTE) had recommended. (The PTE scrutinises the annual Electricity Capacity Reports (ECR) by NG ESO.)

However, as the PTE notes, this is purely hypothetical, and based on National Grid ESO's modelling. In 2020, Watt-Logic analysis[9] (Box 1) indicated that during periods of high winter demand, Britain often exports electricity: Britain exported electricity to Continental Europe during 13% of the hours with the top 5% of GB electricity demand during Winter 2020, while exports accounted for 16% of all hours over that period. Considering Winter 2019, which was less affected by Covid, Britain exported electricity to the Continent in 18% of all hours and 12% of the hours with the highest 5% of demand.

This analysis was subsequently updated[10] for 2022 and 2023. (In 2020 and 2021 electricity demand was significantly impacted by Covid, which is why these years are excluded from the analysis.) Across the two years, Britain exported in 23% of the top 5% of hours with the highest GB electricity demand. This higher figure was likely due to the specific situations in Norway and France in 2022: Norway experienced 20-year-low reservoir levels, while large parts of the French nuclear fleet were offline due to systemic technical problems.

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[6] https://www.gov.uk/government/publications/capacity-market-auction-parameters-letter-from-desnz-to-national-grid-eso-july-2023

[7] https://www.emrdeliverybody.com/Capacity%20Markets%20Document%20Library/Electricity%20Capacity%20Report%202023.pdf

[8] https://assets.publishing.service.gov.uk/media/64b5d6100ea2cb001315e436/panel-of-technical-experts-2023-report.pdf

[9] https://watt-logic.com/2020/12/10/fes-2020/

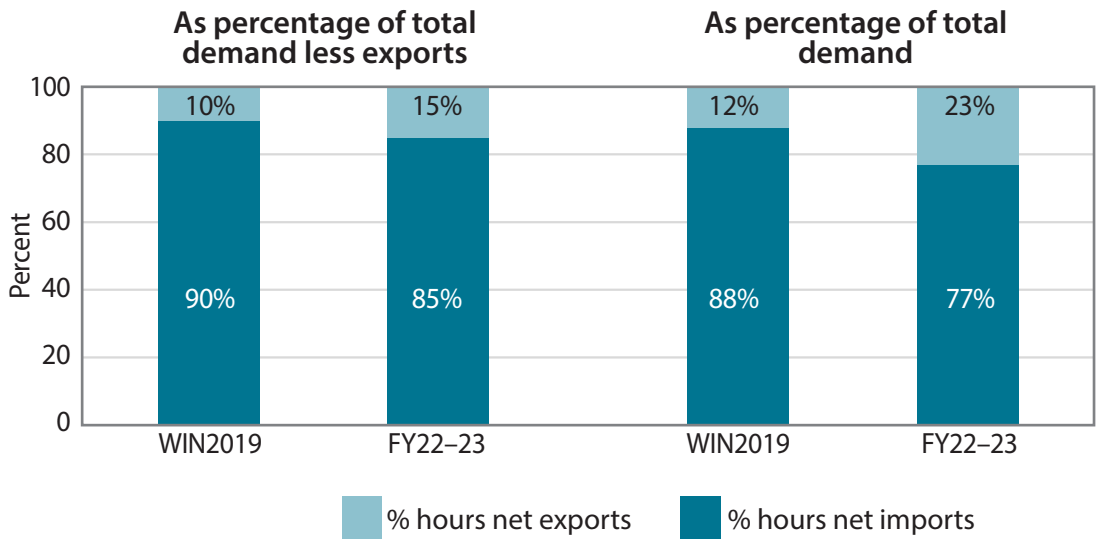
[10] https://watt-logic.com/2024/02/05/interconnector-imports-exports/

Table 1: Capacity market interconnector de-rating factors

Interconnector	Country	Capacity (GW)	De-rating factor (%)
IFA-1	France	2.0	59
IFA-2	France	1.1	60
Eleclink	France	1.0	64
BritNed	Belgium	1.2	61
Nemo	Netherlands	1.0	64
NSL	Norway	1.4	83
Viking	Denmark	1.5	55

Source: DESNZ.

Box 1: Interconnector flows during periods of high GB electricity demand



In the first two columns, GB electricity demand was calculated before exports and the top 5% of hours inspected to see if the interconnectors were importing or exporting overall (from/to continental Europe). In the second two columns, GB electricity demand includes the demand imposed on the system by exports.

NG ESO argues that the exclusion of the impact of exports on demand indicates that the amount of time Britain is exporting during periods of high domestic GB demand was 10% in Winter 2019 and 15% across 2022 and 2023, and that the figures are relatively insigificant.

While this is correct, the analysis indicates that exports impact the periods of overall high GB demand – 68 hours, which would not otherwise have been in the top 5% of demand, have their demand increased so much by exports that they enter this high demand bracket. High system demand is associated with higher prices and lower energy security. Prices rise if more expensive forms of generation have to be used to meet this increased demand, and security falls, because less generation is in reserve.

Source: Data from Gridwatch Templar, analysis Watt-Logic.

While Norwegian reservoir levels have recovered, the country has become increasingly wary of, if not hostile to, exporting electricity. In 2023 it declined to award a licence to the proposed NorthConnect[11] link with Scotland, and passed legislation[12] allowing it to suspend electricity exports in times of domestic shortages. It has subsequently proposed further legislation to allow export restrictions in the case of potential rather than actual shortages[13]. There have also been suggestions of the imposition of export taxes[14] in order to keep domestic prices down. In addition, parts of the ruling coalition have proposed[15] that when existing interconnectors with Denmark reach the end of their lives in the next couple of years, they should not be replaced.

The concerns with France are different. Twice in six years, large parts of the French nuclear fleet, the country's main source of electricity, have been out of action as a result of systemic problems – in 2016 due to problems with excess carbon in the steel used to build the reactors[16], and in 2021–22 due to stress corrosion[17] cracking in some of the cooling circuits. The French regulator has suggested that as the fleet ages, this situation could be repeated in future, and that there will not be a decision on further life extensions until 2026, meaning that some older plants could be forced to close this decade.[18] This means that the high levels of exports from the UK to France experienced in 2022 could well be repeated in future.

Risks and benefits of relying on interconnectors

Interconnectors provide certain benefits to the connected markets, the principal of which are the diversification of generation sources and access to cheaper electricity. Electricity flows from lower- to higher-priced markets, reducing differentials between them, and allowing resources to be used more efficiently across the wider region.

> The interconnector assets that connect GB to our European neighbours bring significant benefits to the UK and the interconnected market in terms of system security, consumer costs and reducing carbon emissions.
>
> National Grid ESO

The use of interconnectors also allows countries to outsource the construction of generation to other countries, meaning they avoid the upfront capital costs and risks associated with their construction (although they do incur some of the capital costs of the interconnector construction). Imports displace more expensive forms of domestic generation, reducing prices to consumers. Some people believe imports displace less green forms of generation, but this is coincidental – imports are only driven by price differentials not by generation type.

Interconnectors allow GB to access cheap imports

A key claim in relation to the benefits of interconnectors is that they reduce electricity prices for British consumers. NG ESO remains strongly committed to the use of interconnectors, only slightly reducing its interconnector capacity expectations in its 2024 Future Energy Scenarios,[19] despite

[11] https://www-regjeringen-no.translate.goog/no/aktuelt/avslag-pa-konsesjonssoknad-om-bygging-og-drift-av-northconnect-kabelen/id2966715/?_x_tr_sl=no&_x_tr_tl=en&_x_tr_hl=en&_x_tr_pto=sc

[12] https://www-regjeringen-no.translate.goog/no/aktuelt/bedre-styring-av-forsyningssikkerheten/id2960788/?_x_tr_sl=auto&_x_tr_tl=en&_x_tr_hl=en-GB

[13] https://www-regjeringen-no.translate.goog/no/aktuelt/styrker-forsyningssikkerheten-for-kraft/id3017651/?utm_source=regjeringen.no&utm_medium=email&utm_campaign=nyhetsvarsel20231208&_x_tr_sl=auto&_x_tr_tl=en&_x_tr_hl=en-GB

[14] https://www.reuters.com/business/energy/norway-may-tax-power-exports-keep-domestic-prices-down-2023-02-15/

[15] https://us.firenews.video/tech-media/vedum-wants-to-cut-two-of-the-power-cables-to-denmark-populist-frivolous-and-easy/

[16] https://www.french-nuclear-safety.fr/asn-informs/news-releases/edf-reactor-steam-generators-in-service-could-contain-an-anomaly

[17] https://www.french-nuclear-safety.fr/asn-informs/news-releases/stress-corrosion-phenomenon-detected-on-reactors

[18] https://www.lemonde.fr/en/environment/article/2023/01/24/french-nuclear-safety-authority-considers-extending-reactors-beyond-60-years-of-operation_6012884_114.html

[19] https://www.nationalgrideso.com/future-energy/future-energy-scenarios-fes/fes-documents

Ofgem's recent 'minded-to' decision[20] to decline all but one of the new interconnector projects proposed under the third cap and floor window (the mechanism through which interconnector subsidies are provided).

In its consultation document relating to this decision, Ofgem says its current work confirms the views formed in its 2021 Interconnector Policy Review,[21] which concluded (among other things) that 'the net welfare impact of future GB interconnection is likely to be positive. However, we expect a shift in the allocation of some welfare benefits from consumers to producers, and between GB and the connecting countries.' It should be noted that typically those producers are in receipt of subsidies which are paid for by consumers.

> Interconnectors are no longer expected to predominantly be a source of cheap electricity imports as they have been when the cap and floor regime was first established, but instead going forward will become a way of providing flexibility and enhancing security of supply in a renewables-dominated energy system.
>
> - Ofgem

In its analysis, Ofgem says that while interconnectors allowed GB to access cheap imports when it had some of the highest electricity prices in Europe, over time, British electricity prices are expected to fall, leading to a higher level of exports which would increase GB electricity prices compared with the situation where no exports take place. This is true for countries which currently export to Britain, and explains why Norway in particular has become much less supportive of cross-border trading, since it has experienced significant domestic price rises since it opened large electricity interconnectors with GB and Germany in 2022.

As noted earlier, there have been political interventions in Norway which may mean that exports from the country are restricted. As Norway has the lowest weather correlation with Britain of all the markets to which Britain is connected, this would have a disproportionate impact on Britain's ability to access imports. 70% of Norwegians believe that high power prices in the country are caused by cross border power cables[22], creating political opposition to greater interconnection with neighbouring countries.

> 'We must have control that we have enough power in Norway. The bottom line for this is our own security of supply. We must be sure that we always have enough water in our reservoirs. There must always be electricity in the socket and we must have enough power for our industry,'
>
> – Jonas Gahr Støre, Prime Minister of Norway

Norway is not the only country to become lukewarm on interconnection - Sweden has recently rejected plans for an interconnector with Germany on the basis that it would be detrimental to connect the Swedish power market to the 'inefficient' German market.

Interconnectors contribute to security of supply

Supporters of interconnectors argue that they increase security of supply, allowing Britain to import electricity when it cannot generate enough at home to meet demand. If this were happening efficiently, we would import electricity when our generation, particularly wind output, was low, and export when it was high.

During 2022–23, imports only met 4.3% of Britain's electricity demand, similar to the contribution of solar power (4.4%), which is only available during daylight hours and not at all during periods of peak winter demand. Some imports also occur at times when they are not really needed and the impact on prices is minimal – for example when wind generation is high.

Watt-Logic analysis[23] of 2022–23 data indicated that during 8% of hours it was windy in all countries (the Continental European countries to which we are connected, plus Germany) and GB imported (Box 2). In 5% of hours it was not windy in all countries and we exported. GB exported in 7% of hours when we had low wind generation – i.e. when imports would have been preferable – and received imports in 13% hours when we had high wind generation – i.e. when exports

[20] https://www.ofgem.gov.uk/consultation/initial-project-assessment-third-cap-and-floor-window-electricity-interconnectors

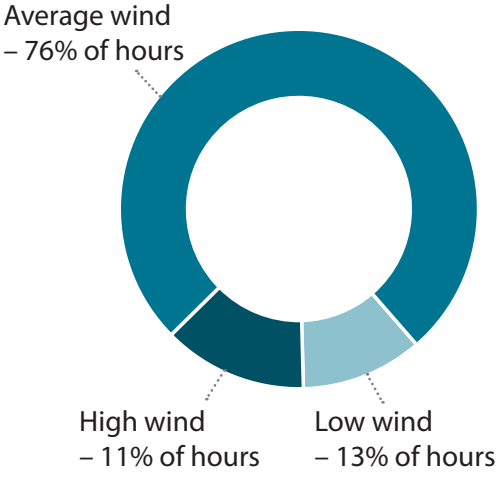
[21] https://www.ofgem.gov.uk/decision/interconnector-policy-review-decision

[22] https://energywatch.com/EnergyNews/article16616144.ece

[23] *Relying on interconnectors for imports carries risks (*https://watt-logic.com/2024/02/05/interconnector-imports-exports/

Box 2: High and low wind output* and interconnector behaviour, 2022–23

GB and its interconnected neighbours†



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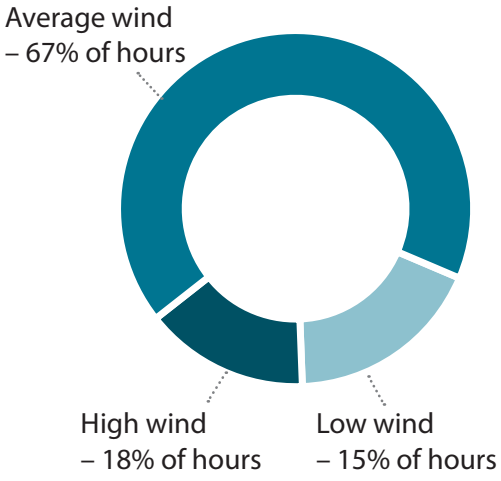
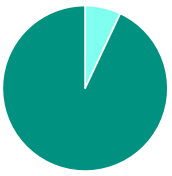


Although there were no flows between GB and either Denmark or Germany during the period, the supply and demand balance in these countries impacts both the connected countries and GB, so they were included in the analysis.

GB imported during 13% of high wind hours, when exports would have been preferable.



GB exported during 7% of low wind hours, when imports would have been preferable.

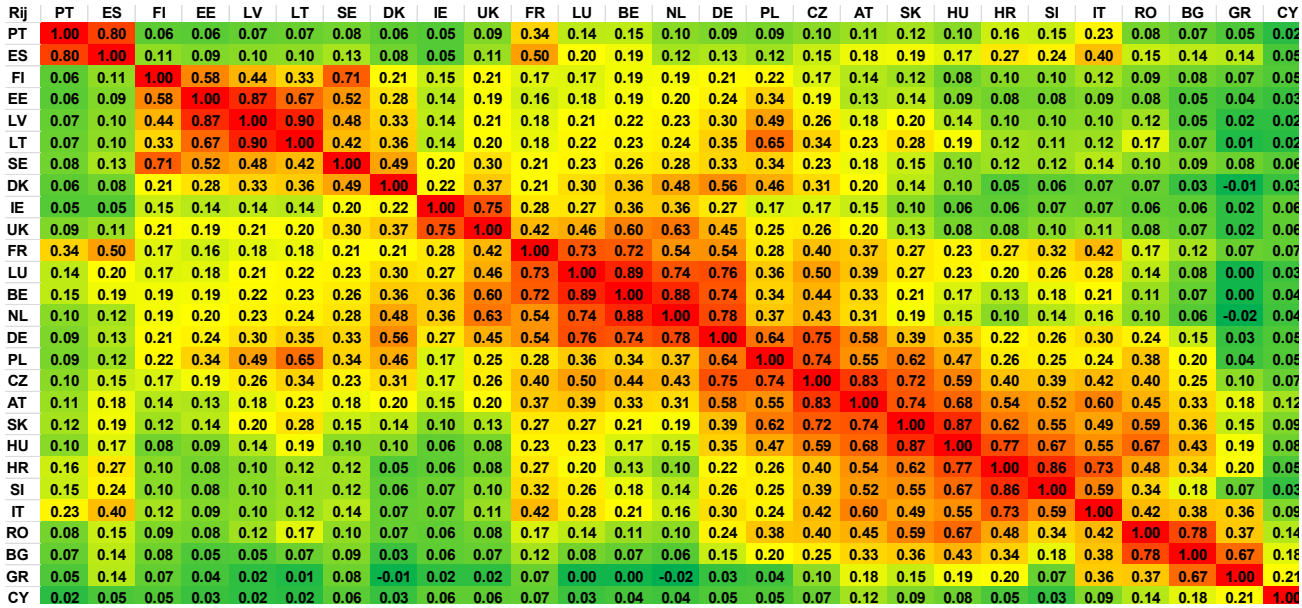
*Defined as more or less than one standard deviation from the mean. †France, Belgium, the Netherlands, Norway, Denmark and Germany.

would have been preferable (regardless of the wind levels in the other countries).

In support of interconnectors, it is sometimes claimed that 'it is always windy somewhere', implying that low wind conditions in GB can be offset by windy conditions elsewhere. But this analysis shows that, for a not insignificant amount of time, this is not true. In 11% of hours there was high wind in both GB and the other nearby countries, and in 13% of hours wind was low in all countries (which is equivalent to just under one day per week).

This analysis also highlights the fact that geographic proximity tends to result in high weather correlation.[24] The heat map in Figure 2 shows the correlation in wind power production between pairs of countries – the higher the correlation, the redder the colour. Countries located close to each other have a high correlation of wind generation since they share similar weather. As many countries in north-west Europe (in fact most countries, except for Norway and France) are following a strongly wind-led energy transition, and most of the markets with which Britain is connected may experience similar weather patterns at the same time, leading to either simultaneously high wind generation producing widespread surpluses or low wind resulting in widespread shortages.

[24] https://www.sciencedirect.com/science/article/pii/S1364032115017013



Rij	PT	ES	FI	EE	LV	LT	SE	DK	IE	UK	FR	LU	BE	NL	DE	PL	CZ	AT	SK	HU	HR	SI	IT	RO	BG	GR	CY
PT	1.00	0.80	0.06	0.06	0.07	0.07	0.08	0.06	0.05	0.09	0.34	0.14	0.15	0.10	0.09	0.09	0.10	0.11	0.12	0.10	0.16	0.15	0.23	0.08	0.07	0.05	0.02
ES	0.80	1.00	0.11	0.09	0.10	0.10	0.13	0.08	0.05	0.11	0.50	0.20	0.19	0.12	0.13	0.12	0.15	0.18	0.19	0.17	0.27	0.24	0.40	0.15	0.14	0.14	0.05
FI	0.06	0.11	1.00	0.58	0.44	0.33	0.71	0.21	0.15	0.21	0.17	0.17	0.19	0.19	0.21	0.22	0.17	0.14	0.12	0.08	0.10	0.10	0.12	0.09	0.08	0.07	0.05
EE	0.06	0.09	0.58	1.00	0.87	0.67	0.52	0.28	0.14	0.19	0.16	0.18	0.19	0.20	0.24	0.34	0.19	0.13	0.14	0.09	0.08	0.08	0.09	0.08	0.05	0.04	0.03
LV	0.07	0.10	0.44	0.87	1.00	0.90	0.48	0.33	0.14	0.21	0.18	0.21	0.22	0.23	0.30	0.49	0.26	0.18	0.20	0.14	0.10	0.10	0.10	0.12	0.05	0.02	0.02
LT	0.07	0.10	0.33	0.67	0.90	1.00	0.42	0.36	0.14	0.20	0.18	0.22	0.23	0.24	0.35	0.65	0.34	0.23	0.28	0.19	0.12	0.11	0.12	0.17	0.07	0.01	0.02
SE	0.08	0.13	0.71	0.52	0.48	0.42	1.00	0.49	0.20	0.30	0.21	0.23	0.26	0.28	0.33	0.34	0.23	0.18	0.15	0.10	0.12	0.12	0.14	0.10	0.09	0.08	0.06
DK	0.06	0.08	0.21	0.28	0.33	0.36	0.49	1.00	0.22	0.37	0.21	0.30	0.36	0.48	0.56	0.46	0.31	0.20	0.14	0.10	0.05	0.06	0.07	0.07	0.03	-0.01	0.03
IE	0.05	0.05	0.15	0.14	0.14	0.14	0.20	0.22	1.00	0.75	0.28	0.27	0.36	0.36	0.27	0.17	0.17	0.15	0.10	0.06	0.06	0.07	0.07	0.06	0.06	0.02	0.06
UK	0.09	0.11	0.21	0.19	0.21	0.20	0.30	0.37	0.75	1.00	0.42	0.46	0.60	0.63	0.45	0.25	0.26	0.20	0.13	0.08	0.08	0.10	0.11	0.08	0.07	0.02	0.06
FR	0.34	0.50	0.17	0.16	0.18	0.18	0.21	0.21	0.28	0.42	1.00	0.73	0.72	0.54	0.54	0.28	0.40	0.37	0.27	0.23	0.27	0.32	0.42	0.17	0.12	0.07	0.07
LU	0.14	0.20	0.17	0.18	0.21	0.22	0.23	0.30	0.27	0.46	0.73	1.00	0.89	0.74	0.76	0.36	0.50	0.39	0.27	0.23	0.20	0.26	0.28	0.14	0.08	0.00	0.03
BE	0.15	0.19	0.19	0.19	0.22	0.23	0.26	0.36	0.36	0.60	0.72	0.89	1.00	0.88	0.74	0.34	0.44	0.33	0.21	0.17	0.13	0.18	0.21	0.11	0.07	0.00	0.04
NL	0.10	0.12	0.19	0.20	0.23	0.24	0.28	0.48	0.36	0.63	0.54	0.74	0.88	1.00	0.78	0.37	0.43	0.31	0.19	0.15	0.10	0.14	0.16	0.10	0.06	-0.02	0.04
DE	0.09	0.13	0.21	0.24	0.30	0.35	0.33	0.56	0.27	0.45	0.54	0.76	0.74	0.78	1.00	0.64	0.75	0.58	0.39	0.35	0.22	0.26	0.30	0.24	0.15	0.03	0.05
PL	0.09	0.12	0.22	0.34	0.49	0.65	0.34	0.46	0.17	0.25	0.28	0.36	0.34	0.37	0.64	1.00	0.74	0.55	0.62	0.47	0.26	0.25	0.24	0.38	0.20	0.04	0.05
CZ	0.10	0.15	0.17	0.19	0.26	0.34	0.23	0.31	0.17	0.26	0.40	0.50	0.44	0.43	0.75	0.74	1.00	0.83	0.72	0.59	0.40	0.39	0.42	0.40	0.25	0.10	0.07
AT	0.11	0.18	0.14	0.13	0.18	0.23	0.18	0.20	0.15	0.20	0.37	0.39	0.33	0.31	0.58	0.55	0.83	1.00	0.74	0.68	0.54	0.52	0.60	0.45	0.33	0.18	0.12
SK	0.12	0.19	0.12	0.14	0.20	0.28	0.15	0.14	0.10	0.13	0.27	0.27	0.21	0.19	0.39	0.62	0.72	0.74	1.00	0.87	0.62	0.55	0.49	0.59	0.36	0.15	0.09
HU	0.10	0.17	0.08	0.09	0.14	0.19	0.10	0.10	0.06	0.08	0.23	0.23	0.17	0.15	0.35	0.47	0.59	0.68	0.87	1.00	0.77	0.67	0.55	0.67	0.43	0.19	0.08
HR	0.16	0.27	0.10	0.08	0.10	0.12	0.12	0.05	0.06	0.08	0.27	0.20	0.13	0.10	0.22	0.26	0.40	0.54	0.62	0.77	1.00	0.86	0.73	0.48	0.34	0.20	0.05
SI	0.15	0.24	0.10	0.08	0.10	0.11	0.12	0.06	0.07	0.10	0.32	0.26	0.18	0.14	0.26	0.25	0.39	0.52	0.55	0.67	0.86	1.00	0.59	0.34	0.18	0.07	0.03
IT	0.23	0.40	0.12	0.09	0.10	0.12	0.14	0.07	0.07	0.11	0.42	0.28	0.21	0.16	0.30	0.24	0.42	0.60	0.49	0.55	0.73	0.59	1.00	0.42	0.38	0.36	0.09
RO	0.08	0.15	0.09	0.08	0.12	0.17	0.10	0.07	0.06	0.08	0.17	0.14	0.11	0.10	0.24	0.38	0.40	0.45	0.59	0.67	0.48	0.34	0.42	1.00	0.78	0.37	0.14
BG	0.07	0.14	0.08	0.05	0.05	0.07	0.09	0.03	0.06	0.07	0.12	0.08	0.07	0.06	0.15	0.20	0.25	0.33	0.36	0.43	0.34	0.18	0.38	0.78	1.00	0.67	0.18
GR	0.05	0.14	0.07	0.04	0.02	0.01	0.08	-0.01	0.02	0.02	0.07	0.00	0.00	-0.02	0.03	0.04	0.10	0.18	0.15	0.19	0.20	0.07	0.36	0.37	0.67	1.00	0.21
CY	0.02	0.05	0.05	0.03	0.02	0.02	0.06	0.03	0.06	0.06	0.07	0.03	0.04	0.04	0.05	0.05	0.07	0.12	0.09	0.08	0.05	0.03	0.09	0.14	0.18	0.21	1.00

Figure 2: Correlation between wind power produced in pairs of EU countries

Source: Monforti et al.

It is not really clear what would happen if several connected markets experienced shortages at the same time. Under normal conditions, electricity flows from the lower- to the higher-priced market, and when markets are short, their prices rise. Without intervention, this could result in a price war between countries, as each tried to out-bid the other in attracting imports. It is unlikely that system operators would allow this to happen.

NG ESO says that it has 'has mechanisms in place to influence flows over the interconnectors that can be used in periods of system stress, allowing them to reverse the flow direction, if necessary'. However, these are not unilateral powers – the operators of the electricity systems at the other ends of the interconnectors have similar powers. Should both nations linked through an interconnector experience system stress at the same time, it is unclear what would happen, but it is likely there would be no flows in either direction, with each country acting to restrict exports in order to prevent their system stress becoming worse. A bidding war would not be in anyone's interests, and would undermine public confidence in cross-border electricity trading.

Other energy transition effects will also have an impact. Currently, most domestic heating in Britian is powered by natural gas, but in France, most homes use electricity. When temperatures drop, electricity demand increases in France much faster than it does in Britain, and France moves from exporting electricity to importing, including from Britain. But the UK Government and governments elsewhere in Europe also have plans to electrify heating, meaning that winter electricity demand will be much higher and more temperature sensitive than it is today. This could well disrupt cross-border electricity flows, with more countries taking the same approach as Norway, protecting their domestic consumers before allowing exports.

Even where countries are willing to export, they may be unable to. Interconnectors may be unavailable due to maintenance and repair requirements, or there may have been accidental damage such as that caused by a ship's anchor to four of the eight cables of IFA-1, the oldest interconnector between Britain and France in 2016.[25] When subsea cables experience damage or technical faults, they can take many months to repair. Recent events in Europe, with the acts of sabotage

[25] https://assets.publishing.service.gov.uk/media/5aa2aa56ed915d4f595c5232/MAIBInvReport03_2018.pdf

against the Nord Stream[26] and Balticconnector[27] gas pipelines, illustrate another risk to availability: deliberate sabotage. Bad actors have shown a willingness to attack energy infrastructure, and electricity cables are just vulnerable as gas pipelines.

Interconnectors reduce emissions

The claim that interconnectors reduce emissions by replacing dirty GB generation with clean imports is only true because imported energy is not included in GB emissions data, irrespective of the source of the electricity. In other words, it does not matter whether the electricity is generated by a coal power station or a windfarm, the impact on GB emissions is the same. However, this is just an accounting trick.

In reality, it does matter what the source of electricity is in terms of overall climate impact. And the truth is that it's a mixed bag. Imports from France and Norway are certainly low carbon, being derived from nuclear and hydro power respectively. But the interconnector with the Netherlands is supplied by a coal-fired power station (which now also co-fires with wood-pellet biomass, which has higher stack emissions than coal). In fact, this interconnector essentially involved the outsourcing of emissions, since a planned coal-fired power station at the GB end of the cable (Kingsnorth D) was cancelled in favour of the interconnector, and a new coal-fired power plant (MPP3) opened in the Netherlands instead.

In any case, interconnector flows are only determined by price. There is no mechanism to ensure that only clean electricity is imported. Similarly, when prices in Europe are higher than in Britain, coal- and gas-fired power stations may be required to start up in order to supply additional exports from GB to Europe, directly increasing GB emissions.

Conclusion

Each year the vulnerability of the GB power system grows as reliable thermal and nuclear generation is replaced with intermittent renewable generation, primarily wind. However, wind lulls can coincide with periods of high system demand (anti-cyclonic weather systems characterised by cold, still weather in winter, and hot, still weather in summer) and can last for days or even weeks, certainly beyond the capacity of any currently existing batteries to back up. They can also strike several countries at the same time.

So far, there has not been a system stress event, triggering delivery under Capacity Market rules, but each year the risk increases. However, the performance of interconnectors in such an event is described by experts as entirely 'hypothetical'. A combination of high weather correlation, political sensitivities and physical risks could all threaten the ability of Britain to attract imports at times of need. Relying on interconnectors could prove to be a huge gamble, and one we will only know we have lost when it is too late. Britain should ensure that it has sufficient sources of domestic generation to meet demand if it is to maintain a secure and robust power system.

[26] https://www.gov.uk/government/speeches/the-sabotage-of-the-nord-stream-pipelines-should-be-treated-with-utmost-seriousness-uk-statement-at-the-security-council

[27] https://www.politico.eu/article/balticconnector-damage-likely-to-be-intentional-finnish-minister-says-china-estonia/

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