Data and model for

Implications of the *National Energy and Climate Plans* for the Single Electricity Market of the island of Ireland

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The following spreadsheets may be downloaded to check and rerun the calculations presented in the paper
SEM wind data 2018 gives the raw wind output by quarter hour, aggregates to hours, and normalises to a constant end 2018 wind capacity to give hourly SEM wind output for a representative (2018) wind year
EU surplus 2018 gives the excess of projected 2026 wind plus inflexible nuclear *less* 2026 load projected as in the Appendix below. If positive SEM cannot export, if negative SEM can export until it raises the number to zero or it meets the export constraint
SEMNEP2026 aggregates all these data sources to project the amount of wind in the model sheet as explained in the notes to that spreadsheet. The model can be re-run with different values inserted into the green boxes to find the effect of changing these values.

If you find any errors, please contact dmgn@cam.ac.uk

[1] The author is an independent member of the Single Electricity Market Committee of the island of Ireland but this paper is written as an independent academic and only draws on published sources. It does not reflect the views of the SEM Committee. I am indebted to comments from an EPRG referee.

Appendix Renewables targets from NECPs

Great Britain

Future generation and load are taken from the Two Degree Scenario in *Future Energy Scenarios* (National Grid, 2019) to find the ratio of annual 2026 projected output from each element to that in 2018.
The scaling factors are: 0.7 for nuclear, 3.53 for off-shore wind, 1.53 for on-shore wind and 1.33 for solar PV and 1 for run-on-river hydro.

France

According to France's PLAN NATIONAL INTEGRE ENERGIE-CLIMAT de la FRANCE Mars 2020 (NECP)[2] (and via Google translate)
In France there are several "stages" of nuclear reactors: …
· EPR: 1 reactor of 1600 MW which should be commissioned in 2023.

On nuclear power it is proposed to "Postpone to 2035 the prospect of reducing the nuclear share to 50% of the production mix of electricity" (p123).
Apart from closing Fessenheim in 2020 (1,840MW), closures will not start until 2029. Coal plants will close by 2022, so the major nuclear phase-out is deferred.[3]

The main sectors for producing electricity from renewable energy are as follows (capacities at December 31, 2018):
· 25.5 GW of hydraulics: hydraulic capacity has been stable since the late 1980s;
· 15.1 GW of wind power; 8.5 GW of solar; 2.0 GW of bioenergy.
Total electricity production in France reached 548.6 TWh in 2018. It exported 86.3 TWh and imported 26.1 TWh, representing an export balance of 60.2 TWh. Consumption = 489 TWh.
"The energy transition law for green growth has set a target of 40% renewable energy in final electricity consumption in 2030. Wind power is planned to increase from 11,7GW in 2016 to 24,1GW in 2023 and to either 33,2GW or 34,7GW in 2028. PV rises from 10,2 GW in 2018 to 20,1 GW in 2023 and 35,1- 44,0 GW in 2028.

Scaling factors from 2018: PV by 2.6; Wind 26/15 = 1.73; (presumably more offshore, less onshore; nuclear assume unchanged as EPR replaces retirements.

[2] At https://ec.europa.eu/energy/sites/ener/files/documents/fr_final_necp_main_fr.pdf
[3] See https://www.gouvernement.fr/en/multiannual-energy-programme-what-are-its-aims

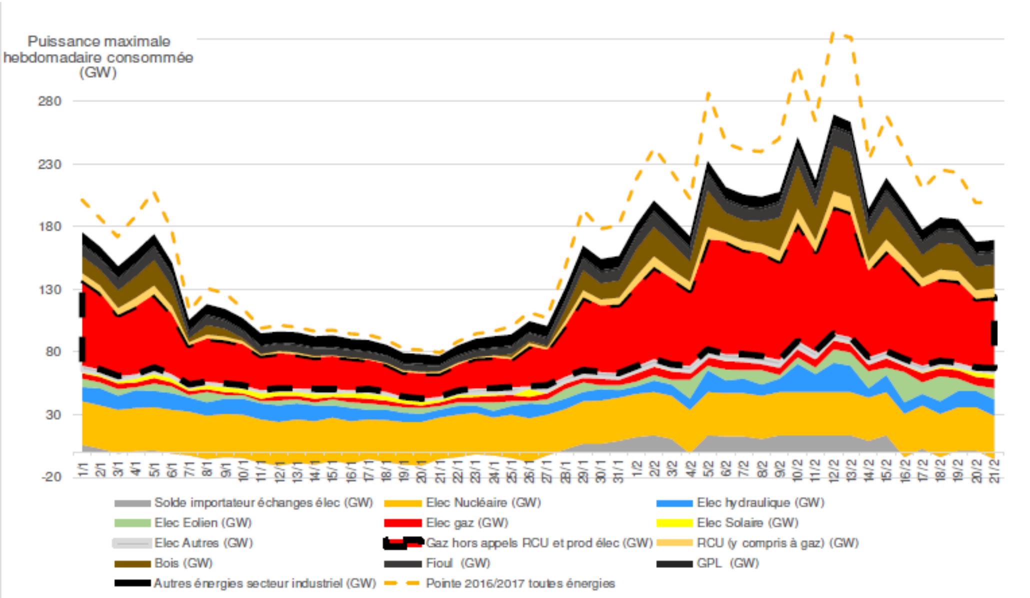

Figure 34 All-energy French power demand curve in 2028 (p182)

Belgium

According to the Draft of *Belgium's Integrated National Energy and Climate Plan 2021-2030* (NECP),[4] "A major change in the energy mix following the phasing out of nuclear power by 2025, with 5,918 MW of decommissioned nuclear capacity having to be replaced." (NECP, p12). Belgium is opting for an energy mix based on flexible capacity, load shifting, storage and renewable energy. The renewables share in electricity will be 40.4% by 2030 (21% in 2018). Wind capacity is shown in 2018 as 3.36 GW (1.2 off-shore, 2.16 onshore) The NECP contains high ambitions for offshore wind, with an expected 4 GW of total installed capacity by 2030. However, the onshore target of 4.2 GW is relatively low. The current draft of the plan incorporates a complete nuclear phase-out by 2025. (Source: https://windeurope.org/newsroom/news/belgium-energy-and-climate-plan-proposes-renewable-energy-target-of-18-3-by-2030/)

The country's cumulative installed PV capacity reached 4.82 GW at the end of 2019 an increase of 0.5 GW on 2018 so 2018 = 4.3 GW. Estimated consumption 2018 84 TWh. At the end of March 2018 the government reaffirmed its phase-out policy and said that it would introduce capacity payments. Elia said that at least 3.6 GWe of new thermal capacity would be needed by the end of 2025. According to the NECP, biomass decreases and Offshore wind does not increase before 2025.

Scaling factors for 2026: nuclear phase-out, 50% increase in on-shore wind, double PV.

Netherlands

The *Integrated National Energy and Climate Plan 2021-2030* (NECP)[5] states "The approach thus focuses on these sources:

i. Generating circa 49 TWh wind energy offshore by 2030;

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[4] At https://ec.europa.eu/energy/sites/ener/files/documents/ec_courtesy_translation_be_necp.pdf

[5] At https://ec.europa.eu/energy/sites/ener/files/documents/nl_final_necp_main_en.pdf

ii. Generating 35 TWh of renewable energy (wind energy and solar power) on land;
iii. Small-scale generation of renewable electricity from, for example, private solar panels, good for circa 10 TWh.

• From 2030, the use of coal to generate electricity will be prohibited by law. The bill offers companies the option of switching to alternative fuels.

• In addition to the ETS, the Netherlands is introducing a national and gradually increasing minimum price for CO2 emissions in electricity generation. This minimum price contributes to increased sustainability and investment security.

With this commitment, the share of renewable electricity of total electricity generated in 2030 is expected to amount to 70 percent."

Total is 94 TWh, which if 70% makes total generation makes that 134 TWh in 2030. 2018 demand was 116 TWh, and 2025 is projected at 114 TWh (Table 4.5). To address security of supply, "interconnection capacity is expected to double from 5.55 GW in 2016 to 10.8 GW in 2025." (NECP, 3.3i)

Table 4.6 The Netherlands' interconnection capacity in megawatts (Source: PBL, 2019a)

Capacity in megawatts	**2019**	**2020**	**2025**	**2030**
Connection				
NL-DE	3950	4250	5000	5000
NL-BE (BE-NL)	1400 (2400)	1400 (2400)	3400	3400

Scaling: On-shore wind and PV: 3.5; off-shore: 10 (from a low base).

Germany

Germany's *Draft Integrated National Energy and Climate Plan* (NECP)[6] states that "Taking into account this dismantling of capacity, around 300 TWh of Germany's electricity will be generated from renewable energy sources in 2030. … A further goal enshrined in the coalition agreement is that of increasing the share of renewables in gross electricity consumption to around 65 % by 2030. Depending on gross electricity consumption, this requires the generation of between 360 and 400 TWh of electricity using renewables, or an installed renewables capacity of between 180 and 200 GW; this calls for a significant acceleration in the growth of renewables." (p34).

"Scenario A 2030 assumes net electricity consumption of 512.3 TWh, whereas Scenario B 2030 assumes net electricity consumption of 543.9 TWh and Scenario C assumes net electricity consumption of 576.5 TWh."

Nuclear will be phased out by 2023. 2018 Consumption is 556.5 TWh

Installed capacity in GW	**Baseline 2017**	**Scenario A 2030**	**Scenario B 2030**	**Scenario C 2030**
Onshore wind	50.5	74.3	81.5	85.5
Offshore wind	5.4	20.0	17.0	17.0
Photovoltaics	42.4	72.9	91.3	104.5
Biomass	7.6	6.0	6.0	6.0
Hydropower	5.6	5.6	5.6	5.6
Other renewables	1.3	1.3	1.3	1.3
Total	112.8	180.1	202.7	219.9

[6] At https://ec.europa.eu/energy/sites/ener/files/documents/ec_courtesy_translation_de_necp.pdf

In 2020 Germany has 49 GW solar PV and onshore wind of 59 GW and over 4 GW off-shore wind in 2018. So if the 2025 targets are midway to 2030, and if PV increases to 100 GW, offshore to 20 GW, onshore wind needs to be 95-117 GW.

Scaling factors for 2026: zero nuclear; multiplying PV and on-shore wind by 1.5 and off-shore wind by 2.5, then both renewables and zero-carbon electricity would be 55% of 2018 grid load.

Spain

According to the NECP, Final electricity demand from non-energy sectors is 232 TWh in 2015, 241 in 2020 and 246 TWh in 2025 (p 240). Recently, the electricity exchange capacity between Spain and France has doubled (from 1,400 MW to 2,800 MW). … An increase in the interconnection capacity with France is planned with the following extensions:

- an interconnection between Aquitaine (FR) and the Basque Country (ES), through a submarine cable through the Bay of Biscay, which will allow the interconnection capacity between Spain and France to reach 5,000 MW;
- an interconnection between Aragon (ES) and Pyrénées-Atlantiques (FR) and an interconnection between Navarre (ES) and Landas (FR), which will increase the interconnection capacity between Spain and France to 8,000 MW.

Gross electricity generation in the Target Scenario* (GWh)

Years	**2015**	**2020**	**2025**	**2030**
Wind (onshore and offshore)	49,325	60,670	92,926	119,520
Solar photovoltaic	8,302	16,304	39,055	70,491
Solar thermoelectric	5,557	5,608	14,322	23,170
Hydroelectric power	28,140	28,288	28,323	28,351
Storage	3,228	4,594	5,888	11,960
Biogas	743	813	1,009	1,204
Geothermal energy	0		94	188
Marine energy	0		57	113
Coal	52,281	33,160	7,777	0
Combined cycle	28,187	29,291	23,284	32,725
Coal cogeneration	395	78	0	0
Gas cogeneration	24,311	22,382	17,408	14,197
Petroleum products cogeneration	3,458	2,463	1,767	982
Other	216	2,563	1,872	1,769
Fuel/Gas	13,783	10,141	7,606	5,071
Renewables cogeneration	1,127	988	1,058	1,126
Biomass	3,126	4,757	6,165	10,031
Cogeneration with waste	192	160	122	84
Municipal solid waste	1,344	918	799	355
Nuclear	57,196	58,039	58,039	24,952
Total	**280,911**	**281,219**	**307,570**	**346,290**

Scaling from actual 2018 to 2026: wind 1.9, PV 4.4.

Appendix D SEM Wind capacity and correlations of wind output with GB

Figure D1 shows wind capacity in IE from two sources (which only give the year of commissioning, not the date), and similarly figure D2 shows more granular data for NI wind capacity (with date of commissioning for the Ofgem data but only the year for the Eirgrid data) (both TSO and DSO connected).

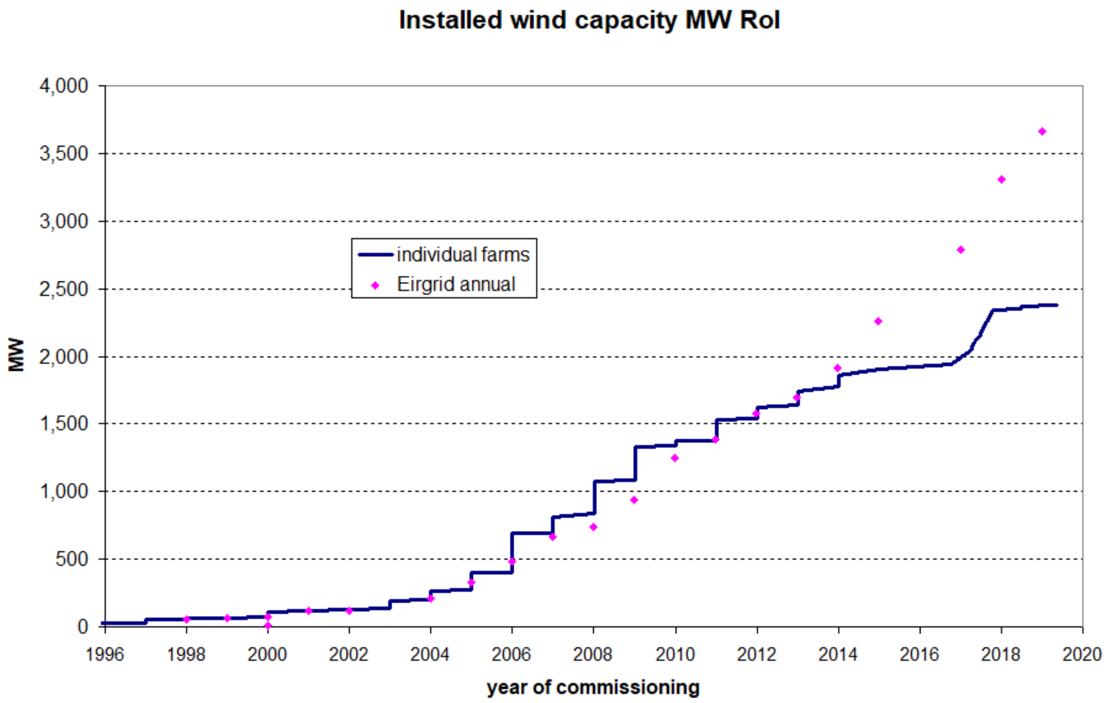

Figure D1 Cumulative wind capacity in Ireland 1996-2019

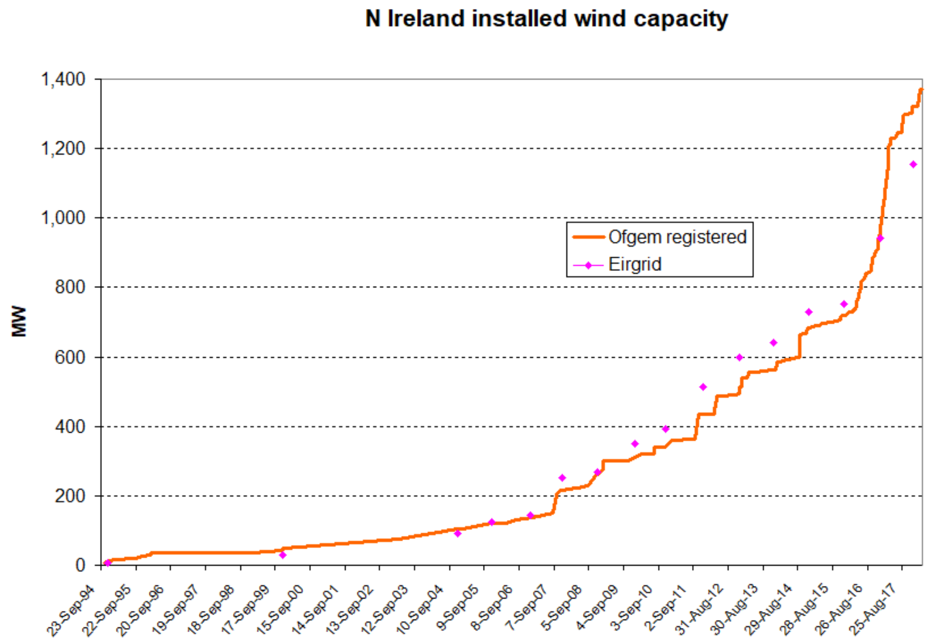

Figure D2 Cumulative commissioned wind capacity in Northern Ireland 1994-2017

Wind output correlations with GB

First impressions are that the correlation of hourly wind output in the SEM and GB (at least over the two whole years 2016-17) is essentially zero (and also over just the winter months). Figure D3 shows the scatter plot of October 2016 to March 2017 – the winter period of higher demand (and wind).

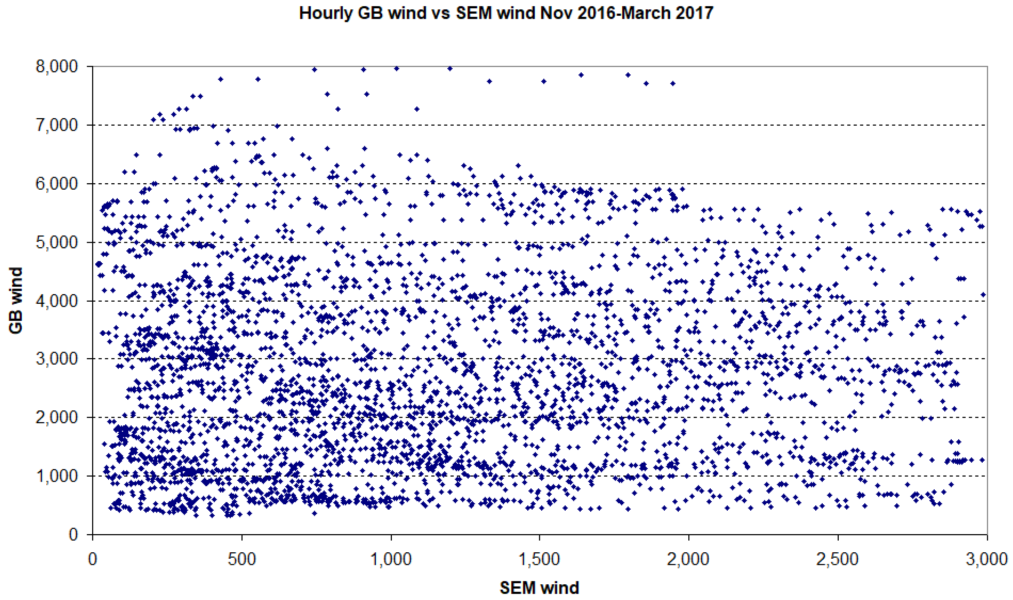

Figure D3 Scatter plot of hourly wind generation in GB against SEM, winter 2016/17

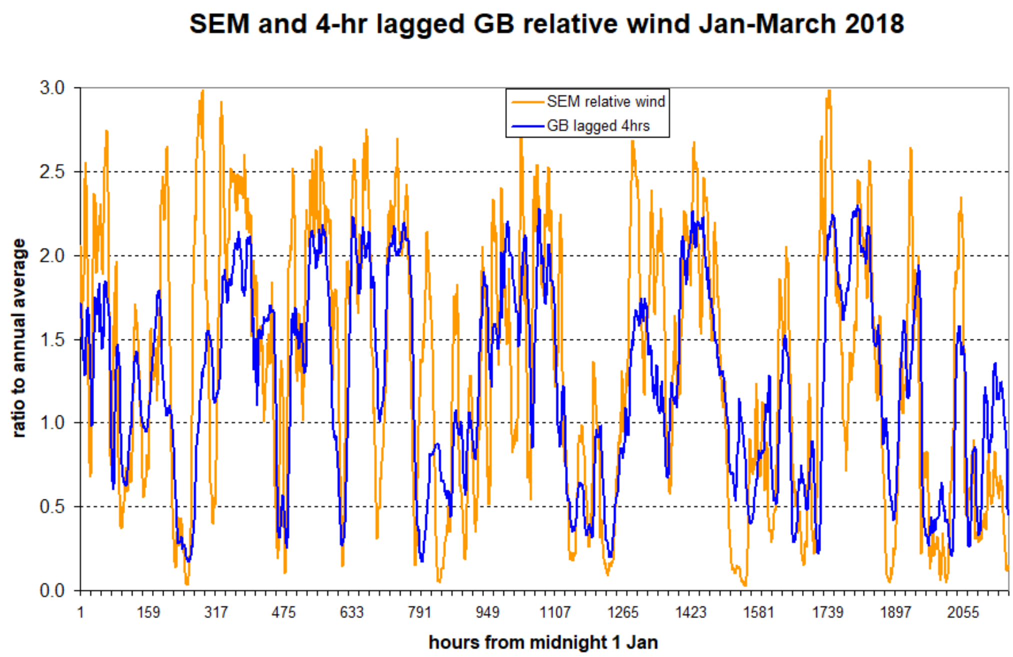

Figure D4 relative wind in GB 4 hours later than relative wind in SEM, Jan-March 2018

However, a more careful study of the kind undertaken by Weiss and Wänn (2013) reveals a closer correlation between current SEM wind output and 4-hour lagged GB wind output, as figures D4 and D5 reveal using more recent data.

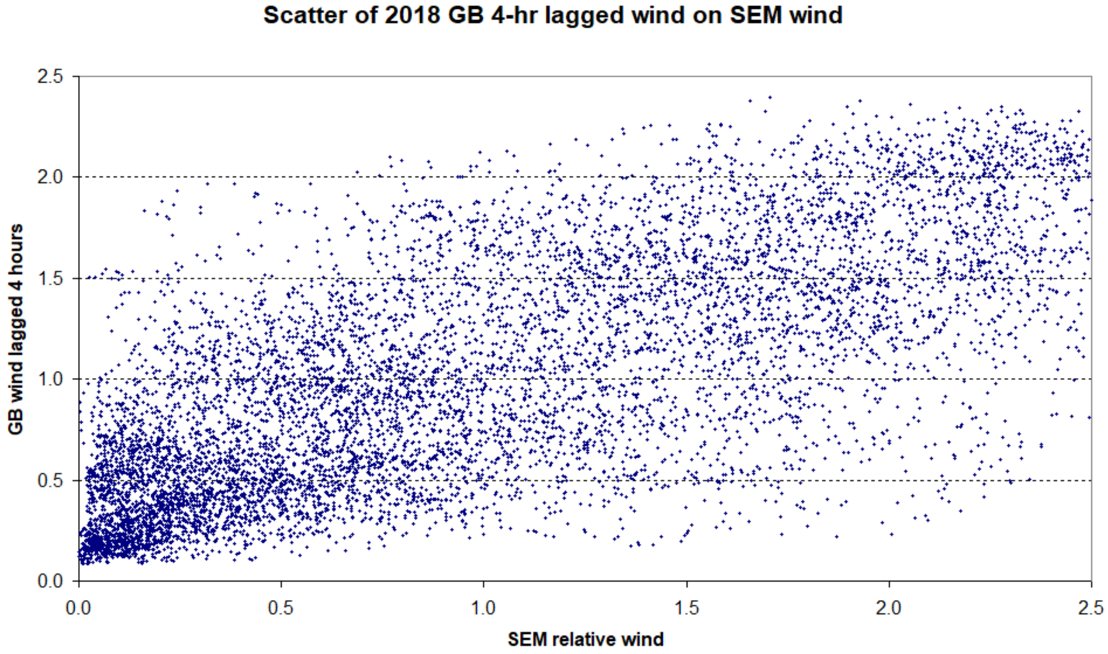

Figure D5 Scatter plot of lagged wind in GB on wind in the SEM, 2018

Correlations across neighours

Figure D6 first derives the wind duration curve for each country separately, scaled to a 40% average penetration, and then the result of adding each country's output in that hour to give the total, and then deriving its wind duration curve. The aggregate curve is flatter, and would exceed twice the average for a considerably smaller fraction of the time.

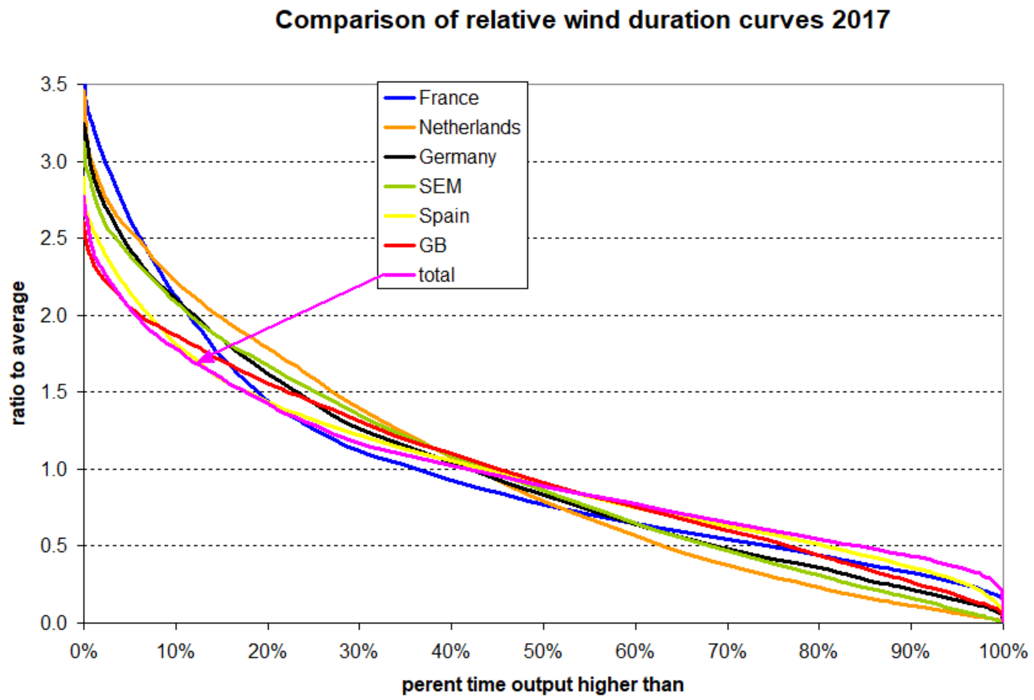

Figure D6 Comparison of isolated and aggregated wind duration curves for 2017.

Table D1 gives the percentage of the time each isolated country would exceed double the average wind penetration, and the amount of wind lost as a percentage of the total wind potentially available (ignoring any curtailment). The amount that would have to be curtailed if each country were isolated (at double average wind) ranges from 5.9% to 15.9% with a weighted average of 11.2%, whilst averaging over all these countries would reduce curtailment to 5.5% (the "total" line in table 1).

Table D1 Impact of aggregating wind

	curtailed	lost
SEM	11.4%	27.3%
GB	5.9%	13.0%
FR	11.5%	29.9%
DE	12.0%	28.9%
ES	7.3%	16.6%
NL	14.7%	35.9%
BE	15.9%	39.0%
DK	14.0%	33.4%
total	5.5%	12.3%
wted av.	11.2%	27.5%

Similarly, the amount of wind generation that would have been lost had it been curtailed at the individual country level varies from 13% to 39% (again with smaller countries having a higher variability and hence more potential curtailment, and larger countries and those like GB with a large share of off-shore wind with less variability). Aggregating the potential loss falls to 12.3%. In each case aggregating wind across these countries more than halves the damaging aspects of variability.

Appendix E SEM Wind variability and scaling

Figure E1 compares the results of taking the 2015 Load and Wind as a basis for scaling up to 2026 and 2018 data, in each case scaling to 55% wind and the same average loads. The two sets of duration curves are almost identical, suggesting that the choice of base year is relatively unimportant, provided they are scaled to the same 2026 conditions.

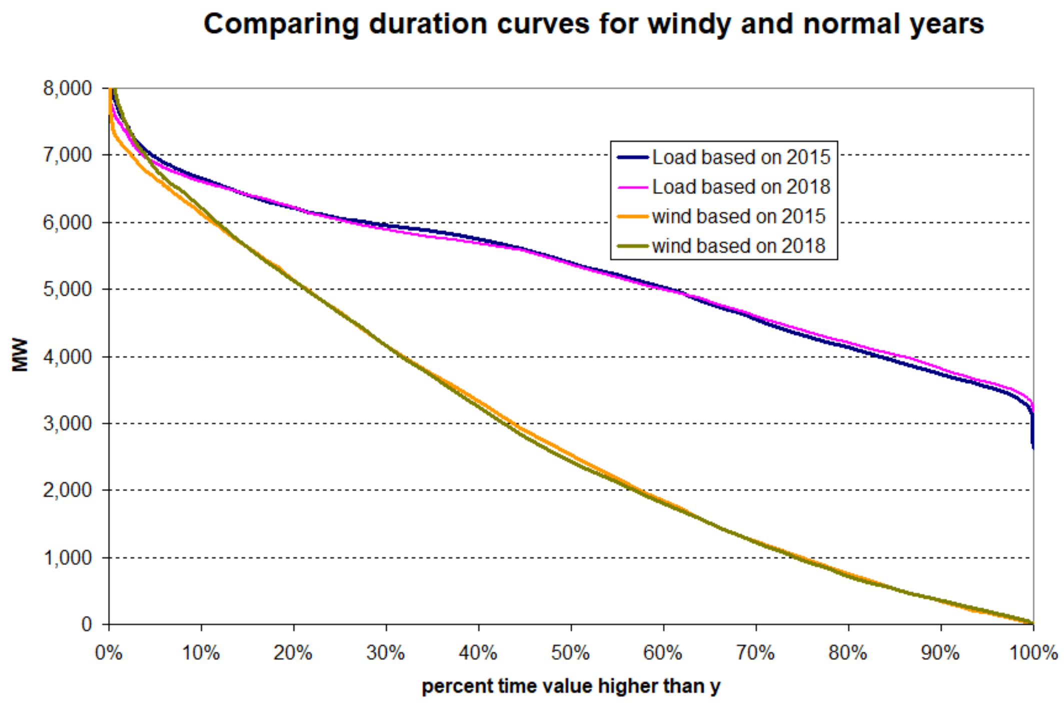

Figure E1 Comparing duration curves based on 2015 and 2018 wind and load data