Dr Alan Jones

Independent Researcher

The Role of Wind Generation

1 Introduction

There is now universal agreement that renewable generation, as a sustainable energy source, is an important part of the energy mix in so far as it helps reduce dependence on fossil-fuels, minimises anthropogenic carbon emissions and thereby assists in mitigating climate change – in a similar way to the use of nuclear energy, but without the concerns for safety and the need for long-term storage of radioactive waste.

The rapid growth of renewable generation over the last decade, in the form of wind and solar, and especially on-shore wind, has led to the realisation that the UK's existing high voltage electricity transmission infrastructure, which was designed around conventional power stations located in accessible, built up areas is no longer compatible with distributed renewable generation that tends to be located in more remote rural locations. Consequently, the growth of on-shore wind, especially in Scotland, along with offshore wind and solar, which is mainly in England and Wales, as the leading forms of renewable generation are the drivers behind the need for new transmission infrastructure that can transmit this renewable energy from the point of generation to where demand exists.

Wind energy, which is the subject this paper, differs from conventional, dispatchable generation in so far as it is intermittent, with the output determined by the strength of the wind at any point in time. Consequently the integration of onshore wind power as the preferred (lowest marginal cost of generation) source of energy into the energy mix available on the electrical transmission network introduces a number of issues - such as balancing supply and demand, guaranteeing security of supply and energy storage, and in the case of infrastructure – in ensuring the capacity, and hence size and scale of any new transmission system needed to convey wind energy meets the requirements rather than exceeds them. This paper explores some of these issues - the efficacy of using wind power, and especially onshore wind, to help balance Great Britain's (GB) supply and demand.

2 The Wind Fleet

It is difficult to give a precise figure for the installed capacity (MW) of the GB wind fleet for two reasons. Firstly, figures change with time as new wind farms are installed, commissioned and brought into service, which means the UK Government renewable reporting statistics that tend to be published once each year can be a year out of date. Secondly, many wind turbines and smaller wind farms are embedded directly into local distribution networks which means they are not visible to National Grid as Energy System Operator (NGESO)[i].

This embedded generation, which also includes the majority of early solar[ii], tends to be consumed locally via the distribution network and hence acts to reduce the apparent demand on distribution and transmission networks rather than contribute directly to the available generation under the control of NGESO to balance demand with supply. Similar comments apply to other forms of renewable electricity, including: hydro; biomass and waste; sewage and landfill gas, and anaerobic digestion that connect to the network at 132kV or lower in England and Wales. In Scotland, because of the traditionally smaller load on the network, 132kV is considered part of the transmission network.

To put these comments into context the total installed GB renewable capacity (MW) in 2021 (the latest figures available) is shown in Table 1, where these data are collated into national figures compiled from each Local Authority region.[iii] The figures in each cell represent the embedded generation – sometimes called 'behind the meter generation,' along with the generation available to NGESO. In other words each cell represent a combined value and to give an idea of how this is split (between embedded and available to NGESO) Table 2 is included.

It is apparent from Table 1 that Scotland provides the major portion of GB onshore wind and hydro capacity while England supplies the majority of offshore wind, along with solar and biomass/waste – the latter from Drax and the Ferrybridge Multifuel station in Yorkshire and the Humber. Wales, meanwhile provides a similar capacity of onshore wind to solar in which solar capacity is almost 3x that of Scotland.

Although not apparent from Table 1 it is interesting to note that five Local Authority areas in Scotland, between them, provide 40% of the entire GB onshore wind capacity: Highland 1888MW; South Lanarkshire 1241MW; Dumfries & Galloway 799MW; South Ayrshire 652MW and the Scottish Borders at 641MW.

Table 1 GB Installed Renewable Capacity (MW) in 2021

Nation	Onshore Wind	Offshore Wind	Solar PV	Hydro	Biomass & Waste	Sewage, Landfill Gas & A/D	Total (MW)
England	3075.5	9585.7	11899.0	44.1	5522.3	1557.4	31684
Scotland	8674.3	945.8	455.1	1658.9	342	184.8	12261
Wales	1283.3	724.0	1213.2	167.9	219.3	80.0	3688
TOTAL (MW)	13033	11256	13567	1871	6084	1822	47633

Source: National Statistics – Regional Renewable Statistics – Renewable Electricity by Local Authority, Published 7 November 2022

3 The Future for Wind and Other Renewables

The installed capacity data shown in Table 1 are expected to increase significantly according to NG in its Electricity Ten Year Statement 2022 (NG ETYS 2022), where all scenarios show an increase in wind capacity between 11000-25000MW (11-25GW) in which the development of further wind generation in Scotland is key to reaching the UK and Scottish Government's targets for 50GW of offshore and 20GW of onshore wind respectively by 2030.

Table 2, which is taken from NG ETYS 2022 Appendix F (Contracted Generation), illustrates the scale of the potential additional generating capacity waiting to access the transmission grid, and hence come under the control of NGESO for balancing purposes, within the next decade or so.

The data from Table 2 (under current installed capacity) can be contrasted against that of Table 1 (approximately, as although they both represent 2021 the dates of publication vary). What this comparison shows is that almost 50% (6698.2/13033.1) of the currently installed GB onshore wind capacity is under the control of NGESO and the remainder embedded, whereas all offshore wind is connected to the transmission network via a grid supply point and hence monitored and controlled by the system operator. Interestingly, all current solar PV capacity appears to be embedded, but that is likely to change with 7581.75MW planned for future transmission connection.

Table 2 also shows almost 16GW of onshore wind (mainly Scotland) and 110GW of offshore wind (mainly in the North Sea and coming onshore in England) waiting for transmission connection and held at some stage in the consenting process – from scoping to commissioning. However, this scale of increase is unlikely to materialise[iv], or even reach the UK Government target of 50GW for offshore wind, simply because of delays in government planning and approvals processes that includes new transmission infrastructure, where it can take 13 years or more to move from concept to operation.[v] These processes may simplify in future to speed up this process.

There is no doubt though, that with this scale of ambition, both Scotland and England, and possibly Wales, will see significant demands for new transmission infrastructure, in the form of overhead pylons, to convey this additional generation from remote rural sites (in the case of onshore wind) and from landing points (for offshore wind) to new grid supply points to enable this remote generation to reach the point of demand.

Table 2 National Grid Electricity Ten Year Statement 2022 – Contracted Generators

	Onshore Wind (MW)	Offshore Wind (MW)	Solar (MW)
Current Installed Capacity	6698.2	12635.5	0.0
Waiting[vi]	15988.1	111236.0	7581.75
TOTAL (MW)	22686.3	123871.5	7581.75

Source: NG ETYS 2022, Appendix F Contracted Generation

4 Turning Capacity into Energy

The installed capacity figures in Table 1 and the further expansion shown in Table 2 refer to power output – the power available at a single point in time. What an investor is interested in though, is energy (MWh), or power multiplied by time, because it is on this basis that investors receive a return on capital employed.

The theoretical energy output over a year can simply be calculated by multiplying the capacity rating by the hours in a year (8760 – unless a leap year). However, because of many factors, both operational and naturally occurring - such as breakdowns, ageing, constraints on the network, varying wind speeds in the case of wind turbines, seasonal and daily variation in solar irradiance in the case of solar PV, or variations in rainfall in the case of hydro, the actual energy output is reduced below the theoretical value. This ratio of actual/theoretical (multiplied by 100 to produce a % value) is known as the load factor, which varies for each renewable technology.

Table 3 shows the load factors from GB renewable technologies for 2021. Perhaps surprisingly, Wales had the highest load factor for onshore wind which, in terms of investor return, means onshore wind in Wales, and England too, is a more attractive financial proposition than Scotland, were it not for the fact that planning consent is easier to achieve in Scotland.

This load factor comparison does not necessarily mean the average wind speed in Wales and England was higher than Scotland in 2021. Another implication is that there were outages and curtailments for some large Scottish wind farms during this period because of transmission network constraints. If this were the case then it is likely to continue for some years, or even a decade or more, until large (multi-£bn) transmission infrastructure projects are approved, funded, built and commissioned, and ultimately paid for by consumers.[vii] In the meanwhile, further expansion of onshore wind in Scotland will only exacerbate the situation, if this indeed was the problem.

It can be seen too from Table 3 that English waters provide the highest return from offshore wind while England and Wales achieves more energy output per unit of installed capacity than Scotland from solar PV, which is in keeping with the relative annual solar irradiance in these countries.

Table 3 GB Load Factors by technology on an unchanged configuration basis[viii]

	Onshore Wind %	Offshore Wind %	Solar PV %	Hydro %	Biomass and Waste %
England	23.3	39.2	10.7	35.2	69.7
Scotland	23.1	34.0	8.3	33.2	67.4
Wales	25.6	29.3	10.6	22.5	77.7

Source: DBE&IS (2022) Regional renewable electricity in 2021

5 The Nature of Wind Energy Output Characteristics

Conventional fossil-fuel generation is classed as dispatchable in so far as either additional units or a reduction of units of generation can be planned long in advance, or alternatively within several minutes, and dispatched to the transmission network as needed, barring unforeseen events, to balance supply with demand.

Wind energy, on the other hand, does not have the same degree of certainty in the level of power output at any point in time although sophisticated forecasting is used as a prediction tool. Wind energy is therefore classed as intermittent, and because of the low cost of generation[ix] is employed on the transmission network when and where it is available, subject to network constraints, ahead of other forms of fossil-fuel generation.

In order to evaluate and characterise the output of wind power (or capacity) and the part it plays in the GB transmission network a simple model has been employed based on data available to and employed by NGESO. Here, data for contracted generation over the period

January 2015 to June 2016 shows NGESO monitored and had network control over a total of 7303MW of installed capacity comprising both onshore and offshore wind[x].

Five minute interval data for wind generation capacity was taken from the GB Balancing Mechanism Reporting Service (BMRS)[xi] run by Elexon Limited[xii] and two intervals, each of one month, were identified as representing a winter period and a summer period when wind was at a minimum. These 5-minute interval data was normalised by dividing by the total installed capacity (7303MW) to present a % probability plot comparing winter (maximum – 1 January 2015 to 1 February 2015) against the summer (minimum – 16 May 2016 to 16 June 2016).

Figure 1, therefore, illustrates the historic probability of the percentage of time the combined GB fleet of on and offshore wind exceeded a percentage of the total connected wind capacity at that time. From this graphical representation it is apparent that the summer and winter characteristics are significantly different, although the degree of difference will vary year by year. One might expect, *ceteris paribus* – that all things being equal, if plotted each month throughout the year a series of curves would result enveloped by the summer month with the least wind and the winter month with a higher average wind speed.

By way of explanation, the way the characteristic curves can be interpreted is as follows: in the case of the winter month, 90% of the time the output from the GB fleet was over 20% of the combined (on and offshore) rating of 7303MW while the output only exceeded 80% for 10% of the time. On the other hand the summer time, which is significantly lower, shows that for almost 90% of the time the output exceeded 5%, but only exceeded 40% for around 10% of the month and at no time did it exceed 50%.

One must remember these data represent the combined on and offshore wind performance and if were possible to display onshore wind alone then the curves would be depressed (lower) and vice versa for offshore wind. Support for this statement comes from National Grid in its Summer Outlook Report, 2016 where it estimated, for planning purposes and based on the previous year/s out-turn, that onshore wind contribution to the transmission grid would achieve a 16% load factor. In other words, on average through the summer of 2016 the energy (MWh) available to the grid was estimated at only 16% of the theoretical value.

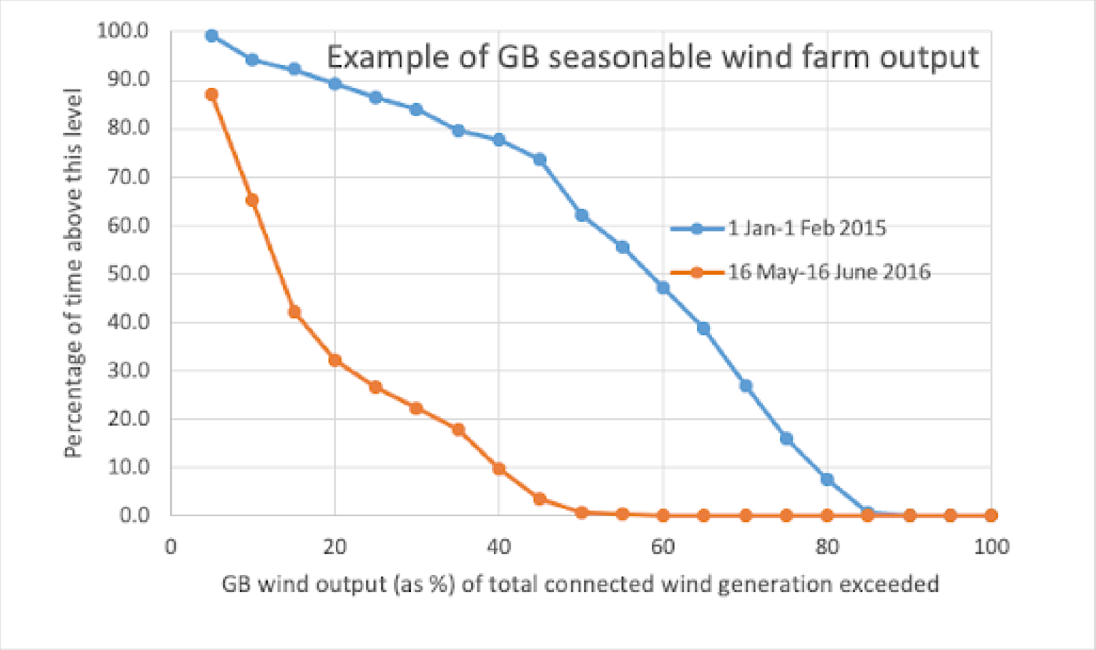

Figure 1 Historic model of GB wind (combining on and offshore wind connected to the transmission network) for 2015-2016 winter and summer periods

What the characteristic curves in Figure 1 seek to demonstrate is the intermittent nature of wind power. The term, intermittent, however, does not convey the full meaning of the nature of wind and the difficulty of utilising power generated through this means on a transmission network. For instance, intermittent does not simply mean the output will be present or not present; the term stochastic would be a better description – having a random probability that is difficult to predict. For instance, the output may or may not be present, the output varies with time and the output (at some or no value) may exist for one or more days at a time, but it's difficult to predict if and for how long. All in all a challenging combination to control as far as balancing supply and demand. One that requires fossil-fuel generating stations, fully staffed, properly maintained and operationally ready to respond within minutes. And all at a cost to the electricity consumer.

6 A Closer look at Onshore Wind

The conclusions drawn from Figure 1 are limited to appreciating the intermittent nature of wind power because of the need to combine onshore and offshore generation data – being the only data on generation freely available in the public domain. This next section aims to examine the characteristics of onshore wind alone using a different approach in order to arrive at more specific conclusions.

Historical daily average wind speeds for GB during 2022 has been taken from a weather data site[xiii] that, in turn, takes information from the Met Office Integrated Data Archive System (MIDAS). These wind speed measurements, taken at a height of 10m, have been converted to 100m, 125m and 150m to represent the wind speeds at typical hub heights for a range of onshore wind turbine applications[xiv].

This wind speed data has been combined with a relatively simple turbine model[xv] to determine the full conversion to output power based on a cube law curve given by:

$$P = \tfrac{1}{2}\, n_u\, p\, pi\, R^2\, U^3 \qquad \text{equation 1}$$

where n_u represents the overall efficiency, p represents the air density and $pi\ R^2$ represents the area swept by the turbine blades - where R is the blade radius.

This model assumes factors other than U, the wind speed, are constants, which means that the output power is a function of the cube of the wind speed and where the rated power output occurs at 15m/s and cut-in occurs at 3m/s (the speed at which the turbine begins to turn, and hence generate), and shuts down for safety at 25m/s. The model is also normalised (the rated power output at 15m/s is represented as 100%) so that the model can be applied to all the various sizes of wind turbine contained in the GB onshore wind fleet.

By applying the 2022 GB daily mean windspeed, corrected for different hub heights, to the normalised model it is possible to obtain a relationship between the number of days the GB onshore wind fleet power output was less than a certain percentage of the GB onshore fleet capacity. It is also possible to show how this varies with turbine hub height.

Figure 2 shows this relationship in which it can be seen, for example, that at 100m hub height there are around 30 days during 2022 during which the output from the GB wind fleet failed to exceed 20% of capacity and for 80 days did not exceed 60% of capacity. By contrast, at 150m hub height these same capacity levels equated to a lesser number of days – in this case, approximately 25 and 70 days respectively.

Figure 2, unlike Figure 1, illustrates in practical terms the limitations of wind power in providing a dependable source of electricity generation. It also illustrates this dependence is marginally improved by employing taller hub heights, although the economic advantage here comes from developers being able to utilise longer turbine blades (R) to increase the capacity rating (which is a function of R^2) of the wind turbine.

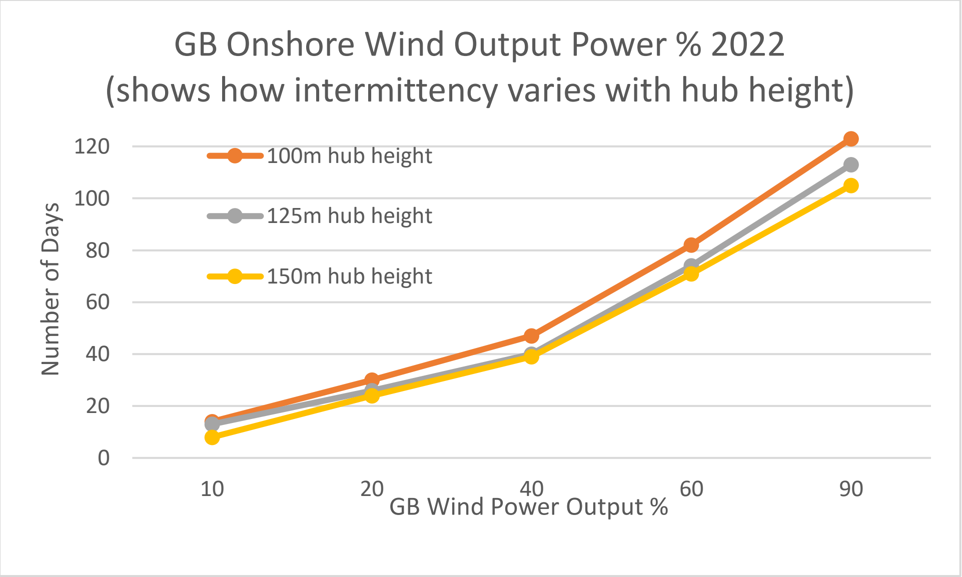

Figure 2 Showing relationship between GB wind power output (%) and the number of days below this level for various turbine hub heights

Other research[xvi] along similar lines to this approach, but based on 1-hour data collected over a much longer timeframe (2005-2013), finds this reduced output exists for much longer periods. For instance, and in this case, GB wind fleet output power is less than 20% for 3448 hrs, or 144 days each year compared to the 30 days shown in Figure 2.

This excess finding extends across all output levels and is likely due to the use of 1-hour sampled wind speed data compared to the daily average windspeed employed used in constructing Figure 2, in which daily averaging eliminates any short-term (hour by hour, or less) variation in output.

This alternative research also finds the most frequently occurring output power level is 8% of the total GB wind fleet capacity while the probability that the fleet achieves full capacity is vanishingly small. It would appear, therefore, from the basis used in this paper that using daily average windspeed most likely generates conservative outcomes – in reality the impact from intermittency is likely to be worse than reported here.

This model-based approach, using the methodology described, albeit conservative in nature, is used to provide an additional layer of detail - to determine the maximum number of consecutive days the combined output remained below a certain level. Figure 3 shows this information.

It can be seen from Figure 3 that the combined output remained less than 10% of capacity (power in MW) for three consecutive days and below 60% for seven days. Note that the 100m and 125m hub height curves are hidden with the 150m curve superimposed on top suggesting that increasing the hub height provides no advantage in this particular circumstance.

One comment worthy of mention, as it is discussed later, is the daily average wind speed data corresponding to Figure 3 shows the consecutive daily lull in GB onshore wind generation occurred over the winter period (10-18 January 2022) when the seasonal demand for electricity was high. A similar lengthy consecutive period, again during winter, occurred between 6-17 December 2022.

The short-term implication is clear: the need for suitably scaled fossil-fuel back-up generation, in the form of gas (backed up by coal when gas is limited), is a necessity. However, the longer term implication is also clear. A GB electricity generation system dependent on intermittent renewable energy and free of fossil-fuels will require large-scale energy storage capacity capable of lasting one or more days, not simply an hour or two – that is unless electricity cuts and/or rationing becomes an acceptable norm for business and domestic consumers going forward.

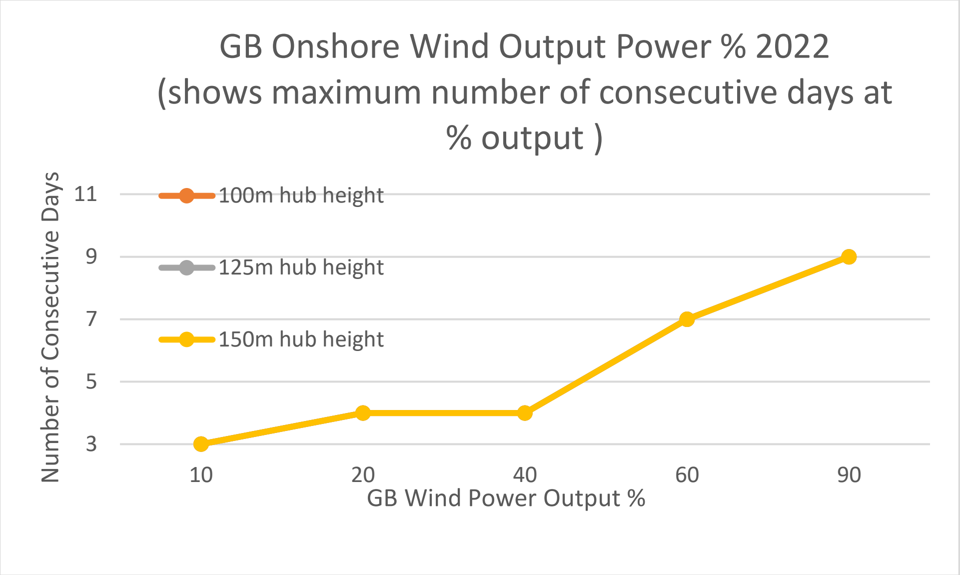

Figure 3 Showing relationship between GB wind power output (%) and the maximum number of consecutive days below this level for various turbine hub heights

7 Discussion

Although it was probably unintended, the more onerous planning laws in England and Wales has led to a proliferation of onshore wind in Scotland because of looser planning requirements and proactive support for renewable energy by the Scottish Government. This has caused, and will continue to cause, for much of each year at least, a distortion in the flow of power from remote areas of Scotland, where wind farms are usually cited, to where demand exists in England and Wales.

This distortion has already led to transmission network constraints for which the consumer pays via their electricity bill, but with the predicted level of future expansion of onshore wind in Scotland and offshore wind in England the transmission network will require significant levels of capital expenditure over the next decade or more to be able to utilise all this additional energy.

Here lies the rub: the unintended consequence – whoever imagined that support for renewable electricity would lead to the wholesale expansion of 400kV overhead pylon transmission lines simply because the existing transmission system is a) in the wrong place and b) insufficiently rated to carry all this renewable electricity. And while many people may support the expansion of onshore wind farms – providing they do not live close to an intended site, very few, if any, would wish to live in proximity to an overhead transmission network.

What Figure 1 seeks to do is to illustrate the intermittent and seasonal nature of electricity generated from wind. The graph, while based on actual generation information from Elexon, combines onshore and offshore wind power and therefore presents a more positive picture than what would have been available from onshore wind alone, because offshore wind power is sustained at higher levels and offers a more secure supply compared to that onshore.

What this graph does highlight though, is the effect large scale weather patterns have both on the seasonal nature of wind power (winter to summer) and also the characteristic shape of wind power. In this case the winter period is typical of a period of lower electricity demand where high pressure is centred over France and Spain with low pressure over Iceland. This stronger than average pressure difference across the North Atlantic resembles the positive phase of the North Atlantic Oscillation[xvii] (NAO) with associated stronger westerly winds and higher air temperatures. The summer phase, by comparison, typically sees weaker wind speeds and warmer temperature and hence lower air density. As equation 1 shows, both factors combine to reduce the output power from wind turbines in the summer months.

Figures 2 and 3 take a different approach – seeking to examine onshore wind alone. Here, a simple model of a wind turbine is used to represent the GB onshore wind fleet, which together with the GB daily mean wind speed is used to calculate the % onshore wind fleet power output for the whole of 2022.

Figure 2 illustrates two points; a) the general under-delivery from onshore wind in so far as although the GB capacity of onshore wind was 13033MW (in 2021, from Table 1), for around 10 days of the year the GB wind fleet output failed to exceed one tenth of the output capability and in a similar manner, for over 80 days, the total output failed to reach 60% of the combined capability, and b) how increasing the hub height helps mitigate the level of under-delivery, but, more importantly, provides the developer with a larger capacity turbine so that more energy (MWh) can be delivered from the same wind speed.

Figure 3, using the same approach, examines the number of consecutive days the combined GB onshore output power failed to exceed a particular level during 2022. The output here relates to a particular period in January 2022 during which the maximum number of consecutive days occurred.

This latter result should come as no surprise, being down to a reversal in the large scale weather pattern over north-western Europe – with high pressure extending from Russia and Scandinavia, and across GB, with anomalous low pressure across southern Europe. Such negative type NOA conditions typically produce colder, calmer conditions over Northern Europe along with an easterly wind, causing GB temperatures to fall close to or below freezing, often for several days.

During such conditions wind power is lower than average across the whole of GB with the greatest reduction seen over Scotland (over 30% lower than average), where the majority of the GB onshore capacity is located.[xviii] Understandably, but rather perversely for the future role renewable wind needs to play in displacing fossil-fuel generation, it is during periods such as the one described that GB sees the highest demand for electricity.

Scotland's onshore wind fleet, even when expanded to 20GW, will be powerless under these cold, wintertime conditions during which, for one or more consecutive days, the demand for electricity is high while the output falls way short of contributing to help meet demand. As Figure 3 also suggests, taller turbines provide little advantage in these circumstances.

At this stage and after making these comments, and ignoring the fact that other research along similar lines presented more pessimistic outcomes, a note of caution should be expressed. While Figure 1 illustrates the peculiar, intermittent nature of GB wind-generated electricity the data are based on the combined output of onshore and offshore wind farms under the control of NGESO and thus excludes embedded wind, most, if not all of which is onshore based. While it is not known what error this exception may make the sceptical reader would be justified in challenging the assumptions used for the onshore wind analysis – the use of a model based approach used to develop Figure 2 and Figure 3, and the outcomes thereof.

Some of the questions arising here might include: how can a single daily average wind speed measurement seek to replicate the actual wind over GB, minute by minute? How well does the average wind speed reading reflect the median to check for bias? How well do the meteorology monitoring stations reflect the disposition of onshore wind farms? How well does a simple cube law model fit the range of makes and sizes and wind turbines in use?

There will also be many, more detailed challenges that experts in their field might level at the approach used in this paper: for example, how a single average daily reading could possibly seek to replicate the particular terrain, height, adjacent structures or tree cover, or the proximity to a coastline where a wind farm may be located, or the number and disposition of wind turbines within a wind farm, all of which have a bearing on the combined output from a group of onshore wind turbines.

These are all valid questions. Responding to them is simply a matter of saying such techniques have been used a number of time in published papers – some in professional journals.[xix] The important thing to say here, in utilising average daily wind speed data applied to a turbine model, is the results are meant to be indicative rather than absolute. They are useful for direction and identifying possible relationships: indicating correlation rather than cause and inferring precision.

In consideration of these challenges and in order to test the veracity of this model-based approach an additional test has been performed - to examine Elexon's historical Balancing Mechanism Reporting Service (BMRS) data for the period relating to Figure 3, namely 10-19 January 2022, for the contribution from wind generation. Figure 4 shows the output both in capacity (MW) as well as % terms based on the combined on and offshore wind installed capacity under the control of NGESO, shown in Table 2.

It can be seen from Figure 4 that the combined wind contribution falls to below 10% of rated capacity over the period 14-15 January and below 20% between 13-15 January while capacity remains at or below 40% from the 11-15 January 2022. It should be noted too, that these figures are conservative because on and offshore wind generation is combined and it is known that the percentage reduction in wind power is lower offshore compared to onshore in such conditions.

These independent findings confirm the assertion drawn from Figure 3 – that specific large-scale weather patterns, the type that usually occur during periods of high demand, can all but remove onshore wind generation from the energy mix for one or more consecutive days.

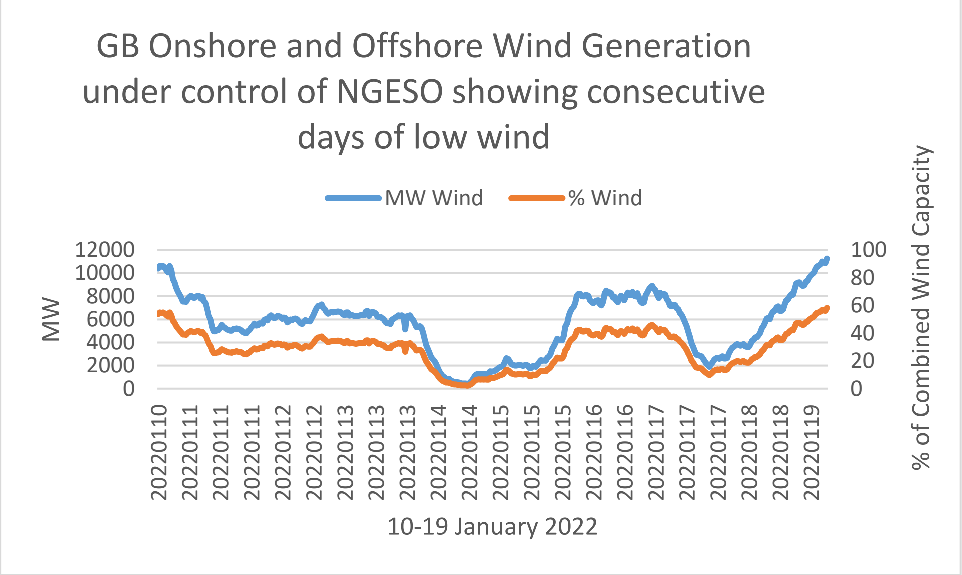

Figure 4 Example of several consecutive days in January 2022 with low wind generation.

Source: Elexon

Without fossil-fuel backup – a goal of Net Zero, or long-term energy storage to provide an alternative means of generation it is unlikely that supply and demand, especially against a background where demand is expected to increase by 50% by 2035,[xx] will remain in balance without drastic action - demand reduction.

To help illustrate this point Figure 5 shows the GB demand (in MW) over the truncated period from Figure 4, Thursday 13 to Sunday 16 January 2022, during which the combined onshore and offshore wind fell to a low level. From Figure 5 it can be seen that weekday demand peaked at around 45000MW (45GW) falling to 30000MW during the night. Were it not for the fact that Combined Cycle Gas Turbine (CCGT) generation capacity was available to make up the shortfall for the wind deficit – as it does regularly, then it would not have been possible to continue to satisfy the level of demand.

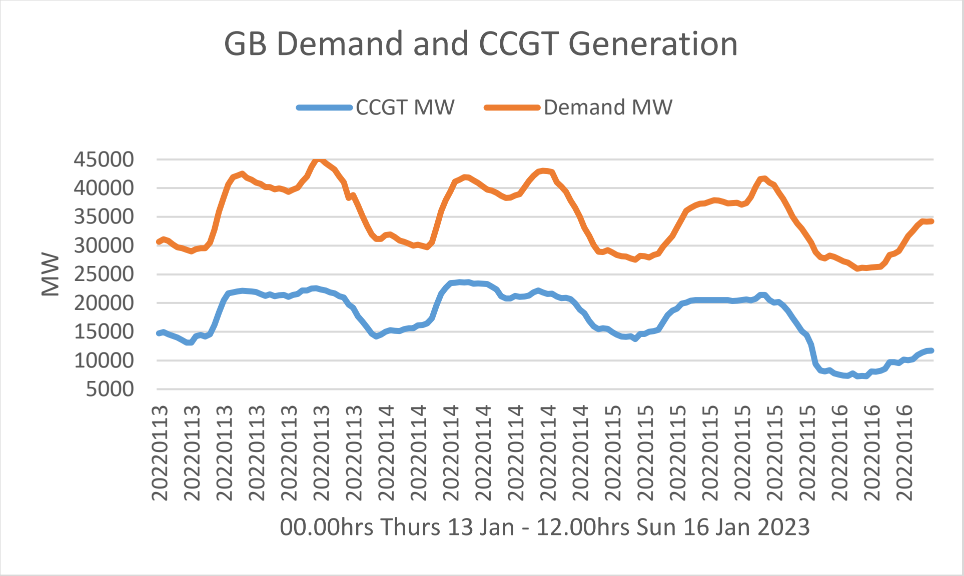

Figure 5 Shows GB Demand and gas generation during lull in wind generation

Source: Elexon

8 Conclusions

Renewable electricity generation achieved a record high in 2022, at 135TWh, or 42% of GB annual demand for energy, due to higher outputs from both wind and solar. This is a success story in turns of reducing the consumption of hydrocarbon-fuels in the energy mix and thereby minimising carbon emissions in the generation of electricity.

However, it is important not to confuse energy with power. Energy is a quantity that is consumed over time, just as consumers pay their bills for energy consumed each month. Power, on the other hand, is instantaneous, and because GB has limited energy storage capability the demand for power, say the instant a consumer switches on their kettle, needs to be matched by an equivalent level of supply in order to control grid frequency at or close to 50Hz.

Wind generated electricity, while doing an invaluable job in providing energy is not so good at providing power simply because the level of power output, as this paper has demonstrated, is difficult to predict, varies with time – sometimes a lot and sometimes over a short timeframe, and sometimes it hardly exists at all for extended periods.

So, while wind power can replace gas and coal as forms of electricity generation it cannot replace the certainty of these dispatchable forms of generation in order to meet the forecast level of demand simply because wind is intermittent and without some other means of balancing demand, as it characteristically varies day by day, the GB grid system will fail without intervention in the form of load shedding.

The supply-demand balance problem will be further exacerbated as demand rises by 50% or more by 2035 and the intermittent GB wind capacity, both on and offshore, is increased to meet this demand. With limited energy storage capability[xxi], balancing services, particularly for the more severe events (deeper and longer) then calls for more fossil-fuel dispatchable generation to be built will become apparent. In these circumstances – of high electricity and low wind power days across many parts of Europe, neighbouring countries may struggle to provide additional capacity to GB via interconnectors.[xxii]

What especially exacerbates this supply-demand issue arising from wind intermittency is the spatial distribution of wind power – with wind speeds having a considerable correlation across the whole of GB and especially across Scotland.[xxiii] This suggests that further levels of intermittency – as wind capacity is increased, could be mitigated by spreading any additional onshore wind across the whole of GB rather than Scotland to maximise the average availability of wind power during high demand.

A more effective solution, given the percentage reduction in wind power supply with increasing demand is lower offshore than onshore, would be for further onshore wind capacity to be sited offshore to more effectively aid the security of GB supply.[xxiv]

One final point, as an adjunct to this paper. Wind power, particularly onshore wind, places a burden on society and especially its most vulnerable members – those living in remote rural locations who are left to carry the burden of hosting wind farms. But, society as a whole carries a further burden – the loss of visual amenity from new overhead transmission networks to accommodate this wind energy and to transfer it to where demand exists, as well as the financial cost arising therefrom – paid for as a levy on electricity consumer bills. Wind energy, often cited as the lowest cost marginal producer, fails to take account of these holistic costs – health and welfare of communities, the loss of natural amenity and the cost of infrastructure needed to accommodate wind.

9 Endnotes

---

[i] National Grid (2016) Summer Outlook Report 2016, for instance estimates the level of embedded wind generation at 4,100MW. This figure, together with the total of 7,303MW for wind generation from onshore and offshore connected to the NETS (as shown in National Grid report, Transmission Networks Connections Update, September 2015, page 40), would suggest a total GB wind generation capacity of around 11,500MW.

[ii] National Grid (2016) Summer Outlook Report 2016 estimated the level of GB embedded solar PV generation at 9,300MW in February 2016.

[iii] See: National Statistics – Regional Renewable Statistics – Renewable Electricity by Local Authority, Published 7 November 2022. Based on RESTATS, the UK's REnewable Energy STATistics database that is the primary source of accurate, timely statistics for UK renewable energy sources. The UK data are published on and available for download from Gov.uk website, principally in the Digest of the UK Energy Statistics (DUKES) and the Energy Trends publications.

[iv] These comments apply to offshore wind as National Planning Framework 4 (NPF4) in Scotland has now made it easier to gain for approval for onshore wind.

[v] C. Moore (2022) writing in the New Civil Engineer, 6 September 2022, cites nearly half offshore wind projects are only at the concept stage. See: https://www.newcivilengineer.com/latest/rate-of-wind-turbine-installation-needs-to-be-tripled-for-uk-to-hit-2030-target-06-09-2022/

[vi] NG refer to this category as: Awaiting consent; Consent Approved; Project Status; Scoping; Under Construction (Commissioning). While it is possible to break down the capacity under each of these headings a single figure has been used here. Appendix F can be found at: https://www.nationalgrideso.com/research-and-publications/electricity-ten-year-statement-etys/etys-documents-and-appendices

[vii] See: National Grid (2020) Electricity Ten Year Statement and National Grid (2021) Network Options Assessment 2020/21 Cost Benefit Analysis (NOA 2020/21 CBA) for details.

[viii] Describes the ratio of the actual energy generated over a year (in MWh) to the theoretical value (installed capacity in MW x 8760hrs). The term unchanged configuration basis describes the amount of electricity

---

generated from schemes that have been operating throughout the whole of the calendar year with the same installed capacity configuration.

[ix] As measured using the Levelised Cost of Electricity (LCoE) calculation.

[x] NG Transmissions Networks Connections Update (May 2015) shows onshore wind at 4328MW and offshore wind at 2908MW.

[xi] The BMRS is the primary channel for providing operational data relating to the GB Electricity Balancing and Settlement arrangements. It is used extensively by market participants to help make trading decisions and understanding market dynamics and acts as a prompt reporting platform as well as a means of accessing historic data. See: https://www.bmreports.com/bmrs/?q=help/about-us/

[xii] Elexon Ltd is the parent company of a group of companies whose principal role is to provide and procure the facilities, resources and services required for the implementation of the Balancing and Settlement Code (BSC). Ekexon is a not-for-profit entity, funded by electricity market participants.

[xiii] The site is called Virtual Crossing Weather and provides a free weather data service comprising a limited set of data, one being daily average wind speed.

[xiv] A PhD thesis by N. Earl (2013) The UK Wind Regime – observational trends and extreme event analysis and modelling, University of East Anglia, School of Environmental Science, p.47 cites Petersen et al., 1998 and Motta et al., 2005 in using an equation (U(z1)/U(z2)) = (z1/z2)^*p* where U(z1) and U(z2) are windspeeds at heights z1 and z2 respectively and *p* is the power law exponent taken to equal 0.14. Using this conversion, wind speed at 100m is equivalent to 1.38 x wind speed at 10m.

[xv] This cube-law model is used by Bett, P.E. and Thornton, H.E. (2016) In their paper entitled: The climatology relationships between wind and solar energy supply in Britain, published in Renewable Energy 87 (2016) pp. 96-110.

[xvi] See Aris, C. (Undated) Wind Power Reassessed: a review of the UK wind resource for electricity generation. A report prepared for the Robert Smith Institute and The Scientific Alliance.

[xvii] NAO is a measure of the large-scale north to south atmospheric pressure difference .

[xviiixviii] See paper by Hazel, E. Thornton *et al*. (2017) Environ, Res. Lett. **12**. 064017, entitled The Relationship between wind power, electricity demand and winter weather patterns in Great Britain.

[xix] See Hazel E Thornton et al 2017 Environ. Res. Lett. 12 064017, The Relationship between wind power, electricity demand and winter weather patterns in Great Britain.

Staffell, I. and Green R. (2014) Renewable Energy. 66 (2014) pp.775-786 How does wind farm performance decline with age?

Kosmina, L. and Henderson, J. (2011) BRE. Wind data for SAP 2012. Ref STP11/WD01.

Aris, C. (undated) Wind power reassessed: a review of the UK wind resource for electricity generation. Adam Smith Institute.

[xx] See House of Commons report – Where will Britain's future energy supply come from? Forrester, C. published 12 May 2022 which references the CCC Sixth Carbon Budget, Electricity Generation.

[xxi] Although many forms of energy storage have and are being explored, such as potential energy, compressed air (CASE), flywheels they tend to be limited in power output and energy storage capability. Battery storage too, while being around 1.6GWh tend to be limited to supplying this over 1-2 hours. Pumped hydro has around 2.8GW capability of which Dinorwig is rated at 1.7GW and can deliver something like 9GWh over around 6 hours. The recently announced Coire Glas pumped hydro scheme, due for commissioning sometime in the next decade, will add a further 1.5GW over around 20 hours. When commissioned this will take pumped storage capability to around 4GW – still not enough to balance demand with intermittent wind during deeper or longer supply variations.

[xxii] Thornton (*ibid*)

[xxiii] Aris (*ibid*)

[xxiv] Thornton (*ibid*)