Go West!

An analysis of the energy system benefits and implications of a more geographically diverse offshore wind portfolio

October 2022

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Preface

As of October 2022, the UK is facing the climate crisis alongside one of the greatest economic crises of this generation, driven largely by volatile fossil fuel markets. This ongoing market volatility is being exacerbated by the geopolitical insecurity resulting from Russia's invasion of Ukraine. The current wholesale price of gas is putting huge pressure on the already stretched incomes of millions of people across the UK through rising prices and bills. With vital net zero targets to be achieved and energy prices spiralling, the need for energy independence and innovation at pace and scale in the UK energy system has never felt so urgent.

In response to fundamental changes in the UK economic landscape since the Net Zero Strategy was published, the UK government has commissioned the Net Zero Review (due to report at the end of 2022). The review will assess the government's approach to delivering its net zero target to ensure it is delivered in a way that is 'pro-business and pro-growth', including how net zero can 'support UK energy security and affordability for consumers and business and the need to rapidly increase and strengthen UK energy production and supply'. Controlling energy costs and strengthening UK energy production and supply requires investment in enduring long-term solutions, including seizing the opportunity of cheap, clean, homegrown renewables.

The UK is a world leader in offshore wind and is aiming to deliver 50 GW of offshore wind by 2030. To date, almost three-quarters of the UK's 13 GW offshore wind capacity has been installed along the east coast of Great Britain. Similar momentum is yet to be established on the west coast, with 8 GW of planned projects cancelled or withdrawn. However, recent innovations in floating offshore wind have enabled the development of projects in deeper water off the west coast. This presents an opportunity for west coast offshore wind projects to address the lack of geographical diversity of the UK's offshore wind fleet and to play a vital role in energy system balancing, energy security and price stability.

Using 20 years of weather data, the *Go West!* study explores and identifies the benefits that pursuing a more geographically diverse offshore wind fleet could bring to both the UK energy system and energy consumers, and recommends the policy innovations required to deliver such a balanced fleet.

About Regen

Regen is a not-for-profit centre of energy expertise and market insight whose mission is to transform the UK energy system for a zero carbon future.

Acknowledgements

Regen would like to thank the *Go West!* project sponsors and contributors.

Magnora Offshore Wind (MOW) is owned by Magnora ASA, a Norwegian renewable energy developer, and TechnipFMC, a global energy services company. MOW develops floating offshore wind projects around the world using the joint expertise and capabilities of both Magnora ASA and TechnipFMC. In the UK, MOW has been awarded an option to lease for a 495 MW floating wind project off the coast of the Isle of Lewis as part of the ScotWind leasing round and is also working on the Celtic Sea leasing round with local partner Hiraeth.

Morwind Ltd, a specialist wind developer based in South West England, is partnered with Corio Generation to compete for floating offshore wind rights in the Celtic Sea. The partnership combines Corio's international industrial expertise and access to capital with Morwind's specialist regional knowledge and strong local stakeholder relationships to identify and invest in new floating wind opportunities in the region. Morwind is committed to working and collaborating with local, regional and national partners, engaging the local supply chain, stakeholders and communities and adding value through innovation, efficiency and social impact. Corio, a portfolio company of Macquarie's Green Investment Group, operates on a standalone basis and has one of the world's largest offshore wind development portfolios at over 20 GW, including projects in England and Scotland.

Northland Power is a global power producer dedicated to helping the clean energy transition by producing electricity from clean renewable resources. Founded in 1987, Northland has a long history of developing, building, owning and operating clean and green power infrastructure assets and is a global leader in offshore wind. We were delighted earlier this year to win the rights to develop 2 offshore wind farms off the Western Isles as part of the Crown Estate Scotland's 'Scotwind' tender.

Simply Blue Group is a leading early-stage blue economy developer. Headquartered in Cork, Ireland, the company has an impressive global pipeline of over 10 GW of floating offshore wind projects, including project Erebus, a 100 MW Test and Demonstration project in the Celtic Sea. Erebus is part of Blue Gem Wind, a joint venture between Simply Blue Group and TotalEnergies, which takes a steppingstone approach to floating offshore wind projects in the Celtic Sea. Simply Blue Group is committed to creating new economic opportunities for coastal communities and developing projects that co-exist with sustainable fisheries and marine conservation.

Regen would also like to thank those organisations that participated in the interim roundtable discussion that informed this report: **BEIS, Burges Salmon, BVG Associates, Celtic Sea Power, Climate Change Committee, National Grid (Electricity Transmission and Electricity System Operator), Offshore Wind Acceleration Taskforce, Ofgem, renewableUK, SP Energy Networks, SSE, The Crown Estate, and Welsh Government**.

Image courtesy of Simply Blue Group

Executive summary

Offshore wind energy forms an important part of the UK's energy mix and is expected to be crucial to meeting net zero emissions targets. The UK government's British Energy Security Strategy (April 2022) set an ambition to deliver up to 50 GW of offshore wind by 2030, including 5 GW of floating offshore wind (FLOW). With current offshore wind capacity (as of Q2 2022) at 13 GW and accounting for 12.6% of the UK's total domestic generation[1], National Grid ESO's Future Energy Scenarios 2022 'Consumer Transformation' scenario projects the installed generation capacity of offshore wind to increase by almost nine times to 110 GW by 2050, providing 56% of total domestic generation[2].

To date, almost three-quarters of the UK's offshore wind capacity has been installed along the east coasts of England and Scotland. 8 GW of projects along the west coast of Great Britain have been cancelled or withdrawn, including several Crown Estate Offshore Wind Leasing Round 3 projects, highlighting that even those west coast projects successfully awarded a lease still face significant challenges to reaching full operation. Whilst innovations in FLOW have begun to mitigate some of the challenges posed by harsh marine environments, simplifying and accelerating the planning and development process would maximise the rate of success and pace of development.

The concentration of offshore wind capacity on the east coast has helped the offshore wind sector reduce costs by focusing investment and development in shallower waters near major construction and manufacturing ports. However, as the UK energy market grows increasingly reliant upon offshore wind as a cheap and emissions-free energy source, the lack of geographical diversity of the burgeoning offshore wind fleet is not optimal for energy system balancing and price volatility. The energy system benefits of a more geographically diverse wind portfolio have become increasingly apparent due to current wholesale price volatility and high system balancing costs.

The *Go West!* study seeks to explore, and quantify where possible, the benefits that pursuing a more geographically diverse offshore wind fleet will bring to the UK energy system and consumers.

[1] Energy Trends – UK April to June 2022. BEIS, 2022 (12 months to Q2 2022)
[2] National Grid ESO's Future Energy Scenarios. National Grid ESO, 2022.

Study approach

The UK's offshore waters were split into a number of discrete zones to provide a basis for the analysis (see Figure 1).

Three primary scenarios and several sensitivity studies were defined to explore the impact of geographical diversity of the UK offshore wind fleet on power generation. Each scenario comprises a 70 GW offshore wind fleet[3], but with varying geographical distribution of that power capacity across the zones. All scenarios include UK offshore wind farm capacity that is operational or under construction as of June 2022, to which additional capacity has been added based on current leases and areas of development activity (such as the Celtic Sea and ScotWind leasing areas).

The primary scenarios – 'Stay East', 'Lean West' and 'Go West' – are illustrated in Figure 2.

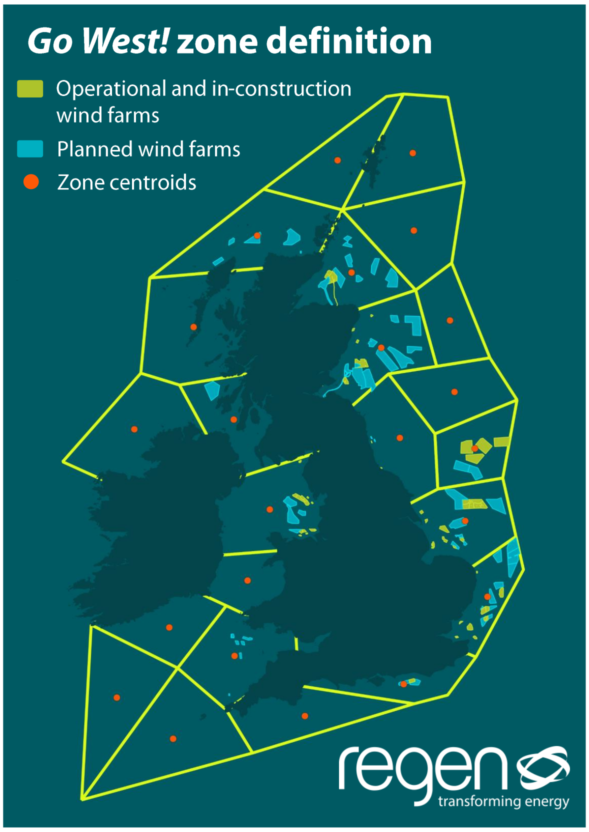

Figure 1: Zones used to model a variety of distributions of a 70 GW offshore wind fleet.

These offshore wind portfolios were combined with 20 years of wind resource and wind farm power output data from the Renewables.ninja[4] website, a tool designed by Stefan Pfenninger and Iain Staffell to help make scientific-quality weather and energy data easily accessible. The resulting offshore wind fleet power generation time history was analysed for each scenario to assess the energy generation potential of a variety of wind farm portfolios across the zones.

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[3] 70 GW was selected as an intermediate target on the trajectory to the UK's 2050 Net Zero ambitions - in line with National Grid's Future Energy Scenarios 2022 offshore wind projections for 2034 (Consumer Transformation scenario) and CCC's 6th Carbon Budget projections for 2040-2048.

[4] See www.renewables.ninja and the related paper *Staffell, Iain and Pfenninger, Stefan (2016). Using Bias-Corrected Reanalysis to Simulate Current and Future Wind Power Output. Energy 114, pp. 1224-1239. doi: 10.1016/j.energy.2016.08.068*

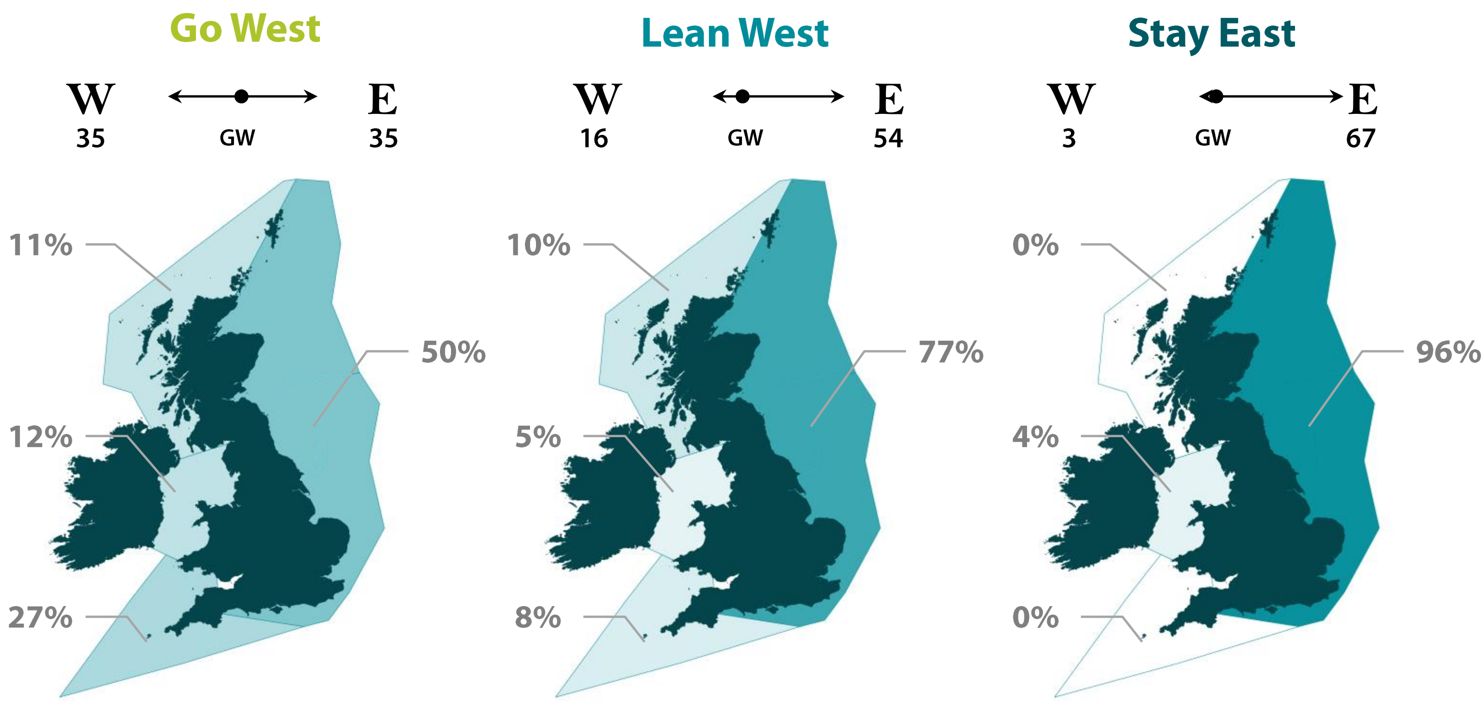


Figure 2: The three primary scenarios used in the *Go West!* study and their associated regional[5] distributions of offshore wind capacity.

Results

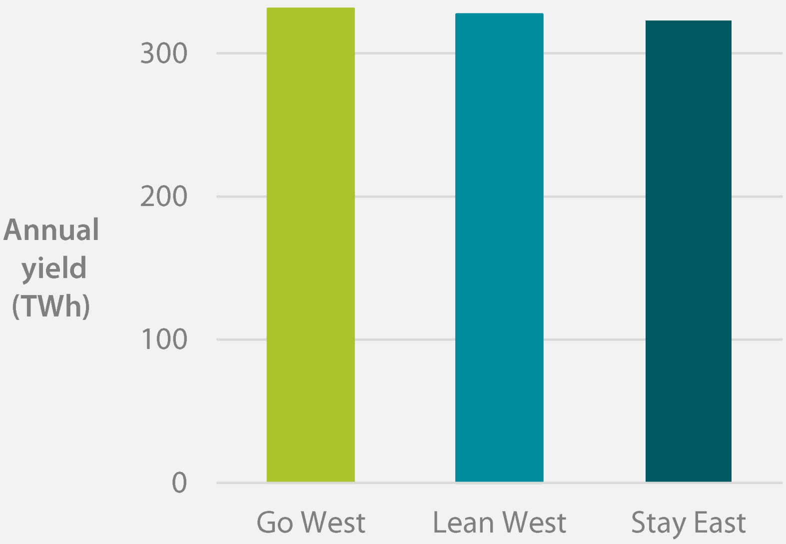
The primary focus of the analysis was to consider differences between the scenarios in:

- Total time spent at very high/low power
- The number of occurrences of very high/low power
- The variability of power generation from one hour to the next
- Total annual yield.

The main findings are illustrated in the below infographics (Figure 3 - Figure 7).

[5] A 'region' in this context is defined as a grouping of a number of adjacent zones. Figure 2 shows that four regions have been used to simplify the comparison of offshore wind capacity distribution around the UK and Ireland per scenario.

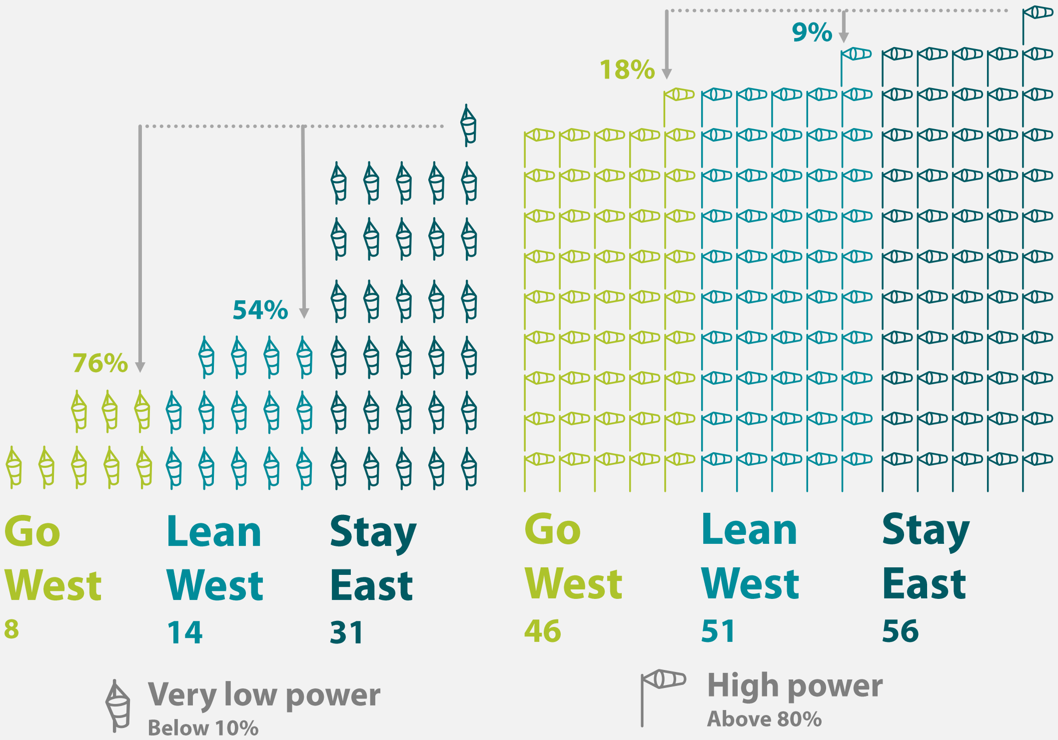
Compared to the Stay East scenario, Go West…



1

…does not reduce average annual yield

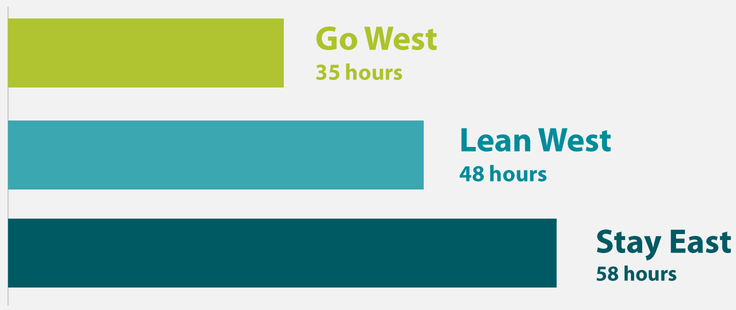
Figure 3: Annual energy generation per scenario
Units: TWh. 'Yield' represents the average annual total of energy generated by the offshore wind fleet in each scenario, calculated as the mean of 20 years of data



2

…reduces the number of 'events' of troughs and peaks in generation

Figure 4: Average number of discrete occurrences (i.e. 'events') per year where the offshore wind fleet is generating at a high/low power level
Units: average number of events per year.
Power level defined by capacity factor.



Maximum duration of a very low power event in 20 years of data

3

…almost halves the maximum 'event' duration of very low fleet power

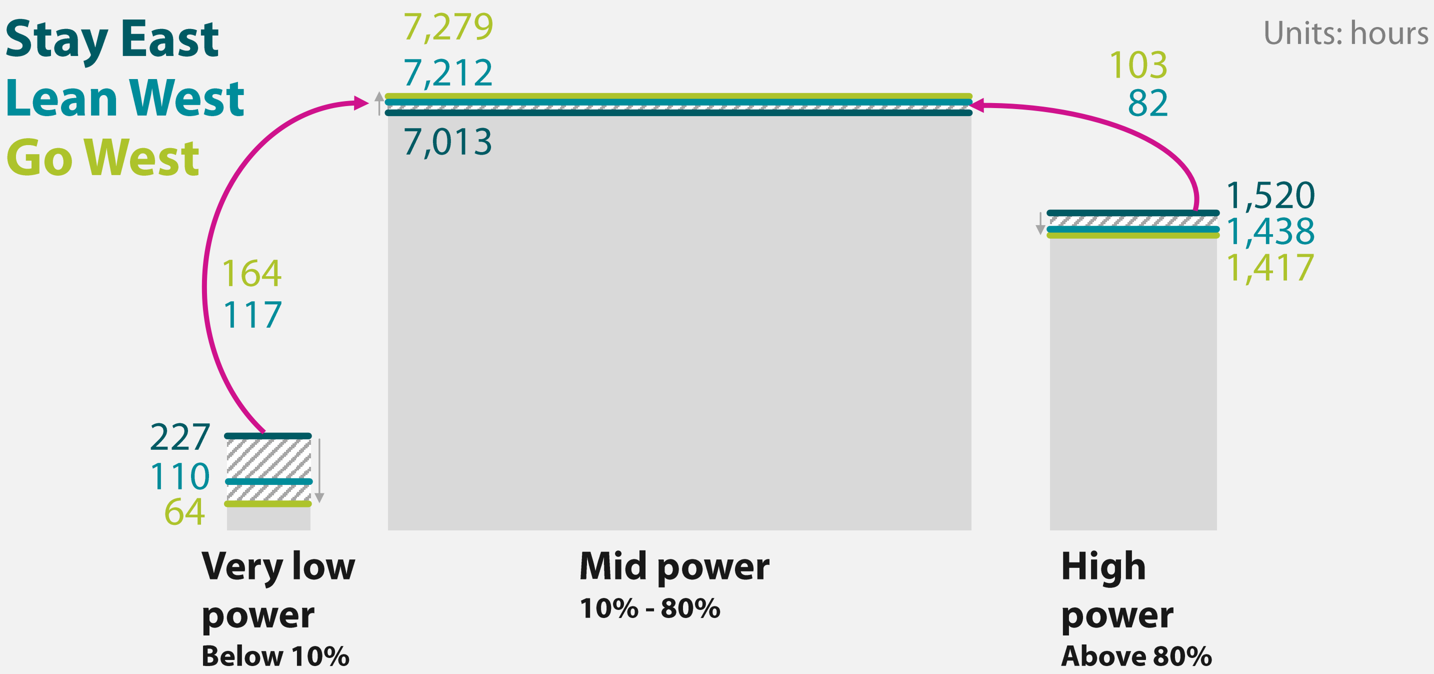
Figure 5: Maximum 'event' duration where offshore wind generation is below 10% capacity factor (20 years of data)
Units: hours

4 …reduces offshore wind generation variability

Figure 6: Ramp rates – the magnitude of hourly fluctuation in total offshore wind power generation
Units: GW/h. Peak change in power per year is the average of the highest ramp rate per year for 20 years of data. Note that these values consider magnitude only and not whether the ramp rate is increasing (positive) or decreasing (negative)

5 …significantly reduces time at very low power ('troughs') and reduces time at high power ('peaks')

Figure 7: Average time per year where the offshore wind fleet is generating at each power level
Units: hours per year. Power level percentages are capacity factors



These results highlight the benefits of a more geographically diverse 'Go West' offshore wind fleet, namely:

- More consistent generation, with reduced duration and occurrences ('events') of high power 'peaks' and low power 'troughs'
- A significant reduction in the longest annual 'event' of very low power[6] (below 10% fleet capacity factor)
- Reduced variability of generation, both hour-to-hour and average annual maximum variability[7]
- No reduction in total energy generation (yield) per year.

The offshore wind power time histories were input into Regen's high-level energy dispatch model, calibrated to reflect National Grid ESO's 2022 Future Energy Scenarios 'Consumer Transformation' scenario for the year 2034. The results highlighted the following benefits of a 'Go West' scenario compared to 'Stay East':

- Increased offshore wind generation
- 17% reduction in the marginal cost of generation[8], as well as reducing price variability by a quarter
- 24% reduction in generation carbon intensity, which almost reaches a level that satisfies the CCC's recommended target of 10 gCO_2e/kWh in 2035
- 6% reduction in renewable curtailment.

There are a number of energy system benefits that can also be achieved with a more diversified offshore wind fleet, as illustrated in Figure 8. These benefits can be grouped into three broad categories (although, in reality, most energy system impacts are interrelated):

1. **Benefits related to the reduction in periods of very low generation, including commodity costs of electricity**, which are driven by increased utilisation of renewable energy and 'merit-order' effects.
2. **Benefits related to the inherent value of geographical diversity of generation,** which improves system resilience and reduces capacity margins and capacity factors. This results in reduced network investment and flexibility costs.

[6] Where a 'very low power event' is defined as below 10% capacity factor of the whole offshore wind fleet

[7] Average annual maximum is the mean of the annual maximum value for each of 20 years of data

[8] Marginal cost of generation is the incremental cost incurred when producing additional units of energy

3. **Benefits of lower generation volatility,** including reduced 'ramp rates', which leads to reduced system balancing and operability costs. It also reduces market risk and wholesale price volatility.

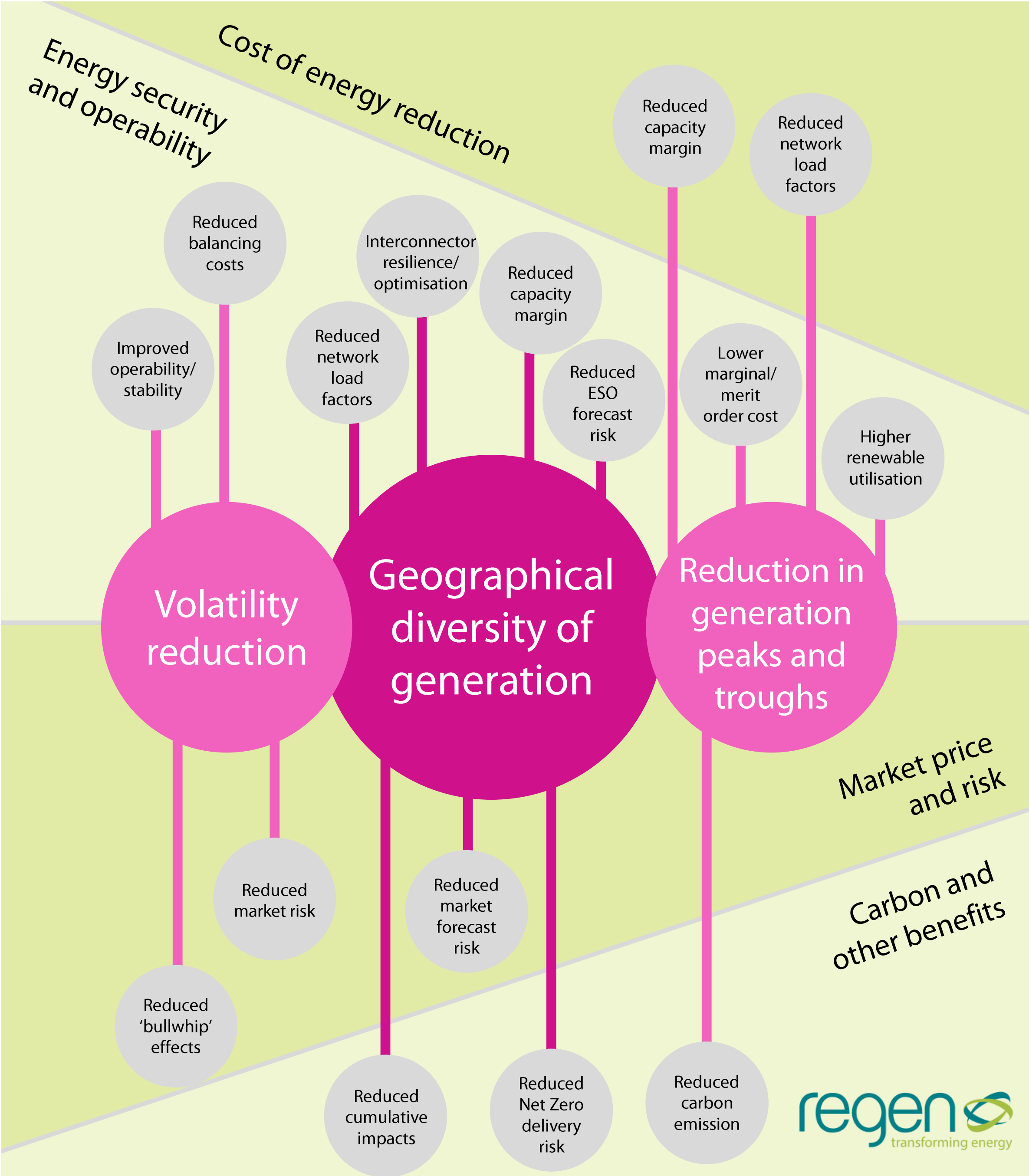


Figure 8: Energy system impacts that can be achieved with a more diversified offshore wind fleet

Benefits related to the reduction in periods of very low generation, including commodity costs of electricity

The *Go West!* analysis highlights a significant reduction in the depth, duration and number of very low wind generation periods resulting from a more diversified offshore wind fleet. Using Regen's high-level dispatch model, this contributed to a reduction in the marginal cost of electricity of 22% (this would be higher if using the current very high cost of gas generation) and higher utilisation of available renewable generation, compared with higher cost and higher carbon fossil fuels, resulting in a 30% reduction in grid carbon intensity, i.e. emissions per kWh generated.

Benefits related to the inherent value of geographical diversity of generation

The more diverse the supply of energy in terms of technology, number of assets, fuel type and geography, the lower the proportional impact of any single failure and, therefore, **the lower the capacity margin needed to maintain a given Loss of Load Expectation**. An increase in the derated capacity of wind generation, and consequently reduced capacity margin requirement, could significantly reduce costs by £75 million per GW of increased offshore wind derated capacity per year[9].

Similarly, diversity of generation can **reduce the overall impact of forecast error**. A concentration of wind turbines in a single weather window means that the impact of forecasting error in that window is amplified, potentially leading to much higher system costs and market price volatility. Diversity of generation across multiple weather windows reduces that risk as an incorrect forecast becomes one of several individual forecasts, thereby reducing its impact overall.

If planned holistically, a more diversified wind portfolio could result in **lower network infrastructure costs** by:

- Spreading variable generation across the network topology and aligning offshore wind with the location of interconnectors and other forms of generation.
- Integrating offshore generation with areas of demand, reducing Transmission Network Use of System (TNUoS) charges for demand customers in areas that regularly require power to be transmitted from other regions.

[9] The 2021 Capacity Market T1 auction clearing price for year-ahead capacity was £75/kW, which suggests a potential annual cost saving of £75 million per GW of increased offshore wind derated capacity.

- Aligning offshore wind generation with new forms of demand and the manufacture and distribution of fuel sources, such as hydrogen.

Conversely, diversity of generation could lead to increased network infrastructure costs if offshore generation is not well integrated with areas of demand, storage and interconnectors.

Diversity of geography and technology are **key components of a smart and flexible future energy system**. As well as balancing national supply and demand, diversity could create more opportunities to increase and optimise energy storage, allow greater use of hydrogen electrolysis at the point of offshore connection, and allow better alignment with interconnectors and Multi-Purpose Interconnectors.

Continuing to deploy offshore wind farms in the same areas has a **cumulative impact** on marine users, the environment, communities hosting infrastructure and other wind farms. At a certain point, these cumulative risks and the absolute reduction of available sea area to develop begin to outweigh the advantage of continuity. Geographical diversity could then become a positive advantage, reducing cumulative development impacts and therefore planning risk, and opening up new areas of resource.

Benefits of lower generation volatility

Go West! shows that a more geographically diverse offshore wind fleet **reduces generation ramp rates** (i.e. reduced generation volatility) from hour to hour. Higher generation volatility increases overall system costs by:

- Increasing the need for balancing market[10] intervention
- Increasing the market price risk for energy traders and supply companies
- Increasing the propagation and severity of 'bullwhip' effects (see Explainer: Bullwhip Effects in section 4.3.3).

In the 12-month period to June 2022, National Grid ESO measured the **system cost of balancing actions** to be around £2.4 billion. Generation volatility can increase forecast errors and the required level and speed of system intervention. The resource and operational pressure to respond to system imbalances within a one-hour window[11] can lead to suboptimal system

[10] The balancing mechanism is a very short-term spot market, used to balance supply and demand in each half hour trading period of every day. This is done by accepting 'bids' and 'offers' from individual generators and demand customer to increase or decrease generation or consumption.

[11] The one-hour period between 'gate closure' and the settlement period in which energy is delivered

solutions, such as the inappropriate use of large-scale CCGT[12] plants to provide balancing services due to their ease of dispatch relative to more flexible and targeted solutions. With the phenomenal increase in the price of gas in the last year, such actions are becoming a critical driver of increased balancing costs. Generation volatility adds to this time pressure and increases the required level of intervention. So, although the ESO Control Room is investing in automation and digitalisation, volatility is likely to increase balancing costs.

System operability is also an important consideration. Four of the five core elements of operability, as defined by National Grid ESO, are directly impacted by the volatility of generation. Two of these – frequency and stability – would benefit from lower generation ramp rates at a national level.

Generation volatility is a key driver of **overall market price** and a balancing risk for energy supply companies and other energy off-takers/consumers. Volatility in renewable generation can cause significant price changes in the wholesale market and the balancing mechanism. These price changes are partly due to the underlying supply/demand balance and the cost of energy (merit order effects). Still, price swings can be amplified by market factors related to sentiment and speculation, particularly due to a perceived undersupply or oversupply of energy that can cause upward or downward price volatility, respectively. Such price swings result in increased risk for generators and consumers and potential excess profits and rents for energy traders, both of which add to overall energy system costs. It is hard to calculate the degree to which market price volatility constitutes an additional system cost (as opposed to a valid price signal), but it is clear that there has been a significant amount of speculative pricing and uneconomic 'bullwhip' effects during the current energy crisis.

Market price volatility and the risk of price cannibalisation increase **investment risk for renewable generators**. This means that investors in new generation have to secure either higher cost capital or additional mitigation measures, such as revenue support or stability and/or a fixed price guarantee, such as a Contract for Difference (CfD). From a whole system perspective, increases in the cost of capital and investment risk increase the overall economic cost of achieving a given level of decarbonisation and energy security.

Potential energy system costs

Additional project costs to build and operate wind farms in new locations are expected, particularly in deeper waters off the west coast. The extent of this cost increase will depend

[12] Combined Cycle Gas Turbine

on the cost-effectiveness of floating wind and the potential higher energy yield that could be captured from larger turbines further from shore. For this study, we have not considered these to be additional energy system costs, but, of course, this is the fundamental question in the trade-off between building projects with the lowest cost of energy versus building projects that optimise overall system costs.

Primary energy system costs include:

- **Energy generation potential** – system costs could be increased if a more geographically diverse offshore wind fleet had a lower total energy yield. However, *Go West!* wind resource modelling suggests that there is little difference between the east coast-biased 'Stay East' and the more balanced 'Go West' scenarios – in fact, Go West has a slightly higher yield.
- **Grid infrastructure and distance to demand** – a key question is whether the diversification of wind generation to the west increases (or potentially reduces) the overall requirement for both offshore and onshore network infrastructure. The current Holistic Network Design (HND) and Offshore Transmission Network Review (OTNR) initiatives consider the overall grid investment and cost of operation associated with different offshore and onshore network topologies. The holistic approach of the HND methodology could be used to conduct a scenario analysis to ascertain the comparative infrastructure costs of a more 'West-leaning' or 'Go West' portfolio. As previously highlighted, based on current TNUoS charges, there is a good argument in favour of more generation in the Celtic Sea area. The case for the North and West of Scotland will depend on the design and cost of the necessary transmission links to demand centres in North West England and ongoing interconnection to Ireland and Western Europe.
- **Potential loss of economies of scale in infrastructure capital and operational expenditure** – this would affect the upfront capital cost and subsequent operation of supporting system infrastructure. Economies of scale could be maximised by building multiple wind farms in the same area from a small number of super-ports, then connected to a handful of super-sized offshore transmission networks and onshore sub-stations. A key question to be addressed is whether the costs of diversifying generation, which may require new ports and network infrastructure, are offset by regional economic benefits and the reduction of cumulative impacts, as mentioned previously.

Delivering a more geographically diverse offshore wind fleet to capture these system benefits will require policy innovation. The following pages detail Regen's policy recommendations.

Recommendations

An integrated, strategic approach to offshore development, leasing and planning:

1. Central and devolved governments, The Crown Estate, Crown Estate Scotland, system operators, networks and regulators need to work together with the offshore wind industry to develop an overarching delivery plan.
2. This delivery plan should include a high-level geographic plan that recognises the energy system, energy security and regional economic benefits of a more geographically diverse wind portfolio.
3. Further research is recommended to fully quantify the energy system benefits and regional growth opportunities of different offshore wind portfolios.
4. Seabed leasing and an accelerated consenting process should be aligned with the long-term delivery plan. They should give transparency and confidence as early as possible to wind farm developers and investors in port infrastructure, manufacturing and supply chain capability and capacity.
5. The Crown Estate's increased ambition for 4 GW of floating wind in the Celtic Sea by 2035 is welcome. However, there is an urgent need to set out the long-term plan for the Celtic Sea area, including the Western Approaches to the English Channel.
6. Offshore wind development needs to be aligned and integrated with the use of conventional and Multi-Purpose Interconnectors (MPIs) to neighbouring energy markets, including Ireland and Western Europe.

Financial mechanisms that support increased diversity of supply:

1. The Contracts for Difference (CfD) mechanism should continue to provide revenue stability for less-established innovative technologies until they reach competitive scale. For floating wind, this means allocating a sufficient strike price and retaining a separate allocation pot and/or a 'minima' budget allocation provision through Allocation Rounds 5, 6 and 7, at least.
2. The government should consider a means to providing a geographic locational signal (distinct from Locational Marginal Pricing) within the CfD scheme that supports diversity of supply. This could be achieved in several ways, such as:
    a. Running a specific Allocation Round for floating wind projects to support their deployment on the west coast.
    b. Running bespoke regional CfD rounds or rounds with regional minima.
    c. Focusing support for floating wind, tidal and other technologies that offer more geographic diversity.

3. The government could consider an energy system value strike price differential within the CfD allocation round. However, this approach may be difficult to calculate and administer.

Infrastructure investment, innovation and supply chain development:

1. Continue, extend and accelerate the process of Holistic Network Design to ensure that offshore and onshore network investment is in place to support offshore wind and interconnector development.
2. Building on the current Offshore Transmission Network Review[13], implement changes to the regulatory framework that will allow both greater collaboration in the development of offshore transmission networks and strategic investment in shared network infrastructure, including MPIs.
3. Extend, increase and accelerate support for port infrastructure development, building on schemes such as the Floating Wind Manufacturing Investment Scheme (FLOWMIS)[14].
4. Establish a coordinated approach to developing regional supply chains in England, Wales and Scotland, extending across to Northern Ireland and the Republic of Ireland. This should build on existing capabilities, such as those that Regen has identified in South West England[15] and by the Offshore Renewable Energy Catapult in Wales[16] and across the UK[17].
5. Expand levelling-up schemes, such as Offshore Wind Growth Partnership[18] and Fit 4 Offshore Renewables[19], to grow a western supply chain basis capable of deploying at scale.

[13] Offshore Transmission Network Review

[14] See Regen's response to the FLOWMIS consultation

[15] Floating Offshore Wind Opportunity Study, Regen, 2022

[16] Benefits of Floating Offshore Wind to Wales and the South West: Supply Chain Report, ORE Catapult, 2020

[17] Strategic Infrastructure and Supply Chain Development, Floating Offshore Wind Centre of Excellent - ORE Catapult, 2022

[18] Offshore Wind Growth Partnership

[19] Fit 4 Offshore Renewables, ORE Catapult

Contents

1 Go West!

1.1 The state of the UK's offshore wind sector

The UK's installed offshore wind capacity stands at 13 GW (Q2 2022)[20], with a further 5 GW in pre-construction[21], and accounted for 12.6% of the UK's total electricity generation in the 12 months to Q2 2022[20]. This capacity not only contributes towards the decarbonisation of the energy system whilst offering greater energy security, but the offshore wind industry is a significant contributor to the UK economy with an estimated turnover of £3.8 billion[22] and employment of 10,100 full-time equivalent jobs in 2020[22].

In January 2022, the UK announced over £60 million in public and private investment to develop innovative floating offshore wind technologies (FLOW)[23]. In April 2022, the UK government published the British Energy Security Strategy, which set an ambition to deliver up to 50 GW of offshore wind by 2030, including 5 GW of FLOW. This target is significantly more ambitious than the UK Net Zero strategy, which targeted 40 GW of offshore wind and 1 GW of FLOW by 2030[24]. Beyond 2030, the CCC's 6th Carbon Budget 'Balanced Pathway' projects 95 GW of offshore wind in 2050[25] and National Grid ESO's Future Energy Scenarios project 74–110 GW by 2050[26], highlighting the vast expansion of offshore wind required to reach net zero emissions by 2050.

To date, almost three-quarters of the UK's installed offshore wind capacity has been installed along the east coast of England and Scotland (Figure 9), whilst almost 8 GW along the west coast of Great Britain (GB) has been cancelled or withdrawn, including Atlantic Array, Celtic Array and Argyll Array (Figure 10). Various reasons were given for the withdrawal of these west coast projects in the last decade, but common factors include adverse seabed conditions, particularly the presence of hard rock, challenging wave environments and the distance to main manufacturing hubs.

20 Energy Trends – UK April to June 2022. BEIS, 2022
21 Offshore wind, Department for International Trade, 2022
22 'Low carbon and renewable energy economy estimates' dataset. Office for National Statistics. 17 Feb 2022.
23 BEIS Floating Offshore Wind Demonstration Programme competition press release
24 Net Zero Strategy: Build Back Greener. HM Government, 2021.
25 The Sixth Carbon Budget: The UK's path to Net Zero. Climate Change Committee, 2020.
26 National Grid ESO's Future Energy Scenarios. National Grid ESO, 2022.

Figure 9: Wind farms currently operational and under construction across the UK

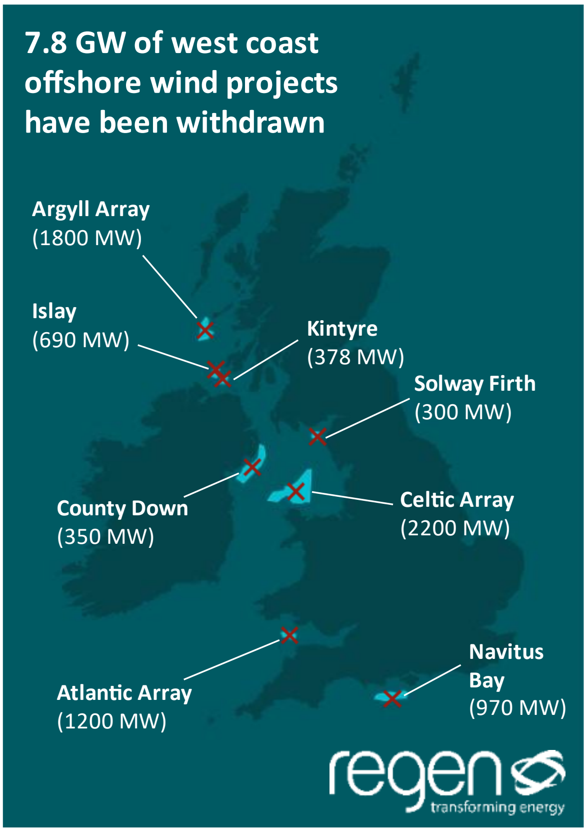


Figure 10: Cancelled offshore wind farms off the west coast of Great Britain 2010-2020

Innovations in FLOW have begun to mitigate the challenges posed by harsh marine environments on the west coast. Nevertheless, offshore wind deployment is still significantly focused along the east coast. Of the 5.7 GW of offshore wind projects currently under construction, 4.6 GW are located east of GB[27]. The July 2022 Contracts for Difference (CfD) Allocation Round 4 (AR4) allocated contracts to five east coast offshore wind projects totalling 7 GW, compared to just one 32 MW FLOW project on the west coast in the Celtic Sea[28].

The concentration of offshore wind capacity on the east coast has helped the offshore wind sector reduce costs by focusing investment and development in shallower waters near major construction and manufacturing ports. This cost reduction is reflected in the most recent CfD auction[28], which saw the offshore wind strike price set at £37.35/MWh[29] - nearly a 70% reduction from the first CfD round in 2015[30] following two decades of deployment. However, as the UK energy market grows increasingly reliant upon offshore wind as a cheap and

[27] Wind Site Agreements (England, Wales & NI). The Crown Estate, 2022.
[28] Contracts for Difference Allocation Round 4 results. BEIS, 2022.
[29] Strike prices based on 2012 prices. £37.35/MWh would equate to £43.37/MWh in today's market.
[30] Contracts for Difference AR1 Outcome. BEIS, 2015.

emissions-free energy source, the lack of geographical diversity of the burgeoning offshore wind fleet is not optimal for energy system balancing and price volatility.

This concentration of most of the UK offshore wind fleet within a single weather window can cause issues for the energy system. When the wind blows across the east coast, UK generation peaks and wholesale prices fall. However, during a low wind period – for instance, when a winter high-pressure system sits over the North Sea and northern Europe – the UK can experience several days of very low wind generation. This is a particular challenge for energy security since energy storage is quickly exhausted, and interconnectors to northern Europe may not be available. The energy system benefits of a more geographically diverse wind portfolio have become increasingly apparent in light of current high wholesale price volatility and high system balancing costs.

Scope for west coast offshore wind capacity

Over the past year, several significant developments across Scotland and the Celtic Sea have highlighted the opportunity to increase offshore wind capacity to the north and west of Britain. In Scotland, nearly 5 GW of capacity outside of the North Sea was awarded through the ScotWind leasing round. The Crown Estate identified five 'Areas of Search' to deliver 4 GW of FLOW power in the Celtic Sea by 2035, with the potential to accommodate an additional 20 GW of FLOW capacity by 2045. These announcements mark a new stage in the growth of the UK offshore wind sector, with large-scale projects located off the north and west of Scotland and, for the first time, off the southwest coast

Case study: December 2021's Dunkelflaute

Between 16–19 December 2021, the UK experienced an excellent example of what can happen when there are persistently low wind conditions in the southern North Sea. A high-pressure weather system endured above the location of 6 GW of offshore wind capacity in the southern North Sea. This caused the UK to experience a 'Dunkelflaute' – a period in which little solar or wind energy can be generated due to calm and foggy conditions.

Figure 11: A weather map of the wind conditions around the British Isles at 07:00 on 17 December 2021.
Chevrons illustrate interconnector flows.

Across GB, wind power output fell below 1 GW within this period, leading to an increase in gas dependency that peaked at around 25 GW and some reliance on coal. This low wind generation across GB, coupled with low generation across northern Europe and electricity prices already nearing £101.15/MWh[31] on 15 December, led to a reduction in capacity margin and day-ahead wholesale electricity prices reaching a maximum of £348.83/MWh[31]. However, there were windier conditions along the English Channel, the Celtic Sea and north-west Scotland as the high-pressure system spilt air out into neighbouring low-pressure areas.

Figure 12: Anticipated build-out of offshore wind around Scotland and in the Celtic Sea. Projects highlighted are accepted ScotWind offers, demonstration/pre-commercial projects acknowledged by The Crown Estate, and Celtic Sea areas of interest.

[31] Market index data. BMRS, 2022. https://www.bmreports.com/bmrs/?q=balancing/marketindex/historic

1.2 Project scope

The *Go West!* study seeks to explore, and quantify where possible, the benefits that pursuing a more geographically diverse offshore wind fleet will bring to the UK energy system and consumers. This study builds upon previous work to outline the future requirements of the whole energy system to reach net zero emissions by 2050, as well as previous assessment of supply chain opportunities in the South West from the development of FLOW in the Celtic Sea. This report draws upon Regen's energy system knowledge and engagement with key industry stakeholders to:

- Use the location of current offshore wind capacity and key resource regions to model several hypothetical future scenarios that explore the characteristics of a more geographically diverse offshore wind fleet around the UK
- Highlight potential system benefits that could be derived from a more diversified fleet
- Outline the main barriers preventing offshore wind expansion off the north/west coast and, where possible, offer strategic policy recommendations that could overcome such barriers.

The primary sources of insight and data used in this report consist of industry and government publications detailing the current energy system, including market and infrastructure insights and the near-term development of offshore wind in UK waters, as well as scientific-quality wind resource data derived from NASA MERRA-2 meteorological reanalysis data. These sources are referenced throughout the report. This study also benefitted from primary insight from its sponsors, Magnora Offshore Wind, Morwind, Northland Power and Simply Blue Group, whom we thank for their valuable input.

2 Methodology

2.1 Overview

The *Go West!* analysis seeks to model a variety of possible future UK offshore wind fleets and assess their respective power generation characteristics.

The analysis methodology, as summarised in Figure 13, is as follows:

- Zoning – the designation of discrete marine zones around the UK and Ireland, used to quantify wind resource at different offshore locations around the UK.
- Wind power data – the acquisition of 20 years of hourly wind power time series data at the centroid of each of the zones.
- Scenarios – the combination of capacity factor time series per zone with 70 GW offshore wind fleet scenarios to model various fleet distributions and produce their power generation time histories.
- Results – the resulting power generation time histories are analysed to assess each scenario's fleet characteristics. These time histories are also input to Regen's high-level energy dispatch model to assess characteristics, such as the proportion of renewable energy content, cost of marginal energy generation and carbon intensity.

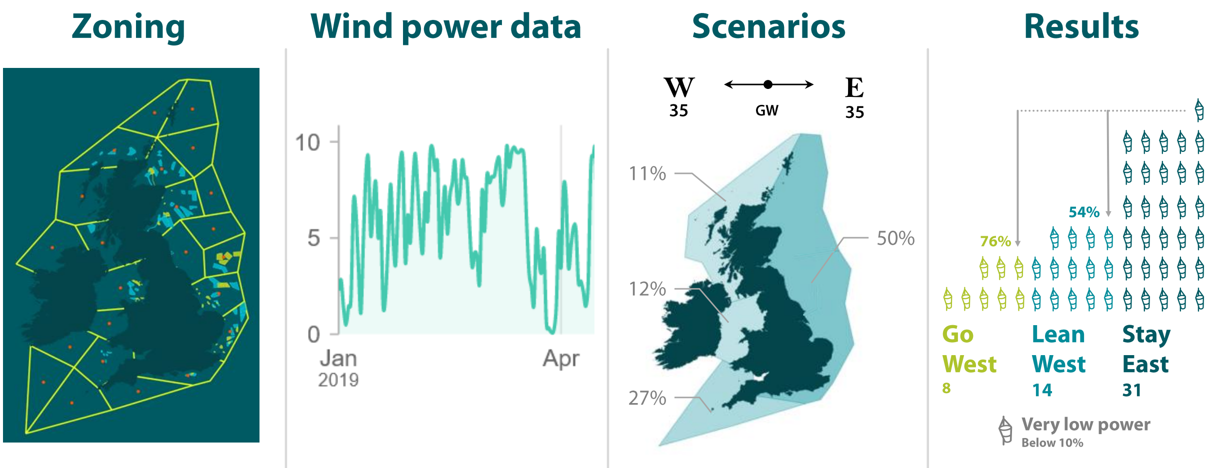


Figure 13: Overview of the *Go West!* data analysis methodology

2.2 Zoning

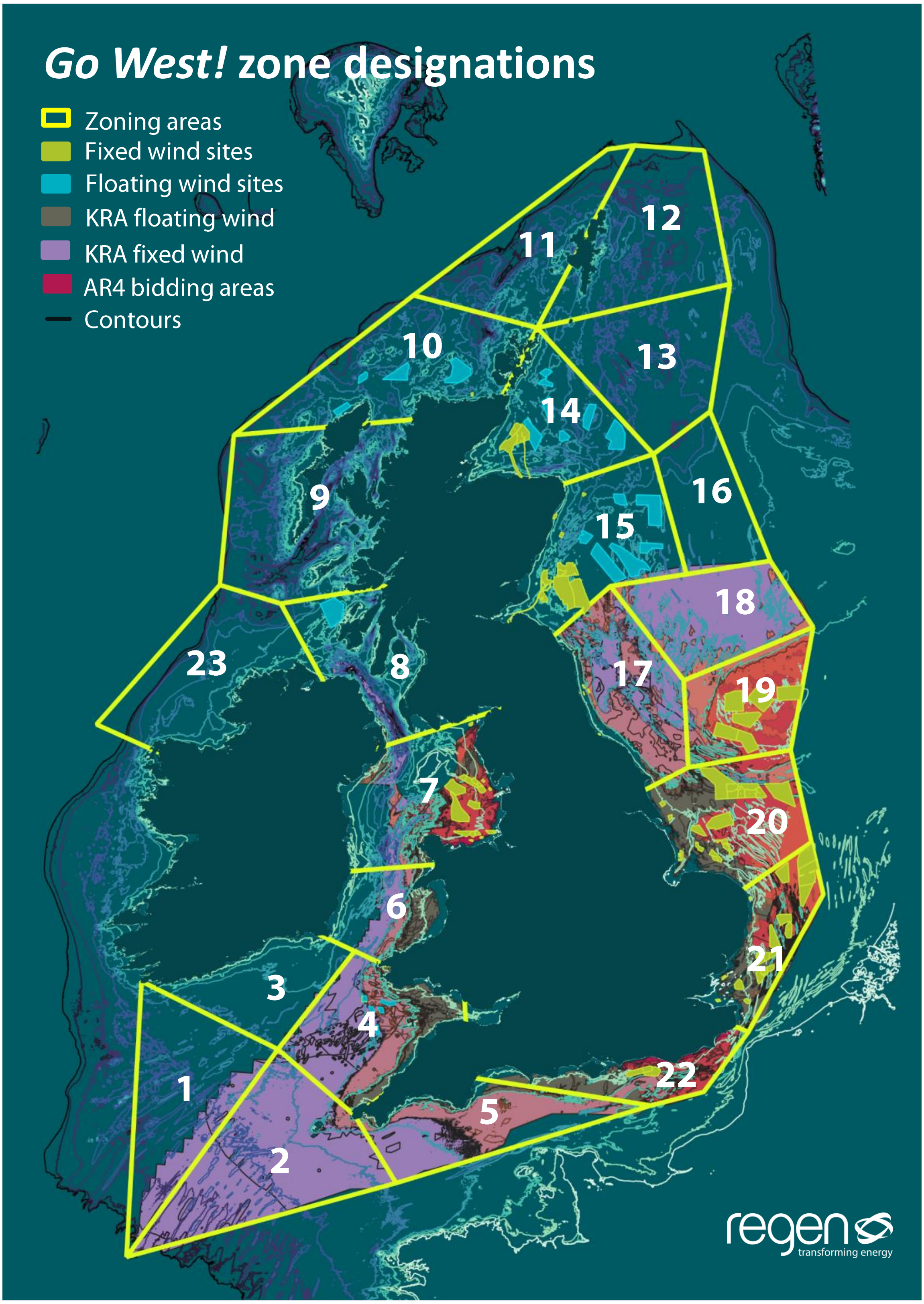


Figure 14: Map of zones designated to assess wind resource around the UK and Ireland.

Offshore waters covering GB's exclusive economic zone (EEZ) alongside a proportion of Ireland's EEZ were split into 23 discrete zones to provide a basis for the analysis.

To produce a baseline of the current distribution of offshore wind capacity whilst also informing areas of future build-out, it was important to ensure that the zones reflected the current UK offshore wind fleet whilst incorporating technical and geological considerations for future projects. With this in mind, several factors were used to inform the boundary and positioning of each zone:

- Locations of operational and under construction wind farms – this set the baseline for the current and near-future geographical distribution of UK offshore wind capacity.
- Locations of devised wind farms – devised wind farms include projects that have secured agreements/options for leases but are still in the planning phase, and projects that are at the pre-planning stage. This includes projects awarded in the ScotWind leasing round and model locations of projects in the Celtic Sea. Although such projects have not been granted leases, they demonstrate the possible future geographical capacity spread that may be granted. It is worth noting that the zones were generated before the release of The Crown Estate's Areas of Search within the Celtic Sea.
- Offshore Wind Leasing Round 4 bidding areas – this provided a general overview of seabed areas already scoped out by The Crown Estate for offshore wind development. It is assumed that future leasing rounds of offshore wind on the east coast will include areas established but not fully utilised within Round 4, and therefore provides a good prediction as to the growth of the eastern offshore wind fleet capacity.
- The Crown Estate's Key Resource Areas (KRAs) – The Crown Estate's KRAs, for both fixed and floating offshore wind, use landscape assessments to define areas of seabed in which respective offshore wind technologies are deemed technically viable over a given period. This provided an estimate of the future build-out of projects based on foundation technology types.
- Bathymetry – the depth of the seabed can limit the deployment of offshore wind turbines in certain areas. Fixed offshore wind monopiles are limited to approximately 50 m depth, so further expansion of a wind farm within an area will not exceed this depth limitation. For floating offshore wind, it is assumed that initial projects will be in depths ranging from 100–125 m with a progression to deeper water as the technology and sector advance.

Boundaries between zones were designated according to the above considerations – e.g. planned and existing projects were not split across two zones, and resource area boundaries were followed as closely as possible – to create a representative discretisation of UK waters.

The coordinates of each zone's centre point can be found in section 6.1.

2.3 Wind power time series data

Wind power time series data was acquired from the Renewables.ninja[32] website, a tool made by Stefan Pfenninger and Iain Staffell to help make scientific-quality weather and energy data available to a wider community. Renewables.ninja takes weather data from global reanalysis models and satellite observations (for wind data, the NASA MERRA-2 model is used). Wind speeds are converted into power output using the Virtual Wind Farm (VWF) model. For more information, see Appendix B: Renewables.ninja data.

2.3.1 Capacity factors and correlation

To date, capacity factors for offshore wind farms around the coast have typically varied from around 35% to 60% and are expected to increase in future with improved siting and turbine reliability. The exact value will depend both on the location and the characteristics of the turbines used. Figure 15 shows indicative capacity factors for each zone calculated for the period 2000-2019 using Renewables.ninja data derived from a generic turbine power curve (see Appendix B: Renewables.ninja data) with a 100 m hub height at the centroid of each zone. As with Renewables.ninja data in general, the values do not consider turbine availability[33] or wake effects. Both factors would be expected to reduce the absolute capacity factors achieved. As wind turbine technology improves in the future, these capacity factors are expected to increase. The BEIS document 'Electricity Generation Costs 2020' projects that the capacity factor for offshore wind turbines commissioned in 2025 will be 51%, rising to 63% by 2040. Figure 15 shows that the calculated zonal capacity factors show good alignment with BEIS projections of future wind turbine characteristics:

[32] See www.renewables.ninja and the related paper *Staffell, Iain and Pfenninger, Stefan (2016). Using Bias-Corrected Reanalysis to Simulate Current and Future Wind Power Output. Energy 114, pp. 1224-1239. doi: 10.1016/j.energy.2016.08.068*

[33] 'Availability' is defined as the percentage of total time, or energy, that a wind turbine or farm can generate electrical power. Events such as turbine faults and maintenance schedules result in reduced turbine availability.

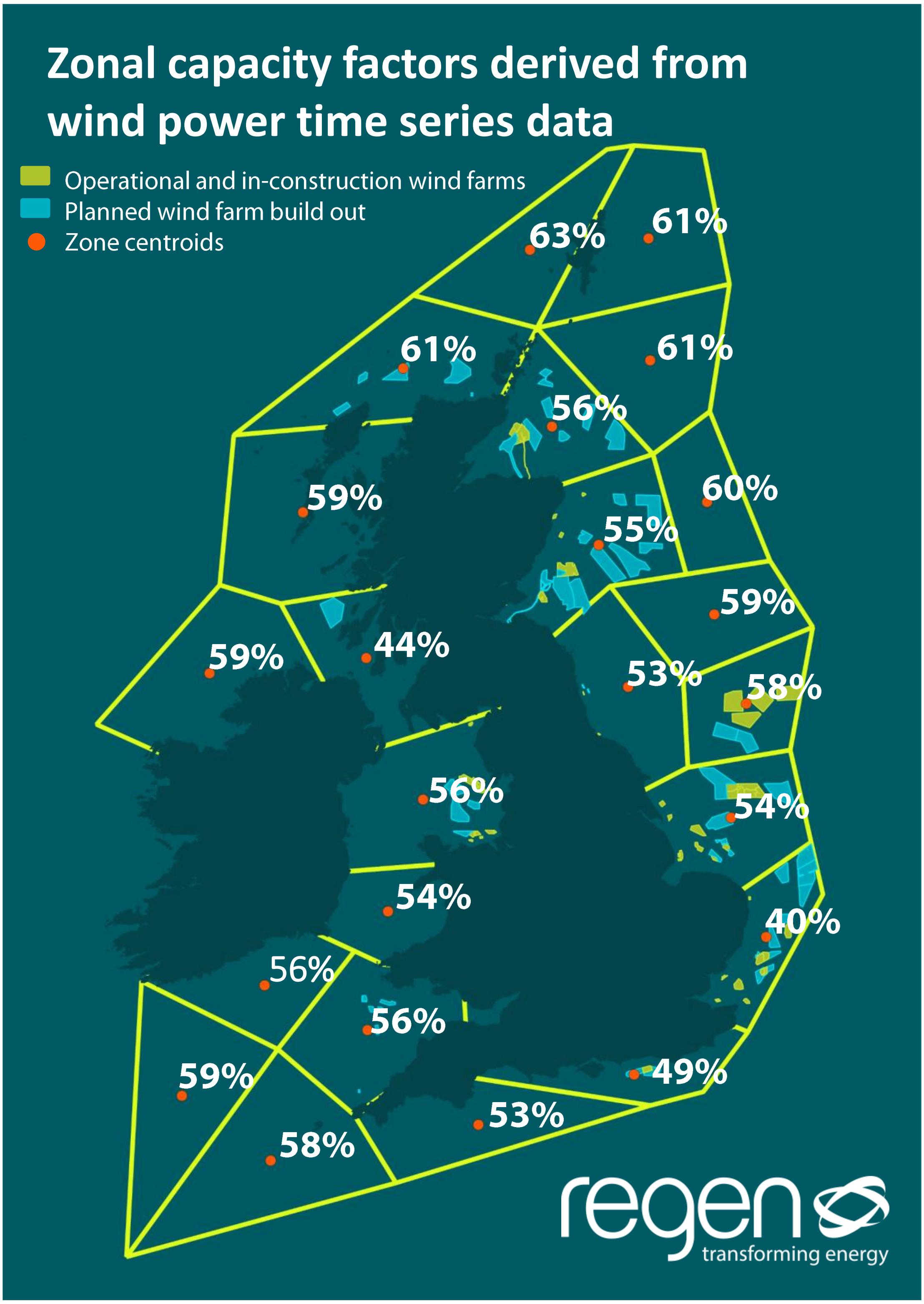


Figure 15: Zonal capacity factors using Renewables.ninja historical (2000-2019) VWF model data.

2.3.2 Example of regional diversity of wind power generation (February 2018)

Whilst zonal wind capacity factors are of interest, it is the level of correlation between zones that is important for the *Go West!* study. Figure 16 shows an indicative one-month time series of capacity factors for three zones around the UK, with a clear anticorrelation of wind resource at certain times.

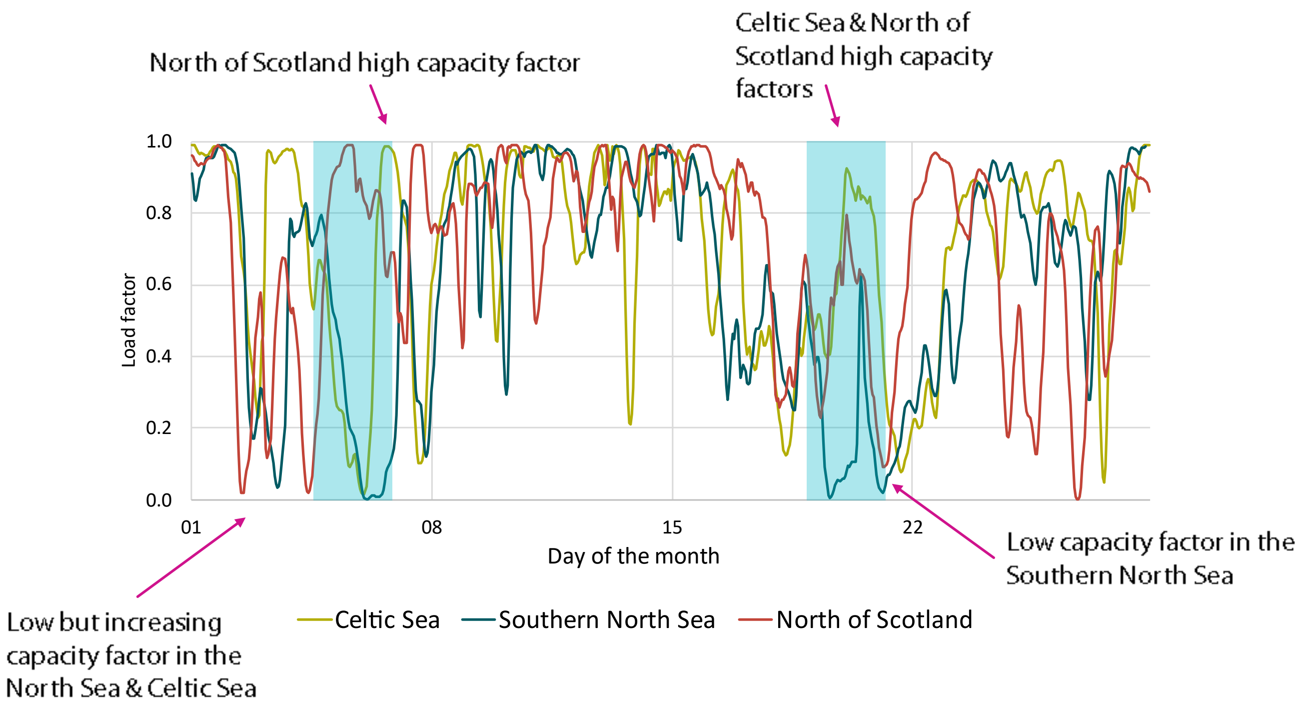


Figure 16: Wind capacity factor time history for February 2018

For example, during the first week, there is a period (highlighted) where the output from the southern North Sea and the Celtic Sea fall close to zero, whilst the North of Scotland is approaching full output. This is followed by an increase in output from the Celtic Sea, which precedes a similar increase in the North Sea capacity factor by around 12 hours.

2.4 Scenarios

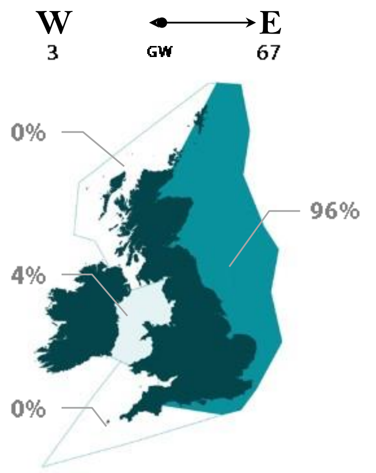
Three primary scenarios and several sensitivity studies were defined to explore the impact of wind fleet geographical diversity on power generation. The following principles were used:

- **Each hypothetical wind fleet scenario comprises a 70 GW offshore wind fleet**. 70 GW was selected as an intermediate target on the trajectory to the UK's 2050 Net Zero ambitions, based on National Grid's Future Energy Scenarios 2022 projected 70 GW of offshore wind capacity in 2034 under the Consumer Transformation scenario. The Energy System Catapult's 'Solving the Offshore Wind Integration Challenge' showed that system cost optimisation indicates at least 50-70 GW in all scenarios, with credible, cost-effective systems designs still possible up to 150 GW. Assuming a 60% capacity factor, the CCC 6th Carbon Budget estimates an installed capacity of 70 GW by around 2040-2048, depending on the scenario.
- All scenarios and associated sensitivity studies include UK offshore wind farm capacity as of June 2022 that is **existing or 'under construction'**.
- Additional capacity to create a 70 GW offshore wind fleet is, where possible, chosen from the **existing pipeline, including early-stage concept projects**.
- **In the primary scenarios, all capacity is within the UK EEZ**. However, one sensitivity study – named 'Go West + Further West' – explores the impact of coordinating with Irish offshore wind developments for the benefit of both countries.

Table 1 illustrates the three primary scenarios used in the *Go West!* study. For more information on the sensitivity study analysis, please see 6.4 Appendix D: Sensitivity studies. Note that installed capacity is defined per zone, but for simplicity, Table 1 illustrates the scenarios on a regional basis.

Table 1: Primary scenarios used for *Go West!* study. Indicative proportions of regional capacities are given, alongside an indication of the east-west offshore wind power capacity balance.

Primary scenarios

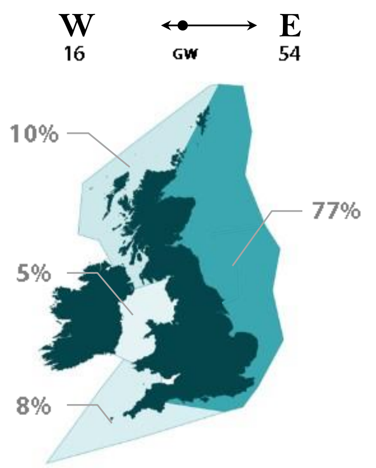


Stay East

Reflects development of east coast projects only

Includes all existing capacity and capacity under construction for all zones.

Further capacity is built using early pipeline proposals in North Sea zones only.



Lean West

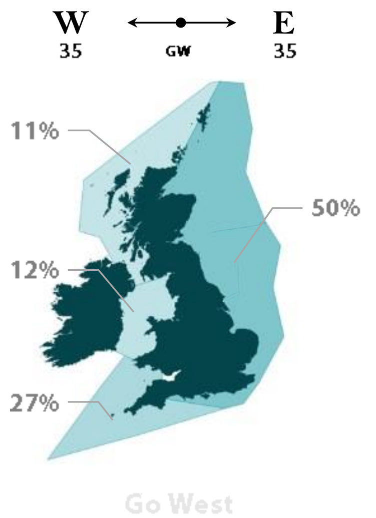
Demonstrates the impact of building out west coast projects that have already been identified.

Includes all existing capacity and capacity under construction.

Includes all proposed capacity in:

- UK Celtic Sea (5.9 GW)
- West and Northern Scotland (6.9 GW)
- Off North Wales (0.75 GW)

The remaining capacity to reach 70 GW is spread across proposed projects in the North Sea



Go West

Shows the benefit of spreading capacity equally between the east and west coasts.

Includes all existing capacity and capacity under construction.

Includes all proposed capacity in west and north zones.

Adds additional capacity in the Celtic Sea, West English Channel, UK parts of the Irish Sea, and north and west Scotland until 50% of capacity (35 GW) is built on the west coast.

3 Results

3.1 Stay East vs Go West comparison

A 'Go West' offshore wind portfolio reduces the frequency and duration of 'peaks' and 'troughs' in generation and smooths generation volatility.

-164 hours per year
where offshore wind power is
less than 10% of capacity

Go West 64 hrs/yr | **Stay East** 227 hrs/yr

-103 hours per year
where offshore wind power is
greater than 80% of capacity

Go West 1.417 hrs/yr | **Stay East** 1,520 hrs/yr

-76%
Number of events per year where
UK offshore wind power is
less than 10% of capacity

Go West 8 events/yr | **Stay East** 31 events/yr

-18%
Number of events per year where
UK offshore wind power is
greater than 80% of capacity

Go West 46 events/yr | **Stay East** 56 events/yr

-24%
Reduction in **average**
hourly ramp rate

Go West 1.0 GW/h | **Stay East** 1.3 GW/h

-43%
Reduction in average
peak annual ramp rate

Go West 7.4 GW/h | **Stay East** 13.1 GW/h

Figure 17: A comparison of metrics resulting from wind resource analysis of the 'Stay East' and 'Go West' scenarios

The above dashboard highlights the primary metrics comparing the Stay East and Go West scenarios, modelling a 70 GW UK offshore wind fleet using 20 years of historical wind data. See the Executive summary for illustrations of this data and analysis of the 'Lean West' scenarios.

A brief description of each dashboard metric is as follows:

Hours per year where offshore wind power is less/greater than X% of capacity

The average number of hours per year where the modelled 70 GW offshore wind fleet is generating power above/below the specified capacity threshold (e.g. 10% of capacity is 7 GW, 80% of capacity is 56 GW)

Event

A single continuous period, lasting one or more hours, where wind power output is lower/higher than a defined threshold.

Number of events per year where offshore wind power is less/greater than X% of capacity

The average number of occurrences each year where the output of the modelled 70 GW offshore wind fleet crosses the specified capacity threshold. This metric does not consider time spent below/above the threshold, only the number of times the threshold is crossed each year on average (i.e. a one-hour and a four-hour period below 10% of capacity are both counted as single events).

Ramp rate

A measure of the magnitude of offshore wind power generation volatility. This metric does not distinguish between increases and decreases in generation power. Ramp rate is the magnitude of the change in power in the space of one hour. Since the resolution of the underlying wind resource data is at hourly intervals, we have analysed the ramp rate at hourly intervals.

Average hourly ramp rate

The magnitude of the average change in offshore wind fleet power generation in a one-hour period.

Mean annual peak hourly ramp rate

A measure of maximum volatility, this takes the peak hourly ramp rate for each of the 20 years of data and then calculates the average of those 20 values.

Note: comparisons and references made to increases/decreases in the following sections relate to data from the Go West scenario relative to the Stay East scenario.

3.2 Regional correlation versus diversity

As highlighted in section 2.3.2, the level of correlation between different regions and zones around the UK is an important consideration in the *Go West!* study. A preliminary analysis correlated each zone with the east coast-focused GB wind fleet power output[34].

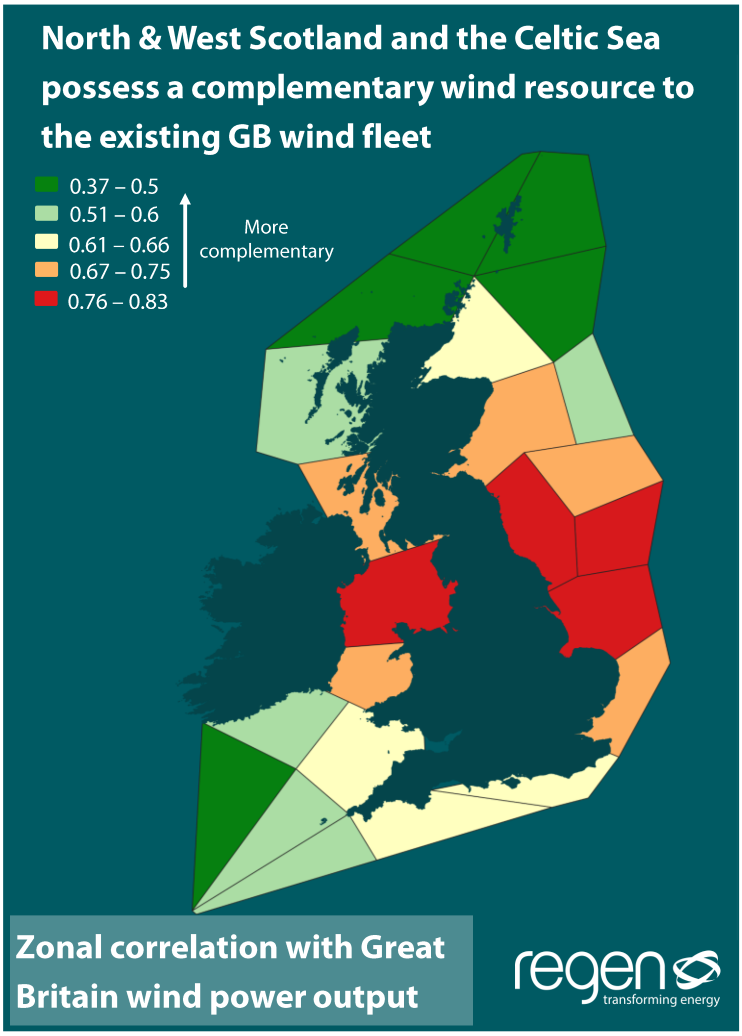


Figure 18: Wind resource correlation between each zone and GB wind power output. Green indicates a lower correlation, meaning a more complementary zonal wind resource. Red suggests a higher correlation and zonal wind resource that is more synchronised.

Figure 18 shows that wind resource to the west and, in particular, north of Scotland and in the Celtic Sea had reduced correlation (i.e. was more complementary) with the current east coast-

34 Zone power output data was acquired from Renewables.ninja. 2018 GB wind fleet power output, including both onshore and offshore, was acquired from National Grid ESO data.

focused GB wind fleet (using data from 2018). This suggests these areas offer a more complementary wind resource when wind resource along the east coast is low.

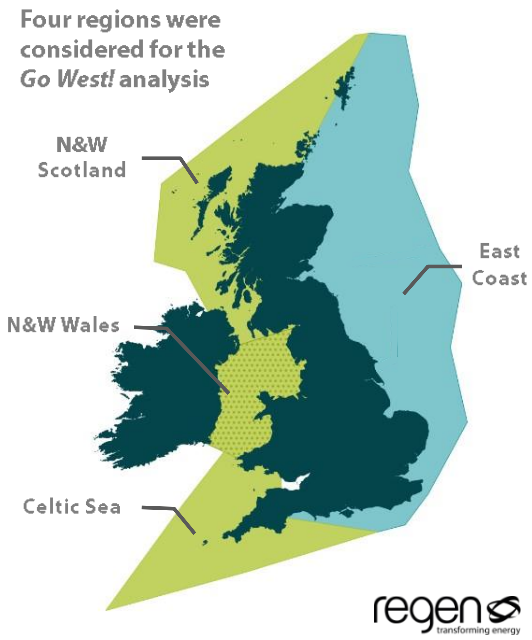


Figure 19: Regions assessed for correlation with east coast wind resource.

A further analysis was performed to assess the correlation between different regions at varying levels of wind speed. Each region (Figure 19) encompasses several zones (defined in section 2.2). The wind speed for each region was calculated as a weighted average of zonal wind speeds within the region, with the weightings for each zone defined by the offshore wind fleet capacity per zone in the 'Go West' scenario. Wind speed data was acquired from Renewables.ninja for 2019.

The wind speed time history for all regions was sorted into deciles[35], with each decile defined by the level of east coast wind speed. Each decile was then assessed to see the level and variability of wind speed in each region and the degree of correlation or diversity with the east coast.

This analysis revealed an important aspect of wind speed correlation across the UK. When wind speeds are lower on the east coast, wind speeds in the north and, in particular, west are higher and, therefore, more complementary to the east coast. But when wind speeds are higher on the east coast, wind speeds in the north and west are also higher, and so are more correlated with the east coast. Therefore, it is expected that the energy system benefits of a more geographically diverse wind fleet would be more pronounced at lower wind speeds.

These results are illustrated in Figure 20, Figure 21 and Figure 22.

[35] The first decile contains 10% of all data points with the lowest East Coast wind speeds, the tenth decile contains the 10% of all data points with the highest East Coast wind speeds, and so forth with deciles between.

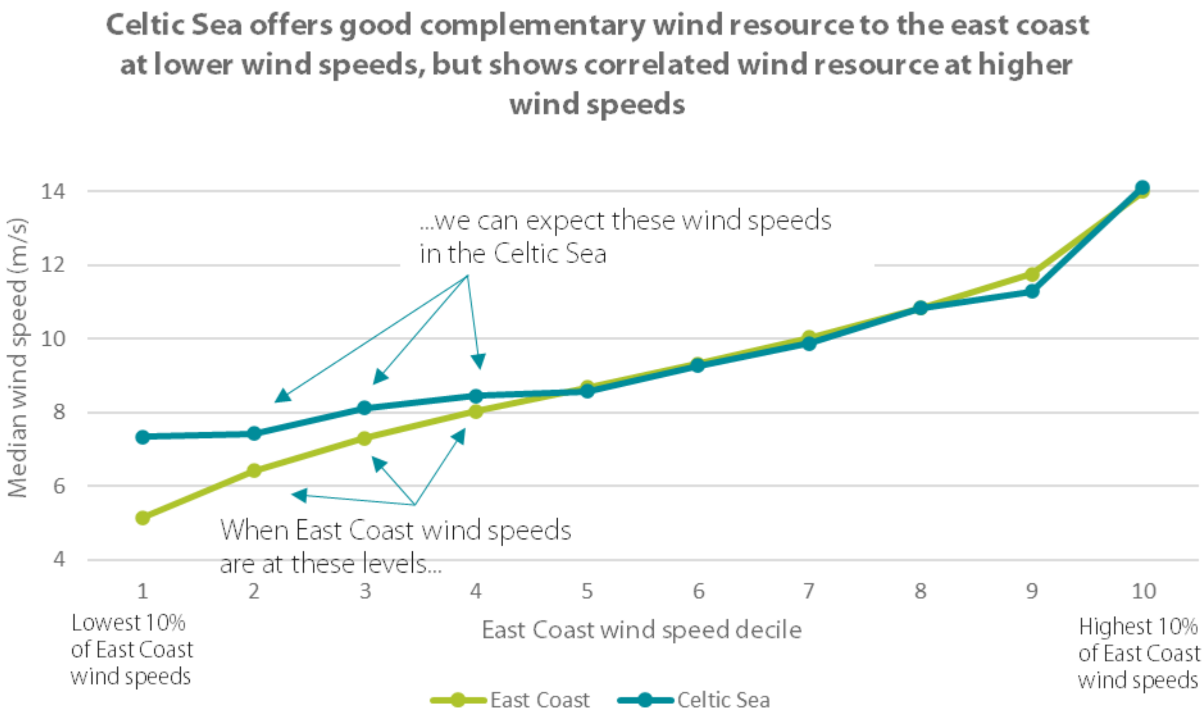


Figure 20: Celtic Sea (median) wind speeds occurring at the same time as east coast wind speeds

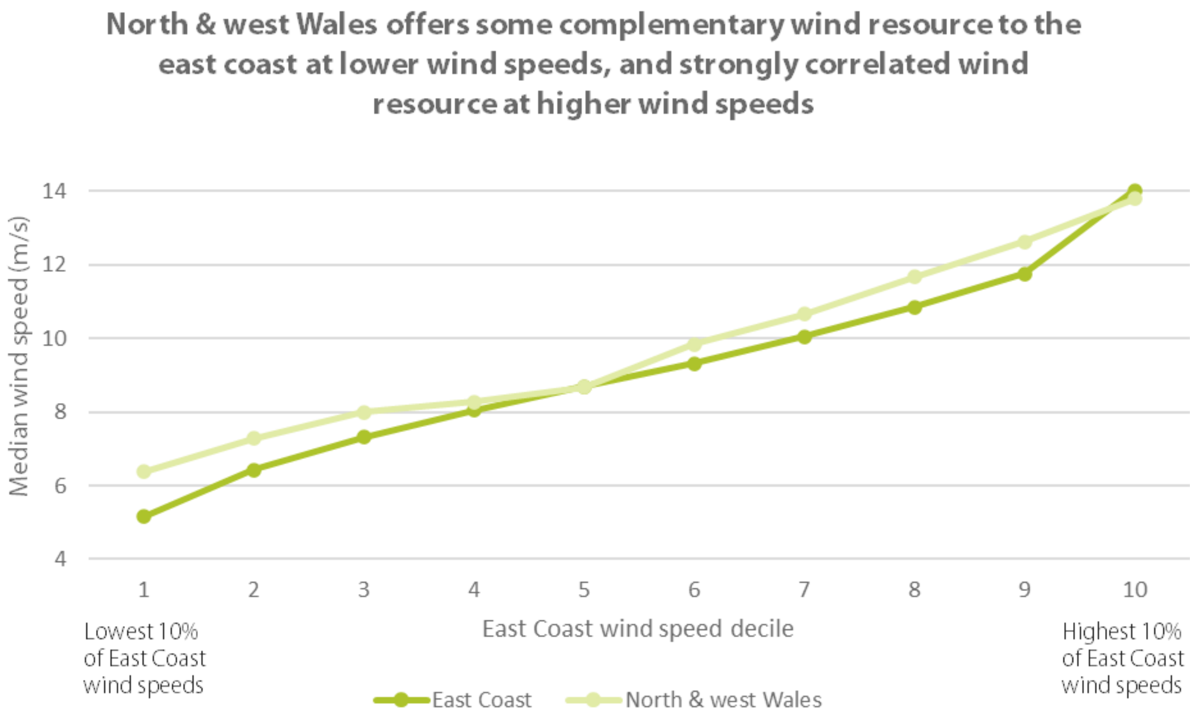


Figure 21: North & west Wales (median) wind speeds occurring at the same time as east coast wind speeds

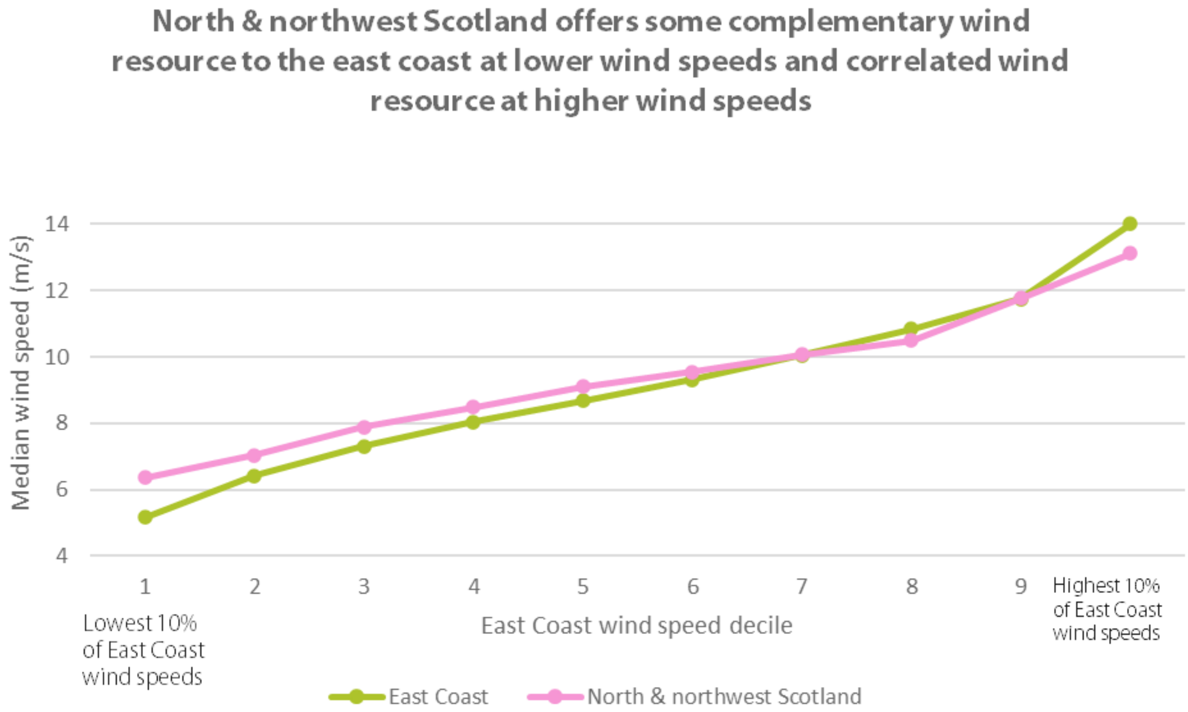


Figure 22: North & northwest Scotland (median) wind speeds occurring at the same time as east coast wind speeds

Figures 20-22 demonstrate that the Celtic Sea, north & northwest Scotland, and north & west Wales regions have reduced wind speed correlation with the east coast at lower speeds and therefore are more complementary, but that the sites have a stronger positive correlation at higher east coast wind speeds.

3.3 Periods of time at high and low power generation output

Relative to the ‘Stay East’ scenario, the ‘Go West’ scenario results in:

- A significantly lower proportion of time at low power (below 30% capacity factor)
- An increase in time spent at mid power (30-80% capacity factor)
- Slightly less time spent at high power (above 80% capacity factor).

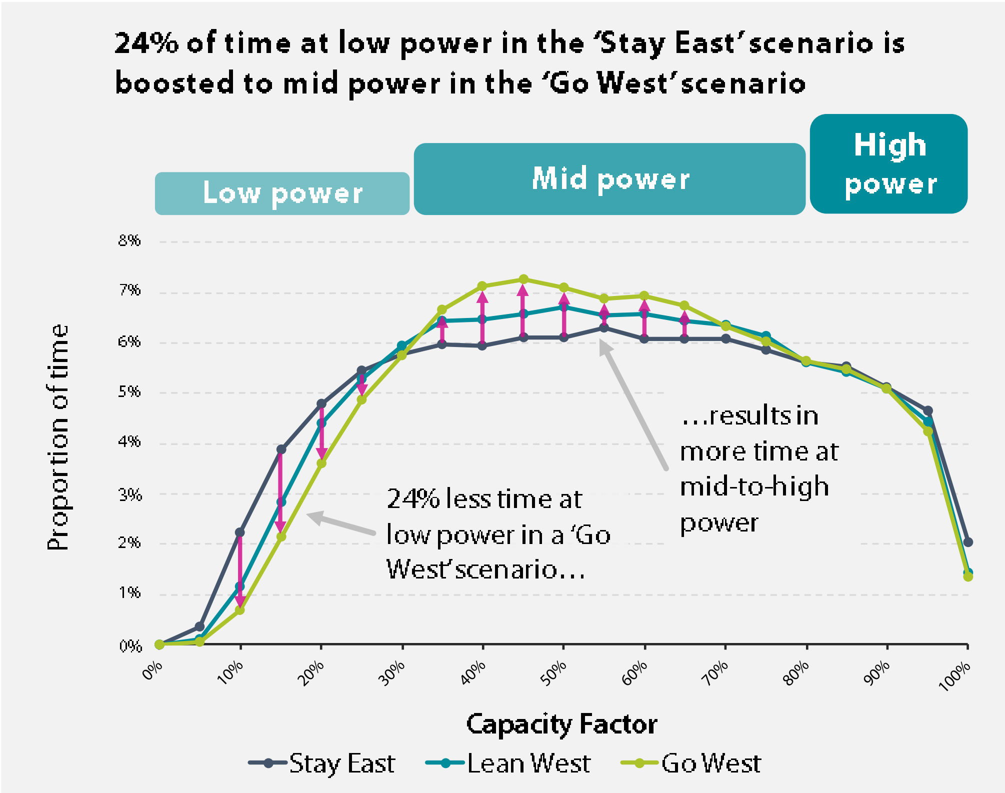


Figure 23: Proportion of time that the modelled offshore wind fleet spends at varying capacity factor levels under each scenario

Figure 23 highlights the 473 hours (24%) reduction in time (one-year average) that offshore wind power is below a 30% capacity factor in the Go West scenario, with a commensurate increase in time spent in the ‘mid power’ 30-80% capacity factor range. This results in a more consistent and predictable supply of offshore wind power, as well as a reduced need for dispatchable, carbon-emitting generation.

The difference between the scenarios during periods of high power generation (defined as periods above 80% capacity factor) is less pronounced, with an average annual reduction of 103 hours per year (a 7% reduction). This could help to reduce the level of renewable energy curtailment during periods when generation exceeds total demand.

Figure 24 shows the 164 hours average annual reduction (72%) in time that the offshore wind fleet is generating power below a 10% capacity factor on a month-by-month basis. In December and January, the time of year when heating and conventional demand peaks, we can see the Go West scenario almost entirely eliminates the time below 10% capacity factor. This will give greater security of supply as home heating becomes increasingly electrified in the UK.

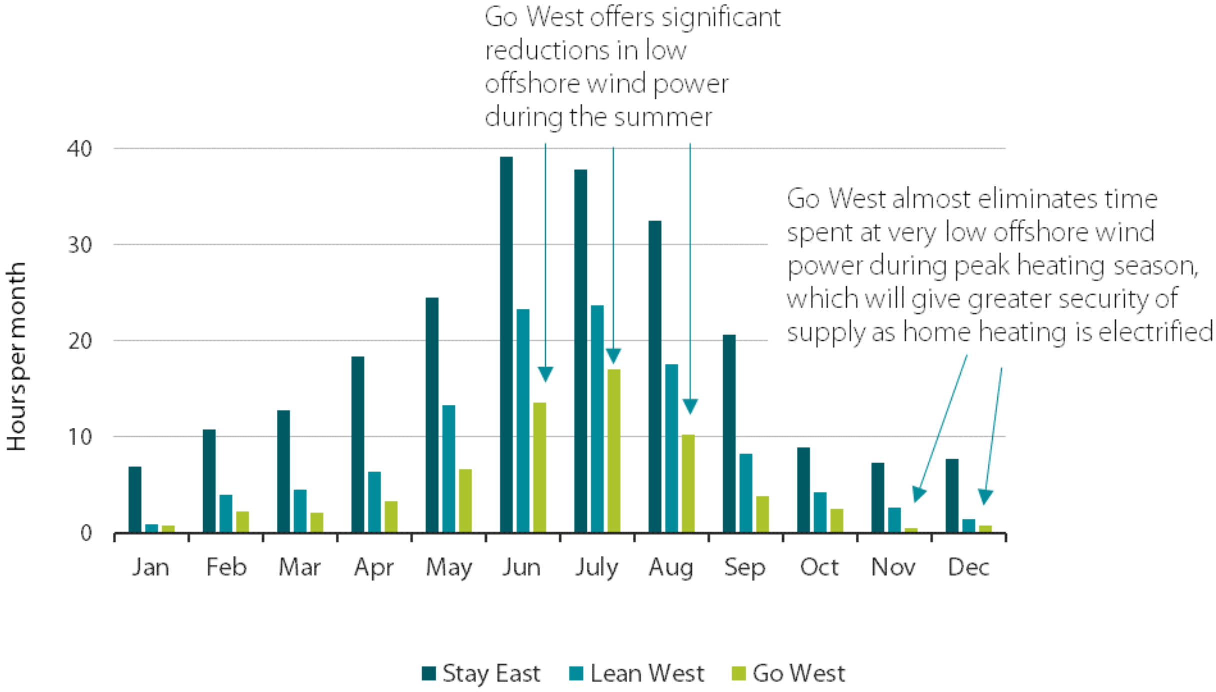


Figure 24: Average time per month where total offshore wind power is below 10% capacity factor

3.4 Number of events at high and low power generation

The 'Go West' scenario significantly reduces the number of events of extreme low and high generation relative to the 'Stay East' scenario.

'Go West' significantly reduces the number of low power (below 10% capacity) occurrences and halves the duration of the longest event in 20 years of data

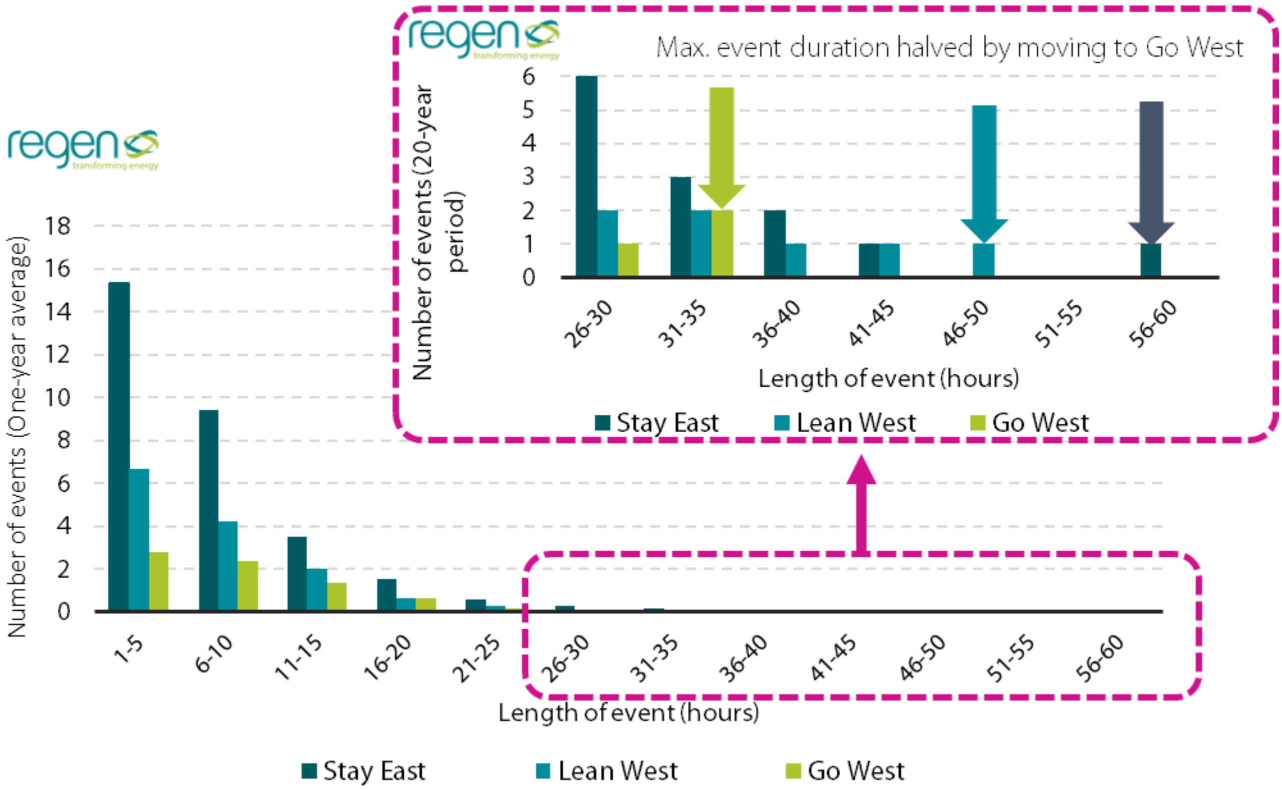


Figure 25: Average annual number and length of events where total offshore wind generation is below 10% capacity factor (one-year average in 20 years of data)

Figure 25 shows the 76% reduction in the average number of events per year where UK offshore wind power is below 10% capacity factor in the Go West scenario. The inset graph highlights the near-halving of the duration of the longest 1-in-20-year event, significantly improving the suitability of battery storage solutions for such low-power events. The coloured arrows indicate the longest duration event for each of the scenarios.

Figure 26 illustrates the 86% reduction in the number of events and their duration in a 20-year period where UK offshore wind power is below 5% capacity factor. Figure 27 illustrates the 18% reduction in the number of events where offshore wind power is above 80% capacity factor.

'Go West' greatly reduces the number of extreme low power (below 5% capacity factor) occurrences from offshore wind

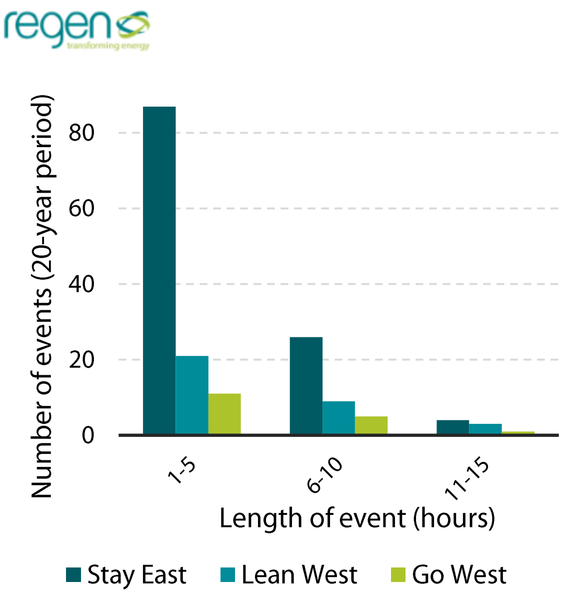


Figure 26: Number and length of events in a 20-year period where total offshore wind generation is below 5% capacity factor

'Go West' slightly reduces the number of occurrences of high power (above 80% capacity factor) by 18%

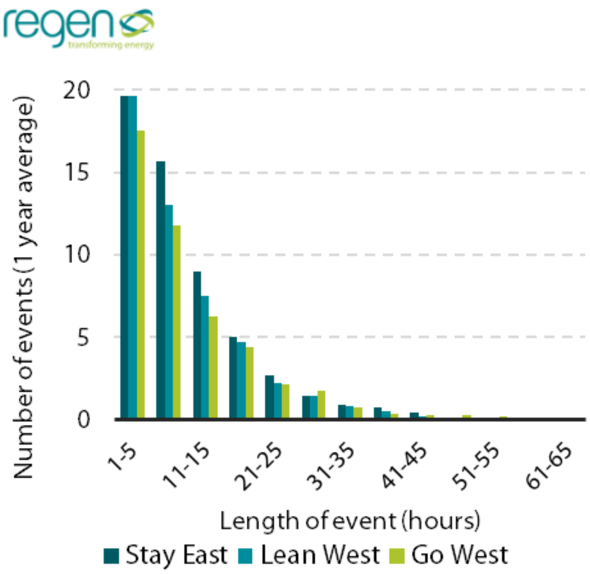


Figure 27: Annual average number and length of events where total offshore wind generation is above 80% capacity factor (one-year average in 20-year data)

3.5 Ramp rate

The 'Go West' scenario has fewer periods with higher magnitude ramp rates than the 'Stay East' scenario, resulting in a less volatile offshore wind power supply, as illustrated by Figure 28.

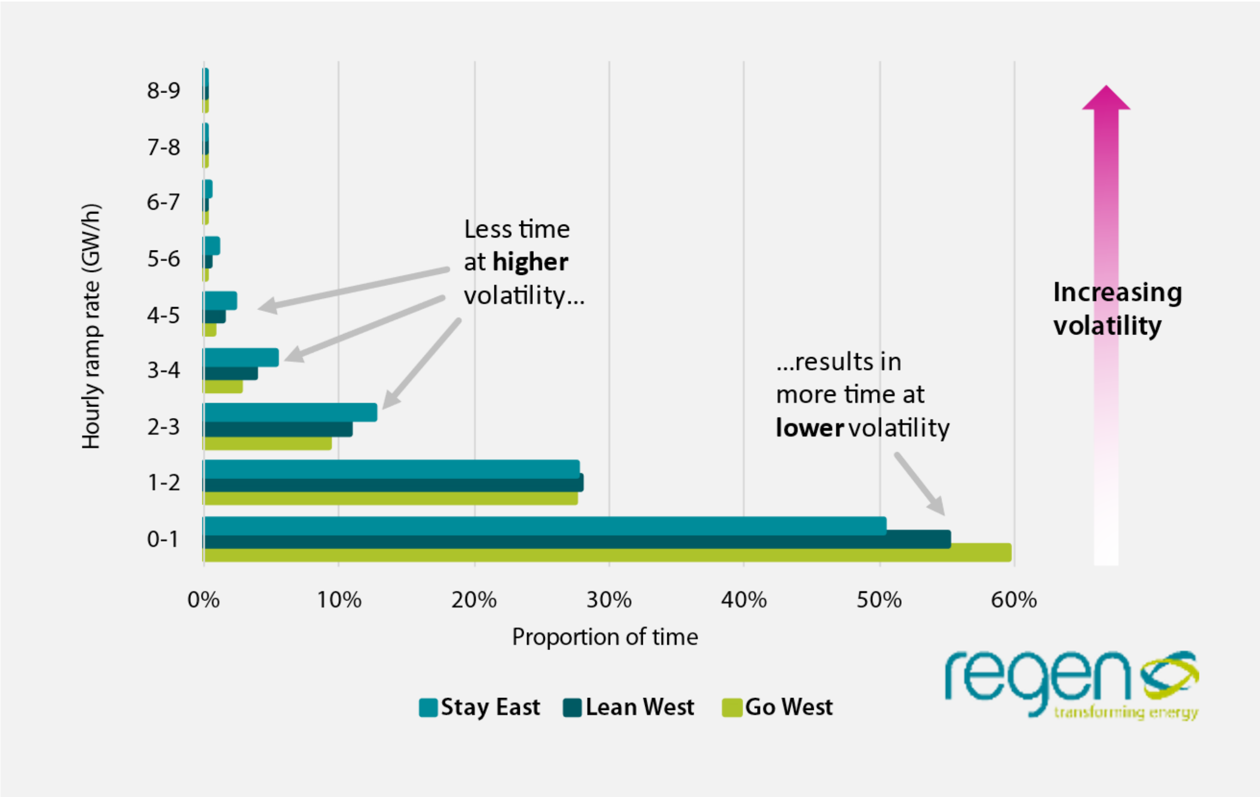


Figure 28: Proportion of time that the modelled offshore wind fleet (per scenario) spends at varying hourly ramp rates

4 Energy system impacts and potential benefits

The *Go West!* analysis shows that the impact of a more diversified and balanced offshore wind portfolio will be to reduce the 'peaks and troughs' of electricity generation, reduce the volatility of electricity supply through lower 'ramp rates', and provide a more balanced geographic spread of electricity generation across GB.

This section of the report sets out the potential sources of system benefits, how they could be impacted by a more diversified wind portfolio and how that benefit (or cost) could be evidenced. It is beyond the scope of this paper to fully explore and quantify each of the system benefits, requiring extensive system and network modelling, but this could be an excellent follow-on project.

Intuitively, the outcomes highlighted above should also result in significant energy system benefits, including a reduction in the capacity margins needed for energy security, a reduction in balancing risk for market participants, lower overall system balancing costs and a reduction in wholesale price volatility. A reduction in wholesale price volatility would itself have a number of subsequent benefits, including reducing market risk and the potential for economic inefficiency through 'bullwhip' (see Explainer: Bullwhip Effects in section 4.3.3) and price speculation effects.

Diversity of energy generation should also reduce the impact of price cannibalisation[36] and improve the overall wholesale capture price for wind farm generators. In a normal market[37], this would allow generators greater revenue certainty, thereby reducing investment risk and potentially accelerating renewable energy deployment.

However, the findings of the *Go West!* analysis suggest that the benefit of diversity is less pronounced during periods of very high wind generation because a) when wind speed is very high in one part of the UK, it is more likely to be correlated with high winds in other regions, and b) once peak generation is reached, wind turbine power output is less variable over a range of high to very high wind speeds.

[36] Cannibalisation – phenomenon where the wholesale price of electricity falls at times when wind generation is highest, which could lead to very low or even negative wholesale prices. This is seen as a major revenue risk for investors in a high renewable energy system.

[37] The capture price benefit is compromised by the operation of the Contracts for Difference scheme. This is discussed further in section 5.

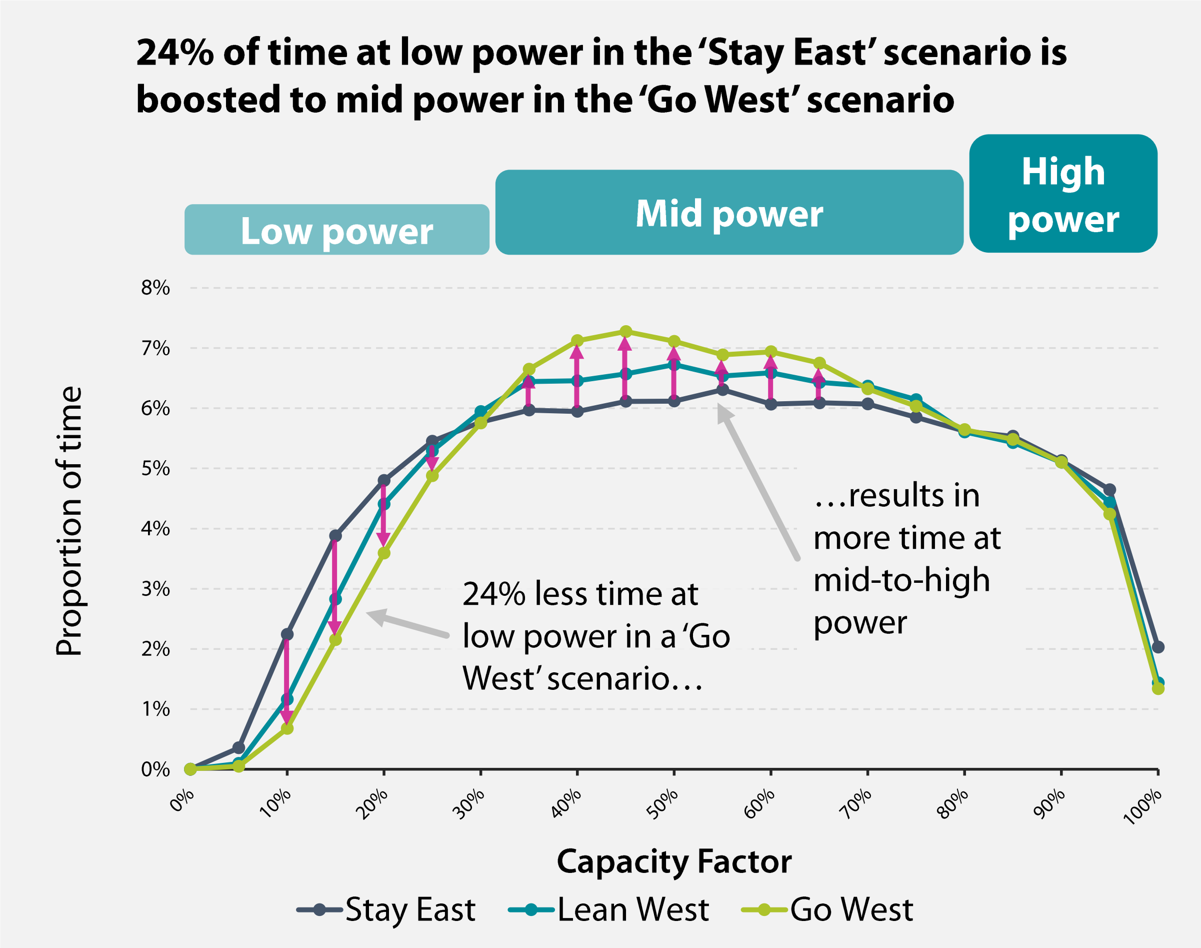


Figure 29: Average proportion of time at different capacity factor power outputs

This asymmetry of correlation and diversity during periods of low and high wind resource is important to understand and consider:

- When wind resource is low, geographic diversity helps to reduce the depth and occurrence of very low wind periods (troughs), providing significant system benefits
- Geographic diversity improves the consistency of offshore wind generation, with more time spent at moderate generation output (30-80% capacity factors)
- But when wind resource is very high in one region, it tends to be relatively high across other GB regions, so geographical diversity is less beneficial – the energy system still experiences similar periods of very high generation peaks and, therefore, lower system benefits.

A more balanced wind portfolio may also bring other benefits that are harder to quantify. For example, the risk of significant generation forecast error could be mitigated by the diversity of generation across a number of forecast areas. Making forecasting errors in a couple of zones that make up a small proportion of all areas has a smaller total detrimental impact than if the entire wind fleet were concentrated into a couple of areas (e.g. the southern North Sea and

Liverpool Bay) where forecasting errors had occurred, in which case the forecasting error would apply to the entire fleet. This would not be applicable, however, if there were systemic forecast errors that affected all regions simultaneously.

In other areas of consideration, the impact is less clear, and the benefits of a diversified wind portfolio would have to be analysed in the context of how the overall energy system architecture is designed and developed. A more diversified wind portfolio may reduce network infrastructure costs, but only if the offshore infrastructure is planned and optimised to make the best use of shared infrastructure across wind farm projects. In the Celtic Sea, for example, energy generation could be transmitted to demand centres in South Wales, the South West, Bristol, and the West Midlands, but only if there is investment in 'non-radial' shared infrastructure to integrate generation with these demand centres.

To simplify the analysis, energy system benefits and costs have been grouped into three broad categories (Figure 30), although, in reality, most energy system impacts are interrelated:

1) **Benefits related to the reduction in periods of low generation, including commodity costs of electricity**, which are driven by increased utilisation of renewable energy and 'merit-order' effects.
2) **Benefits related to the inherent value of diversity**, which improves system resilience and reduces capacity margins and capacity factors, which result in reduced network investment and flexibility costs.
3) **Benefits related to the value of lower generation volatility** include reduced ramp rates, which leads to reduced system balancing and operability costs and also reduces market risk and wholesale price volatility.

The analysis focuses on energy system benefits and therefore does not include other economic and societal benefits related to regional economic development, jobs and skills creation, support for levelling up or other community benefits and local ownership schemes, which could also be the result of a more diversified and equitable distribution of wind energy across the GB energy system.

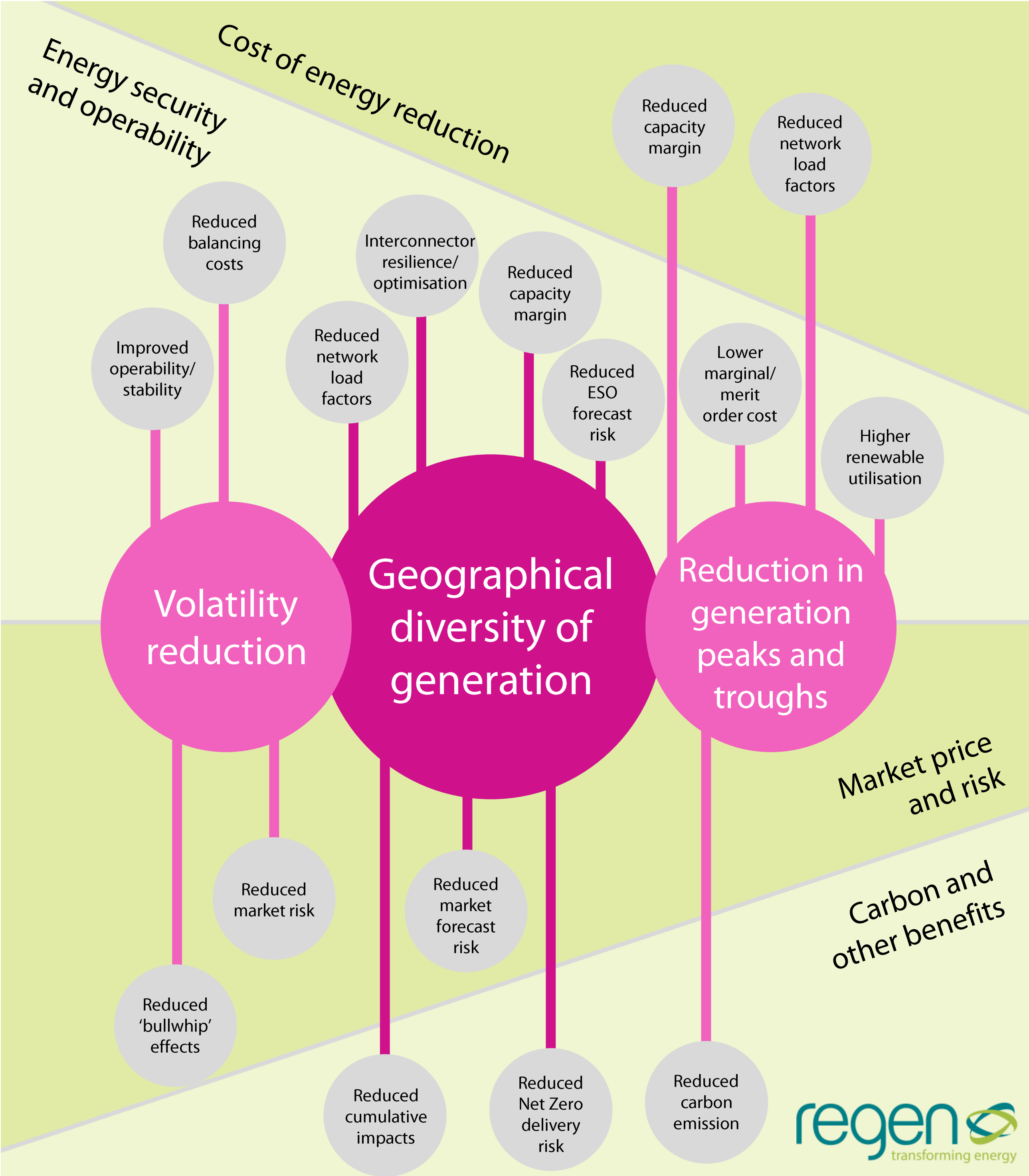


Figure 30: Summary of energy system benefits resulting from a more geographically diverse offshore wind fleet

4.1 The value of reduced peaks and troughs in generation

The *Go West!* analysis highlights a significant reduction in both the depth and number of very low wind generation periods (troughs) resulting from a more diversified offshore wind fleet. Periods of very low wind power generation still occur, but the depth, duration, and number of occurrences of these low generation periods were significantly reduced.

The benefit of diversity during high wind periods was much less pronounced. There was an average reduction of 103 hours (7%) per year where the offshore wind fleet power output exceeded an 80% capacity factor.

A 'Go West' system reduces the occurrence and duration of high and very low offshore wind power, compared to 'Stay East'

-164 hours per year
where offshore wind power is
less than 10% of capacity

Go West	**Stay East**
64 hrs/yr	227 hrs/yr

-103 hours per year
where offshore wind power is
greater than 80% of capacity

Go West	**Stay East**
1.417 hrs/yr	1,520 hrs/yr

-76%
Number of events per year where
UK offshore wind power is
less than 10% of capacity

Go West	**Stay East**
8 events/yr	31 events/yr

-18%
Number of events per year where
UK offshore wind power is
greater than 80% of capacity

Go West	**Stay East**
46 events/yr	56 events/yr

Figure 31: Impact of the 'Go West' scenario on high and very low power offshore wind generation compared to the 'Stay East' scenario

The *Go West!* analysis has included some high-level dispatch modelling (see section 6.5) to compare annual generation technology utilisation and costs using 20 years of offshore wind data. This smoothing of generation has a number of energy system benefits, including an overall reduction in the marginal cost of electricity and higher utilisation of available renewable generation compared with higher cost and higher carbon fossil fuels.

Value of reduced peaks and troughs of generation		
System Benefit	**Value created Go West v Stay East**	**Scale of benefit and evidence**
Reduced use of high-cost and high-carbon assets during low-wind periods	Levelling of generation across the GB energy system reduces periods of very low generation	Dispatch model shows a 23% reduction in the use of gas turbine generation.
Merit order benefits	Reduction in the use of higher marginal cost dispatchable generation during periods of low wind generation	Dispatch model annual average marginal cost of energy was reduced by 17%, using BEIS cost of electricity generation – this reduction would be even greater if the analysis used the current very high cost of gas generation
Carbon emissions reduction	Increased wind utilisation and reduced use of fossil fuels, leading to an overall reduction in carbon emissions	The high-level dispatch model indicates a 24% reduction in grid carbon intensity (i.e. emissions per kWh generated)
Reduction in wind energy curtailment during peak generation periods	Reduction in excess wind, above total demand, including storage and exports, saving lost energy resource. However, this benefit was limited.	Dispatch model annual average wind curtailment was reduced slightly by 4% Using a Levelised Cost of Energy figure of £55/MWh, this equates to a system value of £44 million per year

4.2 The system value of diversity

The value of diversity is well understood by system and network planners and influences all aspects of energy security and network planning. Diversity of both supply and demand, when combined with a probabilistic – or risk-based – approach to energy security, allows energy system operators and network planners to reduce the design demand (network load) and capacity margin (contingency) requirements needed to achieve a given level of energy security and network resilience. In short, greater diversity results in lower costs from network infrastructure or other forms of flexibility service.

There is a compelling argument that increasing the diversity of wind supply and reducing the level of weather-related correlation in wind generation should result in system network planning and investment benefits.

4.2.1 Lower Capacity Margins[38]

At an energy system level, diversity is a key factor that allows the National Grid ESO to estimate the optimal capacity margin needed to maintain a given level of energy security – expressed as a Loss of Load Expectation (LOLE) – during the winter peak demand period, for example. The more diverse the supply of energy in terms of technology, number of assets, fuel type and geography, the lower the proportional impact of any single failure and, therefore, the lower the capacity margin needed to maintain a given LOLE.

This has a direct cost impact since it will determine, amongst other things, how much capacity the UK government needs to secure through the Capacity Market (CM) and the clearing price of that CM auction.

Diversity of offshore wind generation and the reduced occurrence and duration of extreme low wind events would, under the National Grid ESO capacity margin methodology, lead to an increase in the derated capacity of wind generation and, subsequently, a reduced capacity margin requirement. The 2021 Capacity Market T1 auction clearing price for year-ahead capacity was £75/kW[39]. This suggests a potential annual cost saving of £75 million per GW of increased offshore wind derated capacity.

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[38] See for example National Grid ESO Winter Outlook - https://www.nationalgrideso.com/document/264521/download, https://www.nationalgrideso.com/document/212691/download

[39] https://www.gov.uk/government/collections/electricity-market-reform-capacity-market

4.2.2 Network infrastructure cost impacts

The impact of a more diversified portfolio on network load and infrastructure requirements is more difficult to quantify and is beyond the scope of this paper. It would also be heavily dependent on the overall holistic design of network infrastructure, including how offshore wind generation is integrated with interconnectors, energy storage assets and, for example, the location of hydrogen storage. This requirement to think and plan holistically is discussed in section 5.1 'Policy implications and recommendations'.

If planned holistically, a more diversified wind portfolio could lead to lower overall network infrastructure costs for the following reasons:

- There are more points of entry to the transmission network, creating an opportunity to spread variable generation across the network topology and align offshore wind with the location of interconnectors and other forms of generation.
- There is an opportunity to integrate offshore generation with areas of demand. This is especially true of the Celtic Sea area, which is near areas of demand in South Wales, Bristol and the South West, and the West Midlands. These areas currently face higher than average Transmission Network Use of Service charges (TNUoS) for demand customers, indicating that there is a relative imbalance of demand and generation[40] that requires power to be transmitted from other regions.
- There is an opportunity to align wind generation with new forms of demand and the manufacture and distribution of other fuel sources, such as the production of hydrogen.

As a counterpoint, diversity of generation could also lead to increased network infrastructure costs if the offshore generation is not well integrated with areas of demand, storage, and interconnectors.

4.2.3 Diversity and forecast error risk

Diversity of energy generation does not make forecasting easier, but it can reduce the overall impact of forecast errors. A concentration of wind turbines in a single weather window means that the impact of forecasting error is amplified, potentially leading to much higher system costs and market price volatility (these two impacts are closely linked and can be amplified – see section 4.3 'Value of lower generation volatility'). Diversity of generation across multiple

[40] Of the 14 TNUoS regions the South Western region has the highest demand tariff; South Wales has the 10th highest. https://www.nationalgrideso.com/document/207346/download

weather windows reduces that risk as an incorrect forecast becomes one in several individual forecasts, thereby reducing its impact overall.

Forecast error is one of the key triggers of supply disruption events, which can, in turn, lead to 'bullwhip' effects that drive up system balancing and market costs. These are discussed further in section 4.3.3.

4.2.4 Diversity and a smart, flexible and integrated energy system

Diversity of generation, both in terms of geography and technology, is a key feature of a smart and flexible future energy system. As well as helping to balance supply and demand at a national level, diversity of generation also fits well with a future energy system by:

- Creating more opportunities to increase and optimise energy storage
- Allowing greater use of hydrogen electrolysis at the point of onshore connection
- Potentially allowing better alignment with interconnectors and the use of multi-purpose interconnectors, which, in a Go West scenario, would include integration with Ireland and North-West Europe.

4.2.5 Other benefits of diversity

Diversity brings challenges and risk – opening up new areas of seabed for development, investing in new infrastructure, building new supply chains and dealing with new barriers and constraints. It has been tempting, therefore, to continue to build out offshore wind within the same geographic area, to follow precedents and exploit economies of scale, infrastructure, and learning. This has been a key factor that has helped to reduce offshore wind costs over the last decade.

However, there is a counterargument that is now gaining traction. Continuing to deploy wind in the same areas has cumulative impacts on marine users, the environment, communities that are hosting infrastructure and other wind farms. At a certain point, these cumulative risks and the absolute reduction of developable sea areas begin to outweigh the advantage of continuity.

Diversity could then become a positive advantage, reducing cumulative impacts and therefore planning risk, and opening up new areas of resource.

Value of diversity		
System benefit	**Value created** **Go West v Stay East**	**Scale of benefit and evidence**
Lower capacity margin requirement	An increase in the minimum de-rated capacity[41] of wind energy generation leads to a lower capacity margin requirement for the same Loss of Load Expectation (LOLE)	Applying National Grid winter capacity margin derating factor. A 2021/22 Capacity Market T1 auction clearing price for year-ahead capacity of £75/kW per annum[42] suggests a potential annual cost saving of £75 million per GW of increased offshore wind derated capacity.
Reduction of forecast error risk	Diversity of wind turbine fleet capacity across several weather windows reduces the impact of a single forecast error. Statistically, there is a lower probability of an extreme forecast error as the number of individual forecasts increases (unless there is a systemic error across all areas).	Improved system operation performance, including reduced balancing costs, which currently amount to £2.4 billion per annum. Reduced market risk for energy supply companies and traders – reduced extreme price volatility

[41] See National Grid ESO Winter Outlook Analysis

[42] Capacity Market T1 Auction results 2021

4.3 Value of lower generation volatility

As well as diversity of supply, the *Go West!* project has analysed the volatility of energy generation, which has been expressed as a reduction in the 'ramp rate', i.e. the change in power output from one period to the next.

A 'Go West' system reduces average and peak offshore wind generation volatility, compared to 'Stay East'

-24% Reduction in **average hourly ramp rate**		-43% Reduction in average **peak annual ramp rate**	
Go West 1.0 GW/h	**Stay East** 1.3 GW/h	**Go West** 7.4 GW/h	**Stay East** 13.1 GW/h

Figure 32: Impact of the 'Go West' scenario on offshore wind generation volatility compared to the 'Stay East' scenario

As a general rule, volatility of generation output increases overall system costs by a) increasing the need for balancing market intervention, b) increasing the market price risk for energy traders and supply companies, and c) increasing the propagation and severity of 'bullwhip' effects (see Explainer: Bullwhip Effects in section 4.3.3).

This cost of volatility can be mitigated by having a smarter, more responsive, digitalised, and flexible energy system that is better able to respond to volatility. But even these beneficial attributes of a smart and flexible future energy system will have an additional associated system cost.

4.3.1 System balancing costs[43]

The Electricity System Operator Control Room is responsible for the final balancing of the GB energy system and ensuring that supply meets demand at all times. To do this, it manages a balancing mechanism, a very short-term spot market, through which it can call upon individual generators and demand customers to increase or decrease their generation or demand. These balancing actions have a system cost, which National Grid ESO measured at around £2.4 billion over the 12-month period to June 2022.

[43] For a more detailed discussion of balancing costs, see https://www.regen.co.uk/wp-content/uploads/Regen-Insight-Managing-Constraint-Costs.pdf

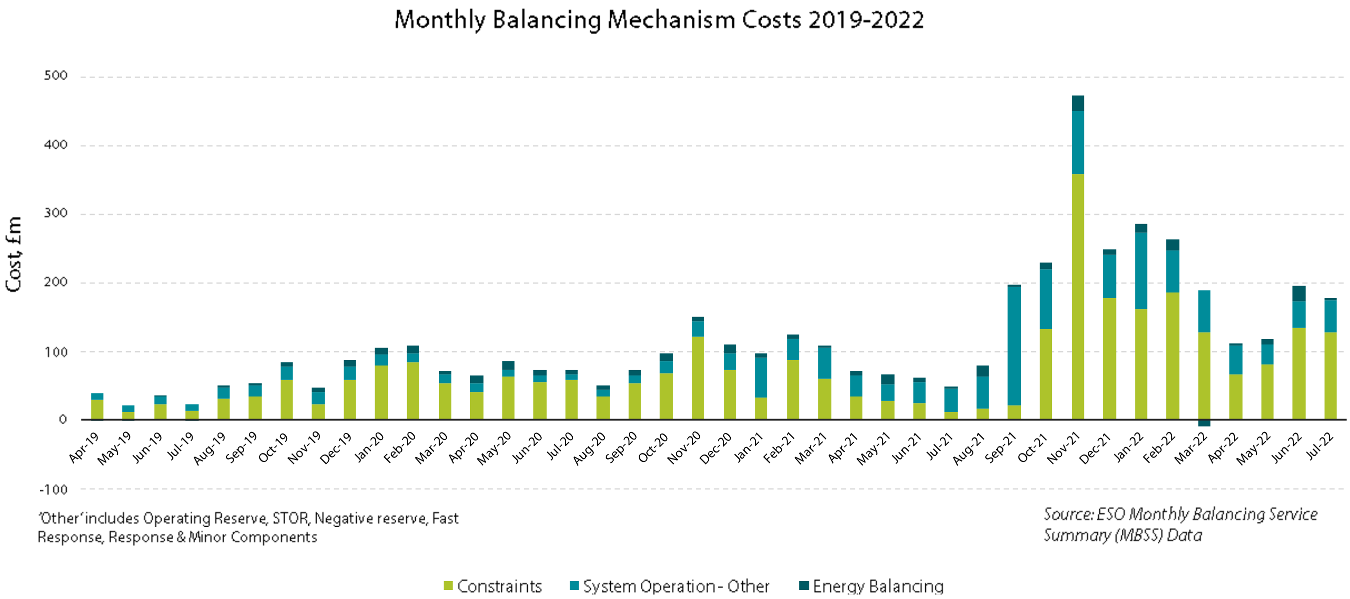


Figure 33: Monthly Balancing Mechanism costs (£ millions) 2019-2022

Many factors drive system balancing costs, including the level of network constraint, system operability and energy balancing. All of these cost drivers are exacerbated by the level of generation volatility within the energy system, which can increase forecast errors and the required level and speed of system intervention.

The speed of intervention, or rate of response, is important. A key challenge for system operators is the resource and operational pressure to respond to system imbalances within a very short time window, currently the one-hour period between 'gate closure' and the settlement period in which energy is delivered. This time pressure can lead to suboptimal system solutions, for example, through the inappropriate use of large-scale CCGT plants to provide balancing services because they are easier to dispatch than more flexible and targeted solutions. With the phenomenal increase in the price of gas in the last year, such actions are becoming a critical driver of increased balancing costs. Generation volatility adds to this time pressure and increases the required level of intervention, and so, although the ESO Control Room is investing in automation and digitalisation, volatility is likely to increase balancing costs.

4.3.2 System Operability

Alongside balancing supply and demand, the electricity system must be 'operable'.

National Grid ESO defines operability along five core elements, four of which are directly impacted by the volatility of generation. Two of the elements, frequency and stability, benefit from lower generation ramp rates at a national level.

Core elements of system operability		
Operability	**Description**	**Impact of generation volatility**
Frequency	Maintaining system frequency at 50 Hz has become more critical as system inertia historically provided by fossil fuel generators falls. This has created a requirement for new markets and business models to provide very rapid frequency response and dynamic containment services.	**Very high.** Changes in generation output can cause frequency deviation. The greater the deviation, the greater the level and speed of response required
Stability	Stability is the inherent ability of the system to quickly return to operation following a disturbance.	**High impact**
Voltage /reactive power	Voltage levels are managed through the injection and absorption of reactive power. This aspect of operability is highly dependent on specific regional conditions, including the generation mix, sources of demand, voltage levels and flow rates.	**High** but regional, so benefits less from offshore wind portfolio diversity
Thermal constraint management	Thermal/network capacity: thermal limits of network infrastructure mean that managing constraints is critical to ensuring the integrity of network assets. Constraint management costs, mainly from actions to curtail generation, are increasing. They also have potential carbon impacts.	**High** but regional and around specific boundary constraints. Diversity of wind supply may reduce or increase key boundary constraints depending on holistic network design
Restoration	Historically, the electricity system has depended on large, transmission-connected fossil fuel generators to provide restoration services.	**Limited impact**

4.3.3 Market risk, speculation and 'bullwhips'

Generation volatility is a key driver of overall market price and a balancing risk for energy supply companies and other energy off-takers/consumers.

Currently, most energy supply companies seek to manage this price risk by establishing a portfolio of trades using different generation technologies and over different timeframes. A typical energy supply company will meet their expected demand profile by buying some renewables in forward markets (for example, via a long-term PPA[44]), other renewables in the day-ahead market and then the balancing supply from fossil fuel and other dispatchable generation.

Volatility in renewable generation can cause significant price changes in the wholesale market and the balancing mechanism. In part, these price changes will reflect the underlying supply/demand balance and the cost of energy (merit order effects), but price swings can be amplified by market factors related to sentiment and speculation. During periods when energy supply is expected to be 'short', market sentiment and speculation can cause upward price volatility. Similarly, during periods when there is oversupply and the overall system is 'long', there can be rapid price falls and even negative pricing.

To the extent that these price swings result in increased risk for generators and consumers, and potential excess profits and rents for energy traders, they will add to overall energy system costs. It is hard to calculate the degree to which market price volatility constitutes an additional system cost, as opposed to a valid price signal that reflects the underlying energy system balance and energy cost. It is clear, however, that during the current energy price crisis, there has been a significant amount of speculative pricing and uneconomic 'bullwhip' effects.

[44] PPA: Power Purchase Agreement

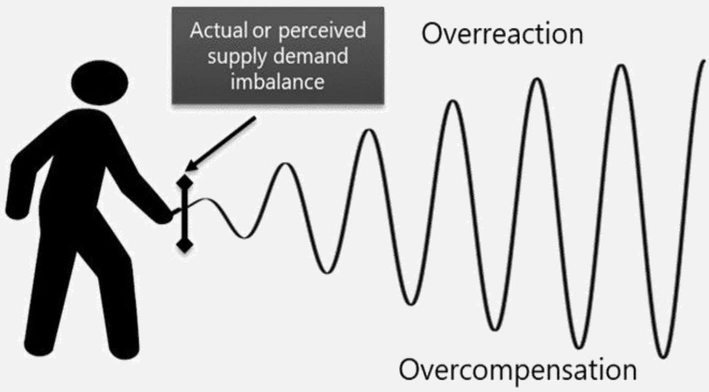
Explainer: **Bullwhip Effects**

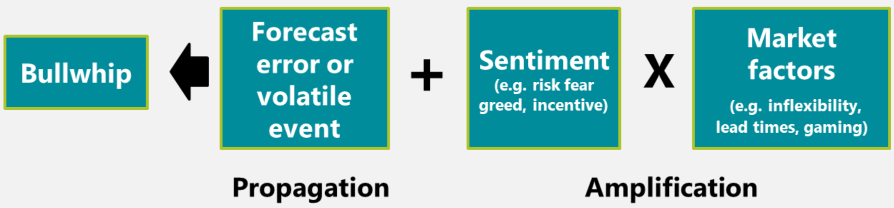
A 'bullwhip' is created when a market event, imbalance or error causes market actors to overreact in the first instance and then overcompensate. The amplified wave that results resembles a bullwhip.

High volatility can sometimes be considered a good thing if it is an appropriate response to 'real' market conditions and sends a positive price signal. A 'bullwhip', however, represents an exaggeration or overreaction that carries an economic/system cost that could be avoided.

Bullwhips are usually propagated by a combination of wrong information, forecast error or actual market events, such as a sudden and unexpected supply shortage (real or perceived).

Bullwhips are then amplified by other market factors, including market sentiment (risk, fear, or greed), lack of liquidity, lack of transparency, inflexibility, long lead times, wrong incentives and, in some cases, deliberate gaming or speculation.





4.3.4 Investment risk and cost of capital

Market price volatility and the risk of price cannibalisation increase investment risk for renewable generators. This means that investors in new generation will either have to secure higher cost capital or require additional mitigation measures, such as revenue support or stability and/or a fixed price guarantee, such as a CfD.

From a whole system perspective, increases in the cost of capital and investment risk increase the overall economic cost of achieving a given level of decarbonisation and energy security.

4.4 Potential energy system costs associated with increased offshore wind portfolio diversity

There are expected to be additional project costs to build and operate wind farms in new locations, particularly in deeper waters off the west coast. The extent of this cost increase will depend on the cost-effectiveness of floating wind and the potential higher energy yield that could be captured from larger turbines further from shore. For this study, we have not considered these to be additional energy system costs, but, of course, this is the fundamental question in the trade-off between building projects with the lowest cost of energy versus building projects that optimise overall system costs.

4.4.1 Energy generation potential

Diversification of wind generation into new areas of the seabed could increase system costs if those locations have lower overall wind resource. However, the *Go West!* wind power modelling suggests that there is little difference in energy output between the 'Stay East' and 'Go West' scenarios; in fact, the annual energy generation potential of the 'Go West' scenario is slightly higher, by 2.9%, than the 'Stay East' scenario.

4.4.2 Grid infrastructure and distance to demand

A key question is whether the diversification of wind generation to the west increases, or potentially reduces, the overall requirement for both offshore and onshore network infrastructure.

The current Offshore Transmission Network Review (OTNR) and Holistic Network Design (HND) initiatives – led by National Grid ESO, Ofgem, BEIS and The Crown Estate – must consider the overall grid investment and cost of operation associated with different offshore and onshore network topologies.

The recently published 'Holistic Network Design – Pathway to 2030' report[45] has identified capital costs of £54 billion (£32 billion in offshore transmission networks and £21.7 billion of onshore grid infrastructure) to achieve the UK government's target of 50 GW of offshore wind capacity by 2030. However, the initial HND analysis only included 1 GW of offshore wind in the

[45] https://www.nationalgrideso.com/future-energy/the-pathway-2030-holistic-network-design

Celtic Sea area[46] and 3 GW in the North and West of Scotland. A second iteration of the HND analysis is due to be published in Q1 2023, which is expected to include 4 GW in the Celtic Sea area and the ScotWind projects that have obtained a lease.

The HND methodology[47] focuses on key cost drivers, including the distance between offshore wind farms and the nearest onshore grid connection point and the scale of onshore upgrades that would be needed. It also includes an analysis of environmental and societal impacts and whether the upgrades are deliverable within the target timeframe. A similar holistic approach could be used to conduct a scenario analysis to ascertain the comparative infrastructure costs of a more 'west-leaning' or 'Go West' portfolio.

As previously highlighted, based on current TNUoS charges, there is a good argument in favour of more generation in the Celtic Sea area to provide energy to South Wales, the South West and the Midlands. The case for the North and West of Scotland will depend on the design and cost of the necessary transmission links to bring energy down to demand centres in North West England and ongoing interconnection to Ireland and Western Europe.

4.4.3 Potential loss of economies of scale in infrastructure capital and operational expenditure

Additional energy system costs from more diversified generation could come from a loss of economies of scale, affecting the upfront capital cost and subsequent operation of supporting system infrastructure. In theory, economies of scale would be maximised if wind farms are built in the same seabed area from a small number of super-ports and then connected to a handful of super-sized offshore transmission networks and onshore sub-stations.

A key question to be addressed is whether the costs of diversifying generation, which may require new ports and network infrastructure, are offset by the reduction of cumulative impacts and regional economic benefits. The challenge of developing more projects within the southern North Sea, including the impact on marine users and onshore communities, has been highlighted by recent planning challenges.

[46] The HND process started before The Crown Estate's announcement of a 4 GW target for the Celtic Sea and before the results of the ScotWind leasing round.

[47] https://www.nationalgrideso.com/document/262676/download

5 Policy implications and recommendations

Several key factors have limited offshore wind development along the west coast. Hard bedrock and challenging metocean conditions, coupled with seabed depths over 70 m, have tested the technical constraints of fixed offshore wind foundations. Limited access to suitable manufacturing areas and assembly/deployment ports has stifled local supply chains, and inadequate grid infrastructure has limited network connections. There has also been a preference for developers and investors to follow the lead of earlier successful projects and avoid the risks associated with new deployment methods in new seabed areas.

Financial pressures and the nature of the UK CfD scheme have also played a key role. Whilst the CfD scheme has been successful in bringing forward new capacity and offering revenue stability to new generation projects, it may have also helped to concentrate wind farm development into the least risky areas. This is because, as the CfD scheme is currently designed, it:

- Reduces investor revenue risk but increases project developer risk, since it offers no support until the final CfD auction, which occurs only after significant development costs have been incurred, thus deterring development in new areas.
- Culminates in a competitive auction based purely on the strike price per MWh (per unit of energy), i.e. it treats all units of electrical energy the same irrespective of where and when they are generated.
- Provides no other geographic locational signal (distinct from Locational Marginal Pricing) or recognition of either energy system or regional economic benefits.

A combination of these factors – technical challenges, logistical limitations, investment risks and policy structure – have tended to favour existing development areas off the east coast. In contrast, west coast projects have struggled to be economically and technically competitive.

Floating wind and the push to develop new projects in the North and West

Policy support for floating wind projects is still needed, despite the high level of interest from developers and investors. Projects off the west coast still face technological and financial uncertainty, meaning there is a risk that these more ambitious projects are either delayed or cancelled. Such an outcome would jeopardise the UK's net zero target and its energy security strategy, as well as forego the potential energy system benefits highlighted in this paper.

Some of these challenges are inherent to offshore development in new areas and deeper waters. Many can be solved by cross-sector collaboration and ongoing cost reduction brought about by innovation and supply chain development. Some of the challenges, however, do require policy support and a more strategic and integrated approach to offshore and onshore infrastructure planning and delivery.

5.1 An integrated, strategic approach to offshore development, leasing and planning

Whilst the UK government has strong overarching targets for offshore wind, there is still no integrated[48] delivery plan for how and where that capacity will be delivered around GB. Progress has been made with the recent ScotWind and Celtic Sea leasing initiatives, but there is still scope for governments, regulators, network planners and the industry to work in a more joined-up manner. An integrated delivery plan is fundamental to targeted strategic investment in the grid, manufacturing and port infrastructure, building supply chains, and accelerating long-term planning and leasing processes.

Due to geography and the need to share infrastructure, developing offshore wind in the Celtic Sea area and to the west and north of Scotland requires a more integrated and holistic approach. The recent HND[49] for onshore and offshore transmission infrastructure is a good example of the required approach. However, there was a misalignment between the scope and scale of the initial HND study and the leasing strategies that have since been proposed, which hopefully will be addressed in future HND iterations.

Whilst not unique to offshore wind projects on the west coast, the current ten-year timeframe from leasing to construction presents particular challenges for projects in new development areas. With the majority of that time taken up by gaining the necessary consents, there is a need to significantly accelerate the consenting process (whilst still achieving the required outcomes) to accelerate deployment. The level of finance required to gather data and undertake the leasing and consenting processes is a significant barrier to entry for smaller developers, particularly in The Crown Estate's leasing rounds, where larger capacity bids are incentivised.

Recommendations

1. **Central and devolved governments, The Crown Estate, Crown Estate Scotland, system operators, networks and regulators need to work together with the offshore wind industry to develop an overarching delivery plan.**

[48] Integrated – meaning a plan that is understood and supported by all parties including central and devolved government, The Crown Estate, Ofgem, Nation Grid and Transmission Operators, ESO, the industry and regional stakeholders

[49] https://www.nationalgrideso.com/document/262676/download

2. **This delivery plan should include a high-level geographic plan that recognises the energy system, energy security and regional economic benefits of a more geographically diverse wind portfolio.**
3. **Further research is recommended to fully quantify the energy system benefits and regional growth opportunities of different offshore wind portfolios.**
4. **Seabed leasing and an accelerated consenting process should be aligned with the long-term delivery plan. They should give transparency and confidence as early as possible to wind farm developers and investors in port infrastructure, manufacturing capacity and supply chain capability.**
5. **The Crown Estate's increased ambition for 4 GW of floating wind in the Celtic Sea by 2035 is welcome. However, there is an urgent need to set out the long-term plan for the Celtic Sea area, including the Western approaches to the English Channel.**
6. **Offshore wind development needs to be aligned and integrated with the use of conventional and Multi-Purpose Interconnectors (MPIs) to neighbouring energy markets, including Ireland and Western Europe.**

5.2 Financial incentives that support increased diversity of supply

The CfD[50] scheme has been key to bringing forward offshore wind investment and in helping the industry to reach a scale and capability at which offshore wind energy costs have plummeted. It is the government's primary financial support mechanism behind the expansion of offshore wind and is becoming a key incentive in the context of the UK's current energy crisis and moves towards greater energy security.

Since its introduction in 2014, over 16 GW of offshore wind capacity has been awarded a CfD. In the recent CfD Allocation Round 4 (AR4), around 7 GW of projects won financial support, including 32 MW of FLOW in the Celtic Sea. It is expected that the CfD scheme, or a similar replacement, will remain in place and continue to support offshore wind projects over the coming decade to 'accelerate low carbon electricity generation to achieve a fully decarbonised electricity system by 2035'[51].

The first FLOW project, the 32 MW TwinHub technology demonstration project, has received a CfD with a strike price of £87.50/MWh (2012 prices). This is a significant milestone at a relatively low strike price. However, it should be noted that this project had already benefited from significant investment in planning and infrastructure as a result of the previous Wave Hub project.

[50] https://www.gov.uk/government/publications/contracts-for-difference/contract-for-difference

[51] https://www.gov.uk/government/news/government-hits-accelerator-on-low-cost-renewable-power

The current CfD mechanism does not, however, account for energy system benefits when allocating financial support and values each generated unit of energy equally, irrespective of where and when the electricity is generated.

The future of the scheme is currently under review as part of the Review of Electricity Market Arrangements (REMA)[52], offering an opportunity to enhance and reform the CfD mechanism to enable the viability of projects using innovative technology, such as floating wind, in new development areas around the UK.

Recommendations

1. **The Contracts for Difference (CfD) mechanism should continue to provide revenue stability for less-established innovative technologies until they reach competitive scale. For floating wind, this means allocating a sufficient strike price and retaining a separate allocation pot and/or a 'minima' budget allocation provision through Allocation Rounds 5, 6 and 7, at least.**
2. **The government should consider a means to providing a geographic locational signal (distinct from Locational Marginal Pricing) within the CfD scheme that supports diversity of supply. This could be achieved in several ways, such as:**
    a. **Running a specific Allocation Round for floating wind projects to support their deployment on the west coast**
    b. **Running bespoke regional CfD rounds or rounds with regional minima**
    c. **Focusing support for floating wind, tidal and other technologies that offer more geographic diversity.**
3. **The government could consider an 'energy system value' strike price differential within the CfD allocation round. However, this approach may be difficult to calculate and administer.**

5.3 Infrastructure investment, innovation and supply chain development supply

All offshore wind projects require a high level of infrastructure investment and supply chain capability development. This includes:

- Offshore and onshore transmission investment
- Assembly and construction ports
- Manufacturing and fabrication centres for key components
- Operations and maintenance facilities

[52] https://www.gov.uk/government/consultations/review-of-electricity-market-arrangements

- Supporting supply chain development
- Workforce and skills development
- Funding for innovation and technology development.

Many of these elements have very long lead times and are developed based on serving multiple projects over a long period of time. This demands a strategic and highly collaborative industrial strategy for the west coast that brings together industry, government, planners, and regional bodies whilst giving certainty and transparency throughout the development process.

An example of such an industrial strategy – including an industry Sector Deal[53], an Offshore Wind Growth Partnership and an Industry Council[54] – has been put in place for the offshore wind sector and has helped to channel billions of pounds of investment into building the UK's offshore wind capability.

In 2021, the UK offshore wind supply chain benefitted from significant investment from national and international organisations, with over £900 million invested in the manufacturing sector[55], creating and safeguarding nearly 3,000 jobs[15].

An industrial strategy that has enabled projects on the east coast now needs to be extended to the west coast. It is expected that, while west coast projects will benefit from investments that have already been made, scaling up offshore wind development in the west will require significant additional investment to overcome the key challenges of port infrastructure and grid capacity. The ORE Catapult estimates that £2.0–2.5 billion is required by 2030 to upgrade port and manufacturing facilities to support a strong pipeline of FLOW projects across Scotland (142 units, equating to 2.5 GW annually) and the Celtic Sea (40 units, or 700 MW annually)[56].

Ongoing innovation is essential in enabling projects to overcome the remaining technical challenges, including optimising FLOW deployment techniques, anchoring and mooring, use of advanced materials and the development of successful O&M strategies.

Given their respective geographical challenges, projects in the Celtic Sea and off Scotland's north and west coast will require a more collaborative and integrated approach than existing projects. This collaboration could extend to the widespread use of shared infrastructure and shared investment in grid, ports, and skills development.

[53] Offshore wind Sector Deal, BEIS, 2020

[54] https://www.owic.org.uk/osw-sector-deal

[55] 'Record year of over £900 million investment in UK offshore wind manufacturing', RenewableUK, 2021

[56] Strategic Infrastructure and Supply Chain Development - Floating Offshore Wind Centre of Excellence, Offshore Renewable Energy Catapult, May 2022

Recommendations

1. **Continue, extend and accelerate the process of Holistic Network Design to ensure that offshore and onshore network investment is in place to support offshore wind and interconnector development.**
2. **Building on the current Offshore Transmission Network Review, implement changes to the regulatory framework that will allow both greater collaboration in the development of offshore transmission networks and strategic investment in shared network infrastructure, including MPIs.**
3. **Extend, increase and accelerate support for port infrastructure development, building on schemes such as the Floating Wind Manufacturing Investment Scheme (FLOWMIS).**
4. **Establish a coordinated approach to developing regional supply chains in England, Wales and Scotland, extending across to Northern Ireland and the Republic of Ireland. This should build on existing capabilities, such as those that have been identified by Regen in South West England, and by the Offshore Renewable Energy Catapult in Wales and across the UK.**
5. **Expand levelling-up schemes, such as Offshore Wind Growth Partnership and Fit 4 Offshore Renewables, to grow a western supply chain basis capable of deploying at scale.**

6 Appendices

6.1 Appendix A: Zone designation

Table 2: Zone designation and characteristics

Zone	Zone number	Centroid latitude	Centroid longitude
South Celtic Sea (Irish)	1	50.163	-8.858
South East Celtic Sea	2	49.484	-7.151
North Celtic Sea (Irish)	3	51.667	-7.610
East Celtic Sea	4	51.114	-5.344
West English Channel	5	50.058	-3.516
West Wales	6	52.521	-5.036
North Wales	7	53.853	-4.458
South West Scotland and N. Ireland	8	55.458	-5.313
West Scotland	9	57.204	-6.926
North West Scotland	10	58.898	-5.354
West Shetland	11	60.380	-2.570
East Shetland	12	60.490	0.193
South East Shetland	13	59.053	0.191
North East Scotland	14	58.158	-2.400
South East Scotland	15	56.796	-1.475
Far East Scotland	16	57.352	1.333
East Coast	17	55.026	-0.645
East Coast Floating	18	56.019	1.368
East Coast AR4	19	54.946	1.937
East Coast (Humber)	20	53.527	1.161
East Coast (Thames Estuary)	21	52.051	1.566
East English Channel	22	50.683	-0.678
North West Ireland	23	54.994	-8.614

6.2 Appendix B: Renewables.ninja data

Wind power time series data was acquired from the Renewables.ninja[57] website, a tool created by Stefan Pfenninger and Iain Staffell to help make scientific-quality weather and energy data available to a wider community.

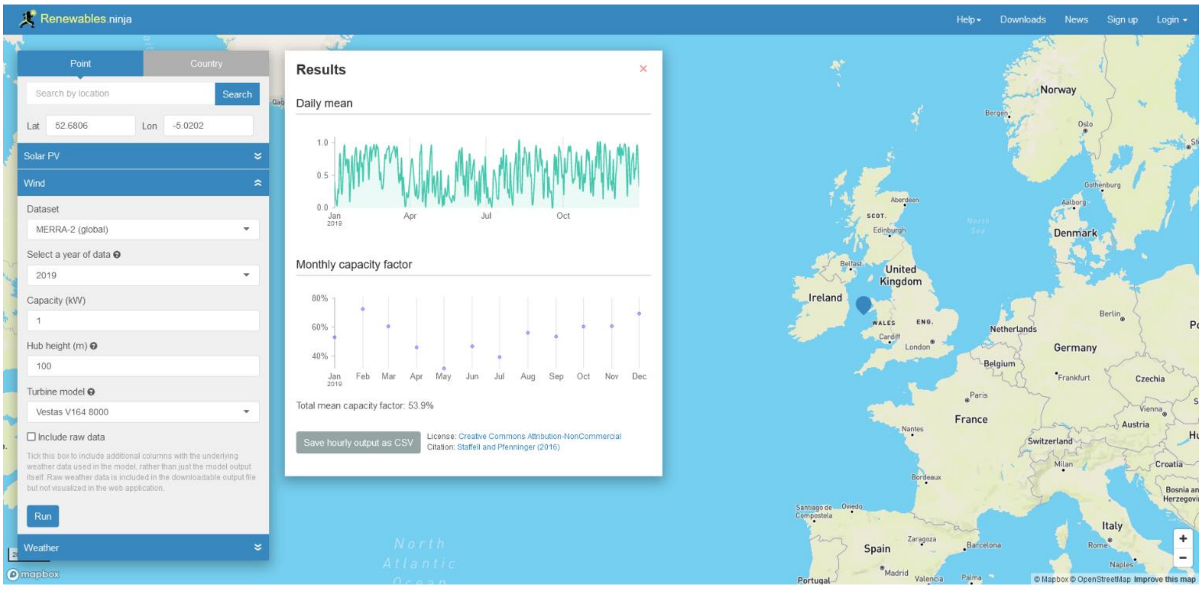


Figure 34: Illustrative screenshot of the Renewables.ninja tool

Users specify the following inputs (associated parameters for this study also given):

- **Location (longitude/latitude):** input coordinates corresponded to each of the zone centroids defined in Table 2.
- **Dataset:** MERRA-2 (global)
- **Year of data:** 2000-2019, maximum data range available.
- **Capacity:** 1 kW, chosen so that output data is equivalent to a normalised capacity factor ready for weighting using the various fleet scenarios and associated sensitivity studies.
- **Hub height (m):** 100
- **Turbine model:** Vestas V164 8000, selected as a generic model

Renewables.ninja takes weather data from global reanalysis models and satellite observations – for wind data, the NASA MERRA-2 model is used. Wind speeds are converted into power output using the Virtual Wind Farm (VWF) model. The VWF model performs the following steps (as illustrated in Figure 35):

[57] See www.renewables.ninja and the related paper *Staffell, Iain and Pfenninger, Stefan (2016). Using Bias-Corrected Reanalysis to Simulate Current and Future Wind Power Output. Energy 114, pp. 1224-1239. doi: 10.1016/j.energy.2016.08.068*

- Acquires wind speeds at 2 m, 10 m and 50 m above ground at each MERRA grid point.
- Interpolates speeds to the specific geographic coordinates of each wind farm using LOESS regression.
- Extrapolates speeds to the hub height of the turbines at each site using the logarithm profile law.
- Converts speeds to power outputs using manufacturers' power curves, which are smoothed (using a Gaussian filter) to represent a farm of several geographically dispersed turbines and the distribution of wind speeds within any given hour.

Validation of the data against the current wind fleet uses monthly and annual data from 23 countries for wide geographic coverage and hourly data from selected countries for high temporal resolution. The performance of the VWF model is excellent, with a correlation to UK hourly capacity factors of 93.5%. Validation against metered output data in new offshore areas has not been possible, but studies show that MERRA replicates offshore wind speeds recorded on oil rigs and buoys with greater accuracy than onshore speeds.

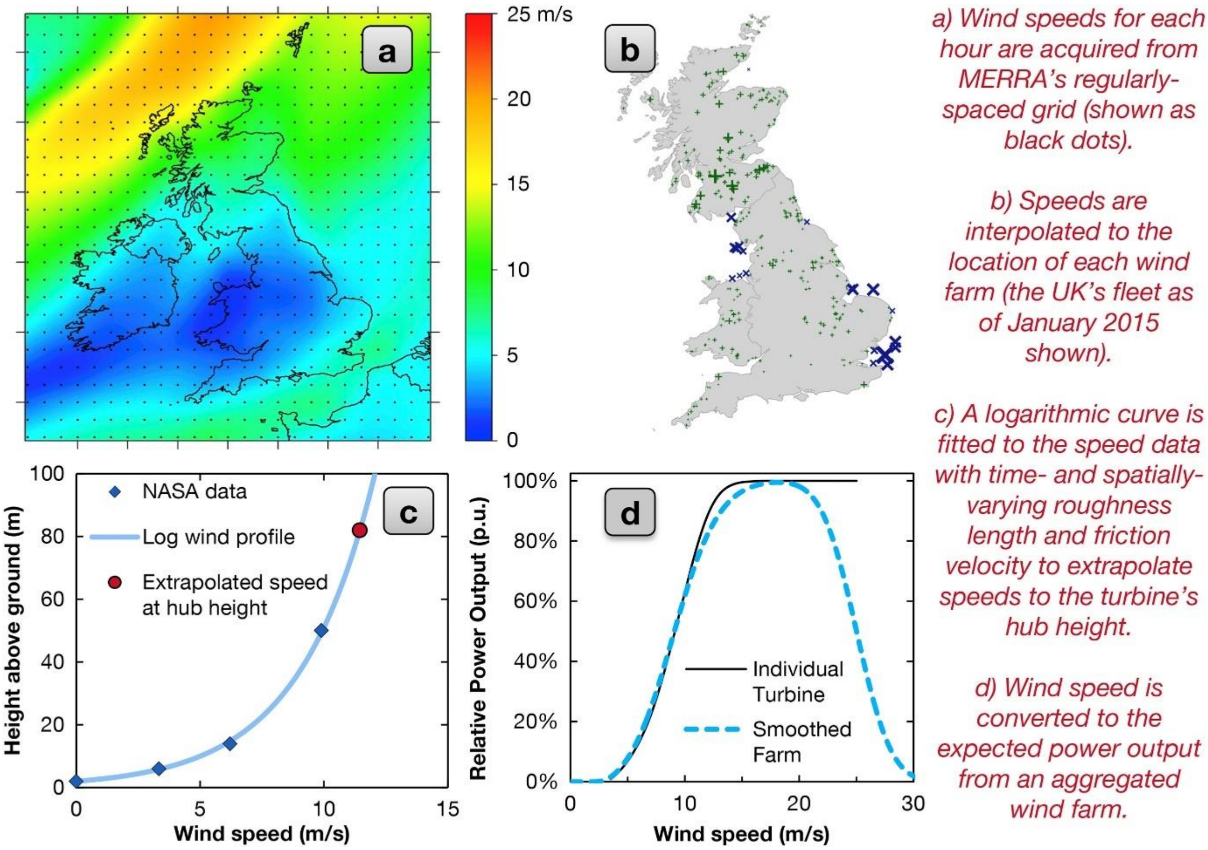


Figure 35: Overview of the VWF methodology

A correction is also applied to the underlying wind speeds to correct for systematic error (defined as the ratio of observed to simulated capacity factors) in the derived power output.

6.3 Appendix C: Data appraisal

6.3.1 Data strengths and limitations

Strengths:

- A 20-year timespan ensures results are not skewed by one particular year
- The use of reanalysis data ensures full coverage and avoids reliance on historic measurements of wind speed or power outputs at specific locations
- The underlying dataset includes bias corrected benchmarked against historical wind power output and validated across Europe.

Limitations:

- The spatial resolution of datasets is suitable for national and regional studies but not for site-specific studies
- Effects of ageing turbines ignored[58]
- No fleet mix was used in the modelling (just one power curve/turbine model and hub height used)
- Spatial resolution of wind resource data uses a 50 x 50 km grid and tricubic weighting function to derive results
- The analysis does not consider wind turbine downtime and turbine wake effects (likely to reduce capacity factors slightly in all scenarios)
- Scenarios do not consider varying onshore wind portfolios (this could be added as a follow on); a fixed onshore wind power time history is used in the dispatch model.
- Use of zonal centre points for wind speed/power outputs series rather than spatial averaging.

6.4 Appendix D: Sensitivity studies

For more information, please contact Jack Adkins at Regen.

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

6.5 Appendix E: High-level dispatch model analysis

6.5.1 Model overview

Regen's high-level energy dispatch model has been built as a framework capable of modelling a generation and demand mix. The model has been calibrated to represent a GB energy system in 2034 based on BEIS data and National Grid's Future Energy Scenarios (FES) 2022, which projects 70 GW offshore wind capacity under the Consumer Transformation scenario. 2034 is forecast to have a large increase in demand and renewables, creating uncertainty as to how large a role merit order technologies will have in the energy system. The dispatch model outputs key metrics that illustrate future costs, emission rates and load capacity associated with the GB generation fleet.

Generation and storage types are organised into five categories based on their historic role and order of deployment in the energy system:

- Base load: nuclear
- Variable: solar, onshore wind, offshore wind
- Merit order: hydro, BECCS, unabated biomass, CCGT with CCS, unabated CCGT, OCGT, hydrogen
- Flexibility: interconnectors (import), installed electrolysis
- Storage: pumped hydro, battery, compressed air, and liquid air storage.

After full deployment of this energy system, the remaining energy (up to a specified capacity limit) is exported via interconnector, with any energy above the capacity limit classified as 'curtailed'[59].

Key parameters, such as installed capacity, efficiency, carbon tax and the marginal cost of energy, are quantified for each technology, sourced from BEIS & National Grid FES 2022 data for the year 2034. Onshore wind and solar generation capacity factor data, calculated using a combination of Elexon BMRS generation data and BEIS Energy Trends capacity data for 2019, is input as a time series at 30-minute intervals. This capacity factor data is then combined with projected onshore wind and solar installed capacity (National Grid FES projections for 2034) to give generation time history data. The Renewables.ninja wind speed data, calculated for each offshore wind fleet scenario, was linearly interpolated to increase the frequency of the data from hourly to half-hourly intervals for input to the dispatch model. The demand profile used

[59] Curtailment is a reduction in the output of a generator from what it could otherwise produce given available resources, typically on an involuntary basis. Reasons for curtailment include transmission constraints, including congestion and system balancing challenges related to oversupply situations and ramp events.

in the model is a scaled and stretched transformation of the National Grid ESO National Demand 2019 demand profile so that peak demand and annual energy demand match the projections given in the National Grid FES data for the year 2034.

6.5.2 Results and analysis

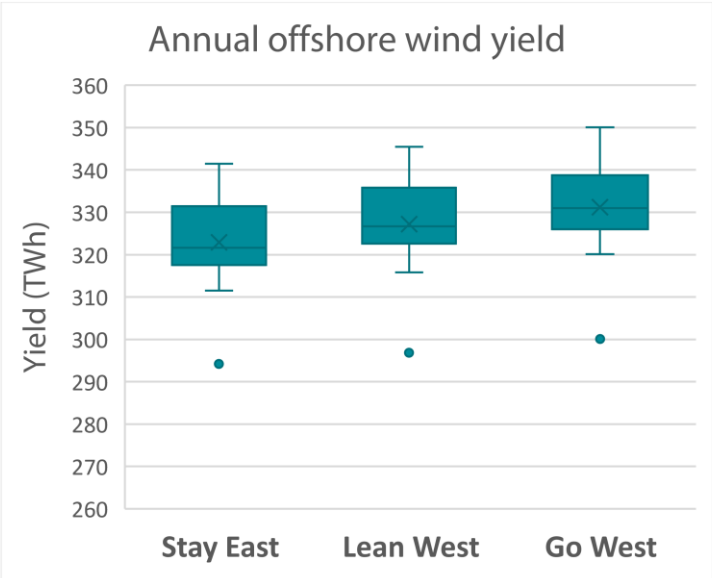
Each of the 20 years of Renewables.ninja wind power data, calculated for each offshore wind fleet scenario, was input to the model to give 20 sets of output data per scenario.

It should be noted that the Renewables.ninja wind resource data does not account for reduced turbine availability[60]. To account for this, two analyses were undertaken: one analysis using the raw Renewables.ninja data (implying 100% availability of the offshore wind fleet) and a second analysis with a reduced offshore wind fleet availability, equivalent to a 10% reduction in energy output, to give a more realistic level of generation across the year[61]. This reduced energy output is applied universally as a scaling factor to every data point in the offshore wind generation time history, as opposed to simulating discrete events where there is reduced availability at certain times for a finite duration.

[60] 'Availability' is defined as the percentage of total time, or energy, that a wind turbine or farm is able to generate electrical power. Events such as turbine faults and maintenance schedules result in reduced turbine availability.

[61] Conroy N, Deane JP, Ó Gallachóir BP. Wind turbine availability: should it be time or energy based? – a case study in Ireland. Renew Energy 2011;36(11):2967e71.

Offshore wind generation



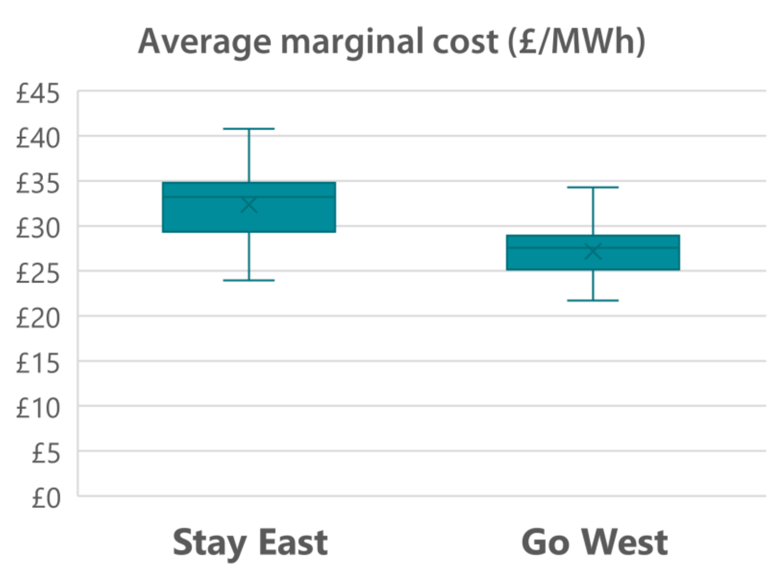
Summary Result

'Go West' increases total offshore wind energy generation by an average of 3.1% per year.

Analysis

As per Figure 23, a more geographically diverse wind fleet results in less time at low power generation and more time at mid power generation, increasing total yield. It also 'squeezes' the distribution curve inwards, resulting in a less variable yield.

Marginal Cost of energy



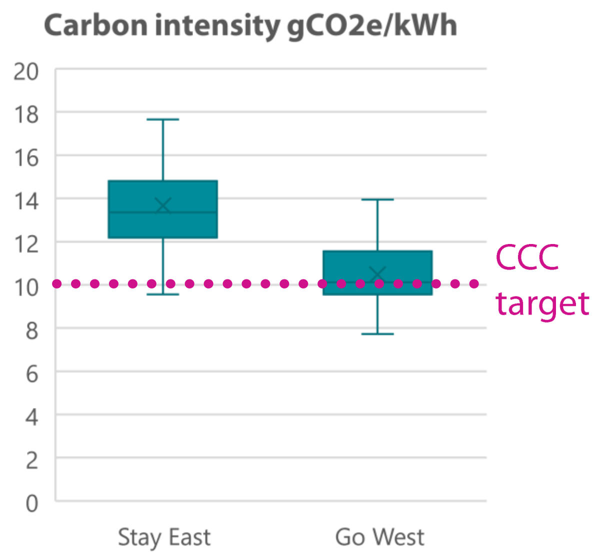
Summary Result

A 'Go West' system reduces the average marginal cost of generation by 17% and reduces variation in price by a quarter.

Analysis

'Go West' has fewer periods of very low generation and therefore reduces the use of very high cost (and higher carbon) generation assets in the despatch merit order.

Emissions



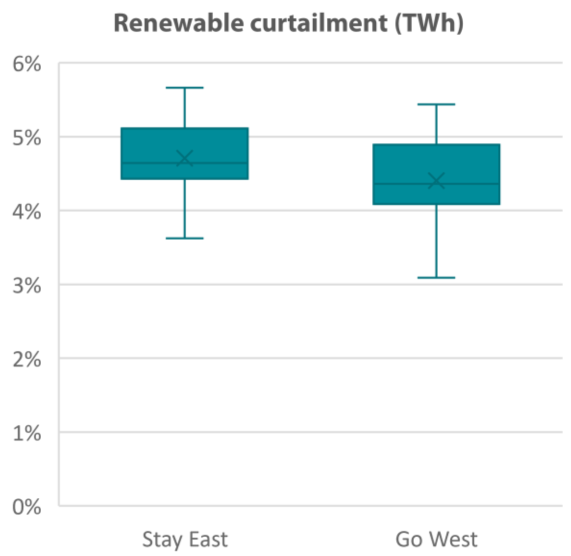
Summary Result

A 'Go West' system reduces the carbon intensity of electricity generation by around 24%, which almost reaches a level that satisfies the CCC's recommended target of 10 gCO_2e/kWh in 2035.

Analysis

'Go West' reduces demand for the more expensive merit order fleet technologies, particularly when the gap between demand and renewable supply is greatest. In effect, this displaces demand from the more expensive merit order technologies to be fulfilled by much cheaper renewable technologies.

Curtailment



Summary Result

A 'Go West' system reduces renewable energy curtailment by about 6% (from a rate of 4.6% to 4.3%)

Analysis

'Go West' reduces demand for the more expensive merit order fleet technologies, particularly when the gap between demand and renewable supply is greatest. In effect, this displaces demand from the more expensive merit order technologies to be fulfilled by much cheaper renewable technologies.

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