

State of the Climate for the UK Energy Sector 2024-25

Authors: Benjamin Hutchins^{1,2}, Matthew Wright^{1,3}, James Mollard^{1,4}, James Fallon⁵, Paula Gonzalez⁵, Ifan Rogers⁵, Iain Staffell⁶, Stephen Swabey⁷, Hannah Bloomfield⁸

Affiliations: ¹Royal Meteorological Society, Reading, UK. ² Department of Meteorology, University of Reading, UK. ³Atmospheric, Oceanic and Planetary Physics, University of Oxford, UK. ⁴School of Geosciences, University of Edinburgh, UK. ⁵Met Office, Exeter, UK. ⁶Centre for Environmental Policy, Imperial College London, London, UK. ⁷AECOM, London, UK. ⁸School of Engineering, University of Newcastle, UK

Acknowledgements for Contributions: David Brayshaw, Emily Wallace, Daniel Drew, Dafni Sifnioti, Laiz Souto



Engage
Enthuse
Educate
Empower

Abstract/Summary



This report explores how meteorological conditions impacted the UK energy sector between April 2024 and April 2025. It also explains historical context for a variety of climate and energy-relevant variables. This report provides a focused assessment of how weather affects the energy sector and complements the annual “State of the UK Climate” publication (Kendon, 2025), which reviews the meteorology of the past calendar year and puts it into a climatological context. Impacts such as damage to infrastructure and disruption to supply during summer and winter are discussed. The report analyses the impact of named storms such as Darragh and Éowyn which caused localised power cuts from damage to infrastructure resulting from high winds and flooding. The report also describes the low wind events in November 2024 and January 2025 which were associated with reductions in renewable energy generation, greater reliance on gas generation and imported energy, and price increases. This report provides an accessible and up-to-date assessment of how extreme weather impacts the UK energy sector, using state-of-the-art weather reanalysis datasets, electricity system fault data, and electricity market data.

The purpose and structure of this report

This is the second report on State of the Climate for the UK Energy Sector, following the initial report for 2023-2024 (Wright et al., 2024). It aims to provide a near-real-time annual review of the impact of weather on the energy sector. Meteorological conditions impacting Great Britain’s electricity system are assessed for the period April 2024 to April 2025, to underpin discussions between the meteorological and energy communities. The report predominantly discusses impacts on the electricity sector, because electricity generation, demand and infrastructure are more exposed to the effects of weather than other parts of the energy sector, such as gas and fuel.

This report examines two categories of impacts: periods when weather affected electricity supply and demand, and periods when extreme weather events damaged infrastructure and caused disruption to electricity distribution.

An overview is provided of the most impactful weather conditions during the year, and their implications for each type of disruption. The report concludes with commentary on how these case studies compare to likely future scenarios of change. This report aims to enhance understanding of the resilience of the UK energy system to weather and climate challenges and to inform preparations for future years.

RMetS Energy Special Interest Group

The Royal Meteorological Society is the UK's professional and learned society for weather and climate. The Society works to strengthen the science and raise awareness of the importance of weather and climate, support meteorological professionals and inspire enthusiasts.

Through the Energy Special Interest Group (SIG), RMetS brings together energy sector professionals, policymakers and academics to discuss the biggest weather and climate issues facing the energy sector. In doing this, the Society acts as a bridge between weather and climate scientists and energy sector professionals by facilitating knowledge exchange, demystifying meteorological terminology and data, and providing networking opportunities.

The Energy SIG produces annual reports on the State of the Climate for the UK Energy Sector (first reported for 2023-24) and runs a program of events. Each November the Energy SIG coordinates the Seasonal Forecast Outlook for the Energy Sector, an online webinar which looks ahead at forecasts for the upcoming winter to discuss predictable drivers, common forecast signals, and the implications for the energy sector. The Energy SIG also coordinates Energy Insights events, which host expert speakers on key issues facing the energy sector.



1. Introduction

1.1. The UK energy system in 2024-25

Electricity system reliability in high-income nations is crucial to facilitating society, high quality of life, and economic production. Energy reliability can be defined as the overall system's ability to perform its function and covers adequacy and security assessments to ensure that operational constraints are met and its response to unexpected conditions is satisfactory.

Energy systems must also be resilient to exceptional circumstances leading to major disruptions. The resilience of the system can be defined as the ability to cope with and recover from extreme disruptive events, such as extreme weather. This requires constant assessment to ensure that future threats can be overcome (National Grid Electricity Transmission, 2024; Ofgem, 2025).

As electricity generation becomes more reliant on weather-related sources such as solar and wind, maintaining reliable energy supply will be more vulnerable to variations in weather conditions. The location and timing of weather-related generation will experience large and rapid variations in response to changing weather conditions across the country (Giddings et al., 2024).

Electricity from neighbouring countries delivered through interconnectors has also increasingly contributed to the British electricity system. Last year, interconnectors provided the third highest amount of electricity after renewable and gas-powered generation (NESO, 2024). Because connected countries also have become more reliant on weather-dependent energy generation, the ability to maintain adequate power across the network is influenced by weather conditions across Europe, not just within Great Britain.

The primary season of concern for the British electricity system is the extended winter season which runs from 1st October to 31st March. During this period, cold snaps typically are associated with increased electricity demand and reduced generation from wind and solar. Both issues also contribute to increased demand for gas. Flooding and windstorms also damage infrastructure during winter, sometimes with consecutive storms causing further damage before full recovery from the previous event has been achieved.

The report here covers the period of 1st April 2024 to 31st March 2025 including the full winter 2024/25 season. This report period also spans the full extended summer season (April through September) when network maintenance of energy system assets is often scheduled, but when there are risks to the network from equipment overheating. In future, energy systems may increasingly experience challenging high demand periods driven by cooling (including air-conditioning) requirements.

1.2 Electricity generation and demand in the UK

During the report period, most GB electricity was generated through wind power (28.1%), followed by gas (27.4%) and nuclear (13.9%), with a further 5.2% coming from solar (NESO, 2025a). This shows a continuing decrease in reliance on gas, which accounted for 40% and 31% of generation in 2022 and 2023 respectively, with small increases in wind and solar. There was also a large proportion of imported electricity (15.3%), higher than 2023 (12.3%), as new interconnectors with Ireland and Denmark became operational (IEA, 2025).

Weather conditions influence renewable generation but also affect electricity and gas demand. Temperature is the primary climatic determinant of energy demand in Britain, alongside daylight hours and wind chill (Thornton et al., 2017; Staffell et al., 2023). Demand is typically highest during the winter, as heating and lighting requirements increase compared to summer. Prolonged cold spells often lead to increases in both electricity and gas demand. In cold and still conditions, there is an increased reliance on non-renewable sources for electricity generation, increasing the carbon intensity of the electrical grid (van der Wiel et al., 2019). Equally, periods of extreme heat have similar considerations, as they are often associated with high pressure atmospheric systems that reduce wind generation, and increased demand due to fan and air conditioning usage (Khoravi et al., 2023).

These prolonged high-pressure events can lead to the potential for energy system stress, increasing carbon emissions and increasing costs for the electricity supply system. Consequently, the balance between renewable generation and electricity demand are often considered alongside one another in the form of demand-net-renewables (demand minus renewable generation). When there is a large discrepancy between the demand and the availability of renewable generation, security of supply is ensured through other generation sources, such as thermal power plants (e.g. gas, coal), storage, and imports from other countries with available supply (DESNZ, 2024).

When renewable generation is higher than demand, excess electricity must either be stored, used by increasing demand, or exported to other markets (DESNZ, 2024). If these outputs are insufficient to increase demand, generation is deliberately restricted ('curtailed') to maintain balance (Drax & LCP, 2022). This system balancing comes with a cost, as electricity producers are paid to reduce the amount of electricity they supply to the network. In 2024, 8.3 TWh of wind energy was curtailed, either due to generation occurring at times of low demand, inability to transmit power from regions of high generation to areas of low generation, or because renewable generation was excessively high (e.g. on cloudless, windy days (Drew et al., 2019)). This included nearly 70% of the production from the recently opened SeaGreen wind farm in Angus, predominantly due to grid congestion (Electric Insights, 2024). This report does not currently quantify the impact of grid congestion because it focuses on how weather affected the whole GB network, but it does identify some cases where congestion contributed to increased curtailment.

1.3. Impacts of weather on energy infrastructure

Many faults across the electricity distribution network occur due to extreme weather events. This report predominately considers the impact on the electrical distribution, transmission network and renewable generation, as these are more exposed to weather than those of the gas network. Where extreme weather events are widespread, or where multiple nearby faults occur over a short period of time, blackouts and disconnections over large areas may result. During winter months, severe windstorms with high wind speeds can result in damage to overhead lines, pylons or poles, and falling vegetation can impact network assets. The heavy rainfall associated with winter storms can lead to flooding and water inundation of ground-based infrastructure such as substations (Souto et al., 2024). In recent years, large scale disconnections have been associated with damage to the network caused by windstorms, such as Storm Arwen in 2021 and Storm Ciarán in 2023 (Ofgem, 2022).

In the summer, weather-related faults are predominantly linked to severe convective storms (thunderstorms) and extreme heat (Souto et al., 2024). Lightning is a major cause of faults, and this is complicated by the fact that strikes are extremely localised and difficult to predict more than a few hours in advance (Lopez, 2018). Rainfall associated with thunderstorms can also lead to flash flooding. Extreme heat can lead to issues for the electricity network. Overheating of assets can increase failure rates, and increased temperatures reduce the efficiency of overhead lines, meaning that the ability to transfer electricity around the network may be limited (McGuire et al., 2025). There are additional hazards associated with extreme heat, such as wildfires and drought, both of which can also lead to degradation and premature aging of assets, and failures of components within the network through overheating and fire damage (National Grid Electricity Transmission, 2024).

1.4. The UK's weather in 2024-25

This report is intended as an addition to the 2024 edition of the State of the UK Climate Report, released in July 2025 by the Met Office (Kendon et al., 2025), which provides a summary of the UK's climate for the previous year. This includes assessing observed weather events from the period, updated assessments of climate trends and variations, and comparing extreme events with recent history and long-term climatology.

Some of the key findings from the 2024 report are synthesized below, alongside the seasonal and monthly Met Office summaries for early 2025 (Met Office, 2025a):

Temperature

- 2024 was the fourth warmest year in the UK in the observed time series (since 1884), joining both 2022 and 2023 in the top 5 warmest years. The number of days in the past decade where temperature anomalies were over 10°C has increased four-fold, compared to 1960-1991 average.

Precipitation

- 2024 was the UK's thirteenth wettest year in records since 1836. Whilst there has been little change to summer precipitation accumulations, October-March periods over the past decade have been 6% wetter than the period 1991-2020, and 16% wetter than the years 1961-1990. In the past decade, instances of monthly rainfall accumulations exceeding twice the monthly average of the 1991-2020 period have doubled.
- November 2024 saw the UK's most notable November snow event since 2010, although substantial snow events are neither as frequent nor as severe as they were in the 1960s-1980s.

Wind

- The UK annual mean wind speed from 1969-2024 has had a downward trend.
- There are fewer occurrences of maximum gust speed exceeding 40, 50 and 60 knots in the past two decades over land.
- Between April 2024 and April 2025, seven named storms have hit the UK.

The report also discusses the effect on indices relating to energy demand:

- In 2024, heating degree days (the total number of days below 15.5°C) were the fourth lowest in the observation series. The previous decade has seen a reduction in heating degree days of 5% compared to 1991-2020, and reduction of 14% compared to 1961-1990.
- In comparison, the number of cooling degree days (the total number of days each year where temperature exceeds 22°C) have approximately doubled over the last decade compared to 1961-1990.

The report also outlines significant events of extreme and significant weather which can impact infrastructure. These include:

- Locally extreme rainfall occurring in late September 2024, with the Oxford Radcliffe Observatory recording the wettest 2-day period in 200 years, and wettest month in 250 years.
- Severe flooding due to precipitation associated with Storm Bert in November 2024 across Mid- and South Wales. Further flooding from prolonged rainfall across the south of the UK also occurred in late January 2025. Prolonged strong winds from an unusual NW direction during Storm Darragh in December 2024, caused significant infrastructure damage. Storm Darragh, along with Storm Éowyn in January 2025, led to red weather warnings being issued by the Met Office.
- Extensive wildfires across Wales, Scotland and Northern Ireland in March and April 2025, due to warmer than average temperatures and very low levels of rainfall.

2. Electricity supply and demand 2024-2025

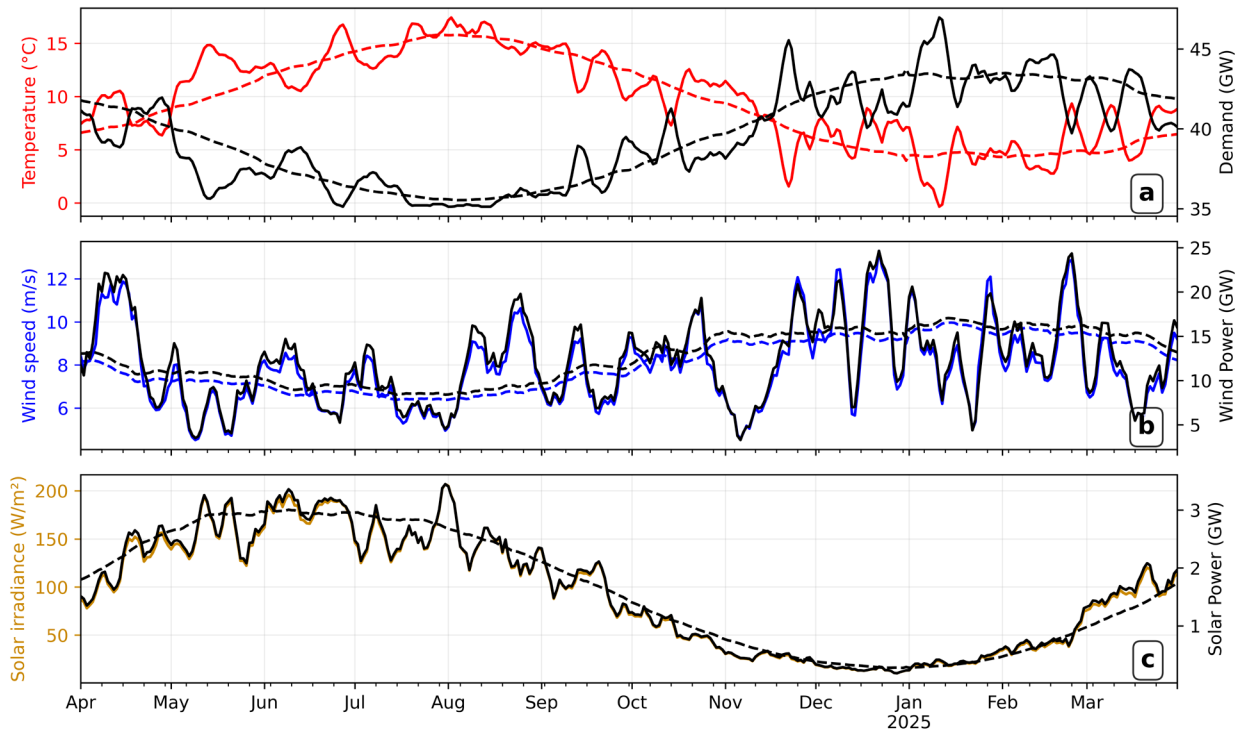


Figure 2-1: a) GB-average 2 m temperature (red) and modelled electricity demand (black) for the UK between April 2024 and April 2025. A 14-day rolling mean climatology is shown for temperature (red dashed line) and weather dependent electricity demand (black dashed line) for the period 1992-2022. b) As in a), but for the wind speeds at turbine hub height (100 m, blue) and the modelled wind power generation (black). The 14-day rolling mean climatologies (relative to 1994-2024) for the wind speeds and wind power generation are shown as dashed blue and black lines respectively. c) UK average downwelling solar irradiance (yellow) and solar generation (black) with the climatology (31-day rolling mean) for solar generation indicated by dashed lines. A 5-day smoothing is applied to the time series to reduce within-week variability. Modelled data from UREAD-ERA5 (Bloomfield & Brayslaw, 2021) including extensions to April 2025.

In Britain, the responsibility to ensure a balance between electricity supply and demand falls to the National Energy System Operator (NESO) preventing either too much generation relative to demand (referred to as the market being long) or too little generation relative to demand (known as the market being short). In Northern Ireland this role is managed by the System Operator of Northern Ireland (SONI). Typically, weather events where the market goes long occur when demand is lower and renewable generation plentiful, such as mild, reasonably windy and cloudless days. Events where the market is short typically occur when demand is higher and renewable generation is lower, such as cloudy, windless cold snaps during winter.

In general, when the market is long, NESO will take action to balance the system. These actions include reducing generation strategically in regions where transmission constraints prevent generated electricity from being moved to where demand is and ensuring short-term balancing from other sources (MacIver & Bell,

2025). The markets running short can cause issues with cost, balancing and carbon emissions. If renewable generation rapidly drops off, then for demand to be met, additional generation sources must be deployed, such as pumped hydropower, interconnectors or gas generation. If generation sources cannot be found to meet the shortfall, then NESO must use other system balancing mechanisms (NESO, 2022; Watt-Logic, 2025). Here we consider both demand and renewable generation from solar and wind between April 2024 and April 2025 to identify challenging periods.

To do this, modelled datasets of weather-dependent electricity demand, wind power generation, and solar generation are used (full details of the methodology are in Bloomfield et al., 2022 and in Appendix A, derived from the ERA5 reanalysis dataset (Hersbach et al., 2020). The datasets are extended through to near-real time from the previous archives found in Bloomfield et al., (2022). These estimates of weather-dependent electricity demand are quantified using known relationships between daily temperature and electricity demand (with human factors, such as the day of the week, removed). The relationship between temperature and demand is captured by a form of heating and cooling degree days described in Bloomfield et al., (2022). The difference between hourly weather-dependent electricity demand and renewable (solar and wind) generation is referred to as “demand-net-renewables”. To give further background for specific case studies, we also use observed sub-hourly demand and supply data from the Drax Electric Insights portal (Elexon).

The annual cycles of temperature and modelled electricity demand, wind speed and wind power generation, and solar irradiance and solar power generation are shown in the three subpanels of Figure 2-1. Electricity demand tends to be higher during the winter when colder temperatures drive increased demand related to heating (Figure 2-1a). Unlike other European countries, there is little cooling driven demand for air conditioning during warmer conditions in the summer in GB, so this is not currently modelled. In the future, the increase of air conditioning is likely to add a cooling-driven demand to the GB electricity network (Staffell et al., 2023). Climatologically, wind power generation is higher during the winter due to higher mean wind speeds (Figure 2-1b). During the winter, solar power generation is much lower caused by a reduction in daylight hours and reduced solar irradiance during these months (Figure 2-1c). The climatologies, shown as dashed lines, demonstrate how the values of the meteorological variables and modelled energy variables compare to typical values for that time of year. The difference between the absolute values in Figure 2-1 and these climatologies are used to calculate the anomalies presented in Figure 2-2.

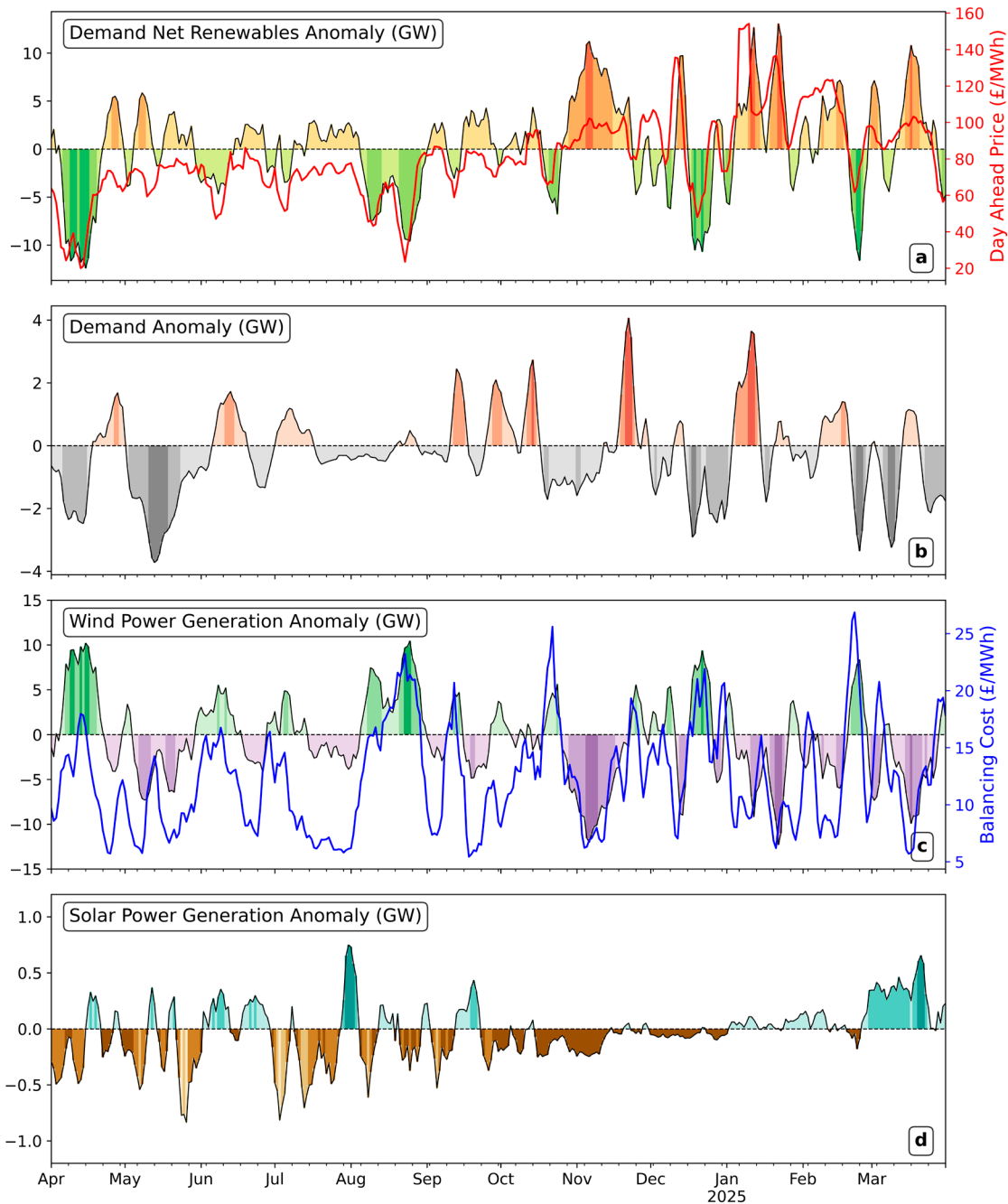
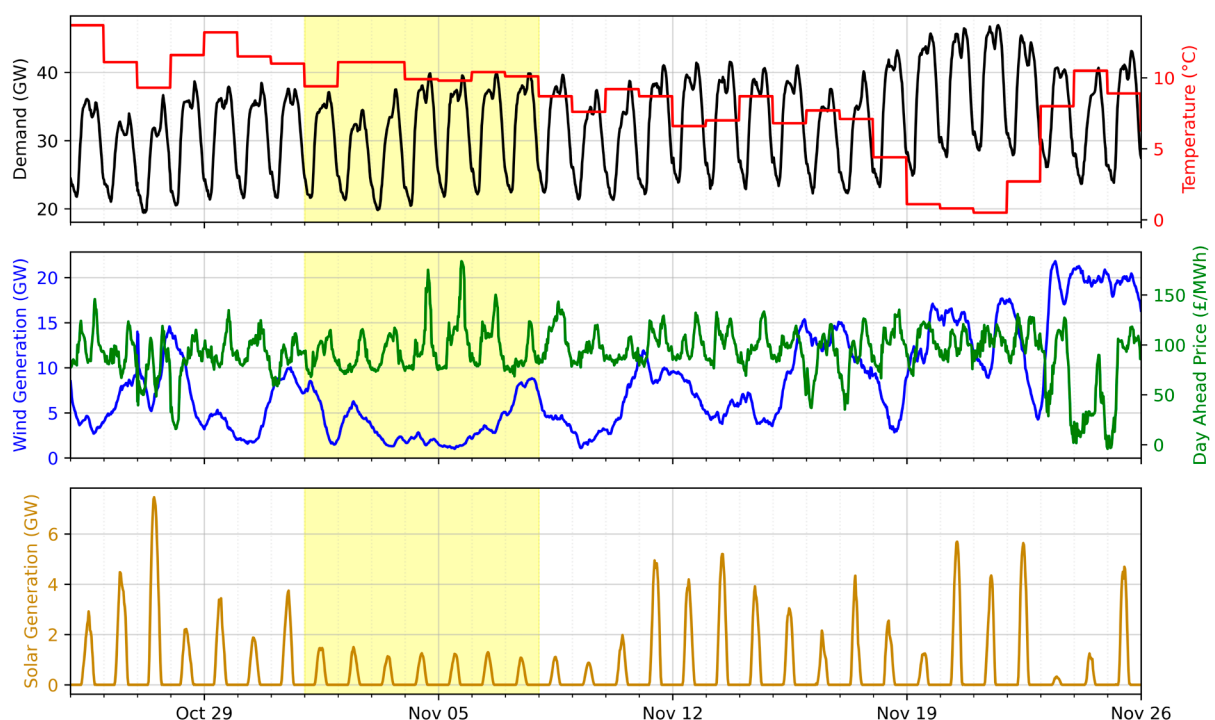


Figure 2-2: a. Demand net renewables anomalies (GW, modelled wind and solar generation subtracted from modelled weather dependent electricity demand) for Great Britain between May 2024 and April 2025. Anomalies are calculated relative to a 14-day rolling mean climatology between 1992 and 2022 (31-day rolling mean for solar). The 2024-25 values are plotted with a 5-day rolling mean to smooth over day-to-day variability. Positive days within one standard deviation of the climatology are plotted in yellow, days within 1-2 standard deviations are plotted in orange, days between 2-3 standard deviations are plotted in dark orange, and days over 3 standard deviations are plotted in red. This is the same for negative anomalies and shades of green. Day ahead electricity prices (£/MWh) are plotted on the right-hand y-axis in red (smoothed with a 5-day rolling mean). b. As in a., but for anomalies in weather dependent electricity demand. c. As in a., but for wind power generation anomalies, plotted alongside the balancing cost (£/MWh), smoothed with a 5-day rolling mean. d. As in c., but for solar power generation. Modelled energy data from UREAD-ERA5, price data from Drax Electric Insights / Elexon Portal.

By subtracting the smoothed day-of-year climatology for the past 30 years (1993-2023), Figure 2-2a highlights the periods where demand-net-renewables is high relative to the typical values at that time of year. In general, 2024-25 had fewer positive anomalies during the summer when compared to the winter. When considering challenging periods of high demand-net-renewables, November 2024 and January 2025 stand out due to the extended duration of these anomalies in early winter and two sharp spikes in anomalies in mid-winter. These challenging periods are explored in greater depth in Sections 2.1 and 2.2.

The day ahead electricity prices (Elexon, 2025) are also shown in Figure 2-1a. Prices tend to be lower when demand-net-renewables is low and there is a reduced need for flexible generation sources – and conversely prices rise when more flexible generation is needed. Challenges related to balancing demand and supply when demand-net-renewables is negative are also shown in Figure 2-2. Surplus renewable generation, particularly wind power (Figure 2-2c), and network constraints contribute to increasing costs to balance the system, which is one element of the total system cost. Getting the most cost-effective network is a strategic balancing act which has a multitude of factors, including maintenance of system stability whilst minimising any constraint payments. These events are costly, with £400 million spent on curtailed wind in 2024 (Drax, 2025). This was a particular issue during August 2024, where a surplus of wind generation (Figure 2-3c) and near-average levels of demand led to a prolonged period of high balancing costs (lasting for around two weeks). This case study is explored in greater detail in Section 2.3.



2.1 November 2024 – extended dunkelflaute period

Figure 2-3: Hourly electricity demand, daily mean temperature, hourly wind power generation, prices and solar generation for GB during early November 2024. Event period is highlighted in yellow. Hourly energy demand, generation and price data from Drax Electric Insights / Elexon Portal.

A high-pressure system over Europe for the first week of November (Figure 2-4) brought low wind and cloud cover to the UK, known as a ‘dunkelflaute’ (dark calm) event (Met Office, 2024a). From 3 November, settled conditions kept wind generation below 5 GW (capacity factor < 0.17) for four consecutive days, while solar generation remained under 1.5 GW (capacity factor < 0.08) throughout the week due to low clouds trapped by the high-pressure system. As the working week began, generation from gas increased and day ahead power prices spiked between the 4 and 6 of November. UK demand did not exacerbate this event as it remained relatively low throughout the week due to southerly winds bringing milder air as well as cloudy nights increasing nighttime insulation.

The extent of the high-pressure system meant that Germany was also facing a renewable shortfall, and increased demand due to colder easterly winds. While both the UK and Germany used natural gas as flexible generation, interconnectors also played an important role in managing this period of tight margins. Germany imported over 10 GW throughout the 6 November 2024 (Agora Energiewende, 2025), up to a quarter of its demand towards the last days of the event. While the UK and Germany are not directly interconnected yet, as wind generation recovered, the UK increased its exports to continental Europe and increased its imports from Ireland.

By the middle of the month, the high-pressure system moved to the west over the North Atlantic, bring cold northerly winds to the UK. While demand was higher, clearer skies and stronger winds brought a recovery in both solar and wind generation (Met Office, 2024a).

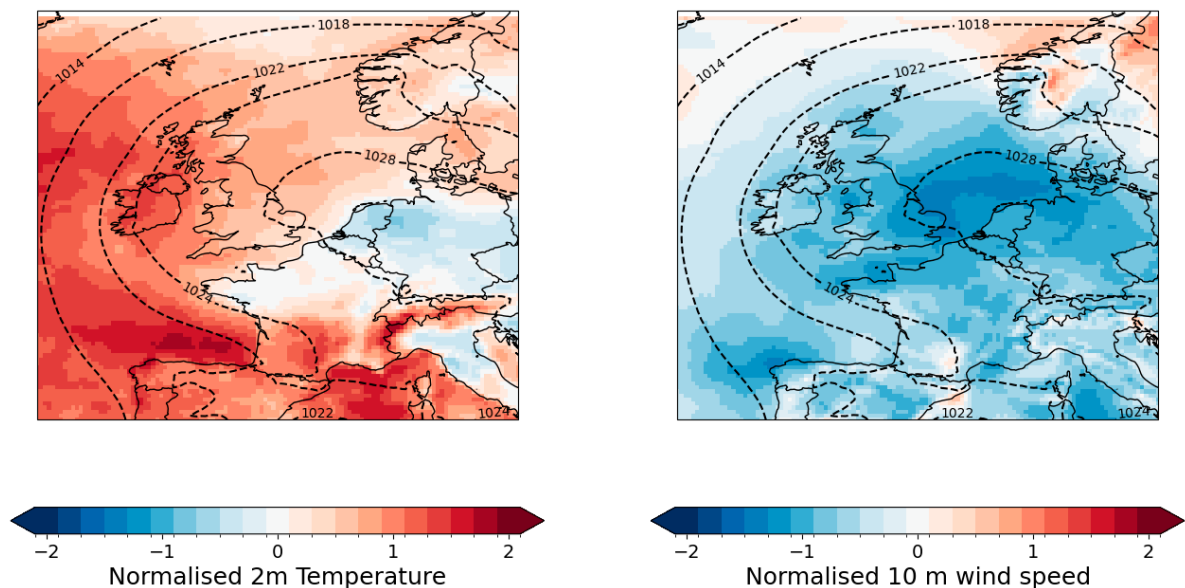


Figure 2-4: Temperature (left) and 10m wind speed (right) normalised anomalies for 1-7 November 2024. Labelled contours for mean sea level pressure (hPa) during this period are superimposed. Normalised anomalies are calculated relative to a daily climatology for the period 1992-2022 and normalised by the mean and standard deviation. Values taken from ERA5 reanalysis datasets (Hersbach et al., 2020).

2.2 January 2025 – two challenging Demand-Net-Renewables peaks

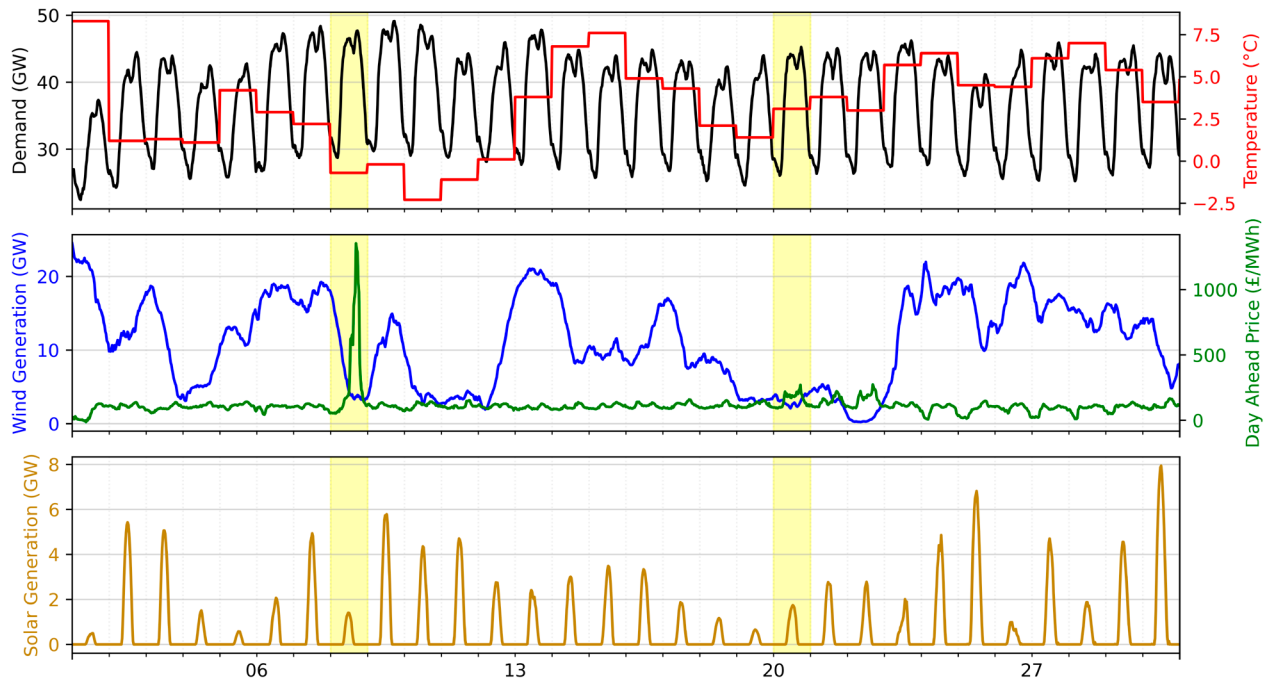


Figure 2-5: Hourly electricity demand, daily mean temperature, hourly wind power generation, prices and solar generation for GB during January 2025. Event periods are highlighted in yellow. Hourly energy and price data from Drax Electric Insights / Elexon Portal.

Two periods of potentially challenging conditions occurred during January 2025, around 8 and 20 January.

Leading into 8 January, temperatures were dropping (Figure 2-5, top row) but wind power was abundant with around 18 GW of generation (Figure 2-5, middle row). However, on 8 January, the colder temperatures coincided with low winds and cloudiness (Figure 2-5 and 2-6) and occurred on a weekday (i.e. associated with higher demand than a weekend). Wind power dropped sharply by around 15 GW and solar power generation also dropped, whilst demand remained high (Figure 2-5). This was compounded by a reduction in interconnector availability of around 3 GW going into the 8th (NESO, 2025b; NESO, 2025c).

In response to forecasted tight margins, NESO issued a Capacity Market Notice, at midday on 8 January, urging generators to prepare extra capacity for the 5 pm peak. Most of the forecast shortfall was met by the Viking Link interconnector from Denmark (Montel Energy, 2025), with the remaining margin being met by domestic gas generation. This rapid deployment of gas generation caused the spike in real time prices seen in Figure 2-5, with the overall daily balancing cost exceeding £21 million, around 10 times the normal daily balancing cost (Watt-Logic, 2025). Conditions around the 20 January had a similar potential to be challenging, with a period of low wind (Figure 2-6) and cloud cover, leading to low wind and solar generation (Figure 2-5). However, greater availability of gas generation, with around 20 GW immediately available compared to 10 GW on 8 January, combined with near-average temperatures that kept electricity demand lower, meant that margins were adequate and prices did not spike (Figure 2-5).

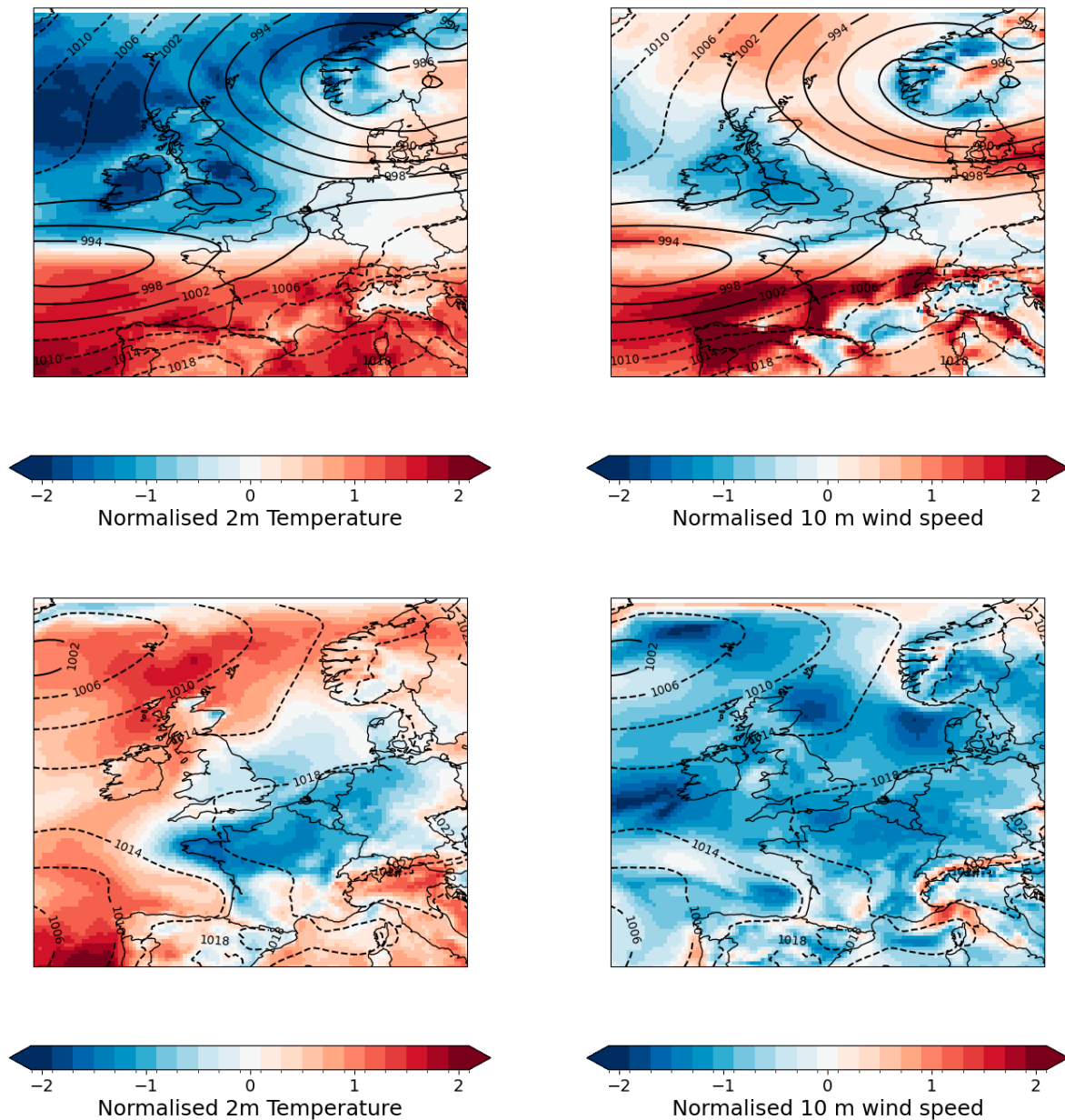


Figure 2-6: Temperature (left) and 10 m wind speed (right) anomalies on 8 January (top row) and 20 January (bottom row). Labelled contours for mean sea level pressure (Pa) during this period are superimposed. Normalised anomalies are calculated relative to a daily climatology from 1992-2022 and normalised by the mean and standard deviation. Values taken from ERA5 reanalysis datasets (Hersbach et al., 2020).

AECOM insight on the Dunkelflaute events

Data on solar generation and wind generation capacity show that national average monthly wind speed aggregated by the regional share of onshore and offshore wind generation capacity was, compared to the 20-year mean, down by 2 knots in November 2024 and 2.5 knots in January 2025.

National average solar generation capacity, similarly weighted by regional share of solar generation, compared to the 20-year mean, was down by 0.5 hours a day in November 2024, 0.8 hours a day in December 2024 but up by 0.3 hours a day in January 2025 (DESNZ, 2025)

The impact of dunkelflaute on energy generation across the UK has been reported in several companies' annual reports.

- SSE reported that higher numbers of dunkelflaute days impacted the consistency of their renewables output (SSE, 2025).
- FGEN attributed a 7.7% [financial] under-performance compared to budget as largely caused by low wind and solar resource availability. Their wind portfolio generated energy 17.8% below the sector target (FGEN, 2025).

The low wind speeds meant demand for short-term peak generation increased, with high prices benefiting companies with stored energy systems in their portfolio, such as hydropower and pellet-fuelled thermal generation. For example, Drax reported that during October and November 2024 the prolonged period of low wind speed led to higher demand for power from their assets (Drax, 2024a). This benefited Drax's flexible capacity in its pumped storage and hydro businesses, but also in its biomass generation business (Drax, 2024b).

2.3. August 2024 – high renewable supply, low electricity demand

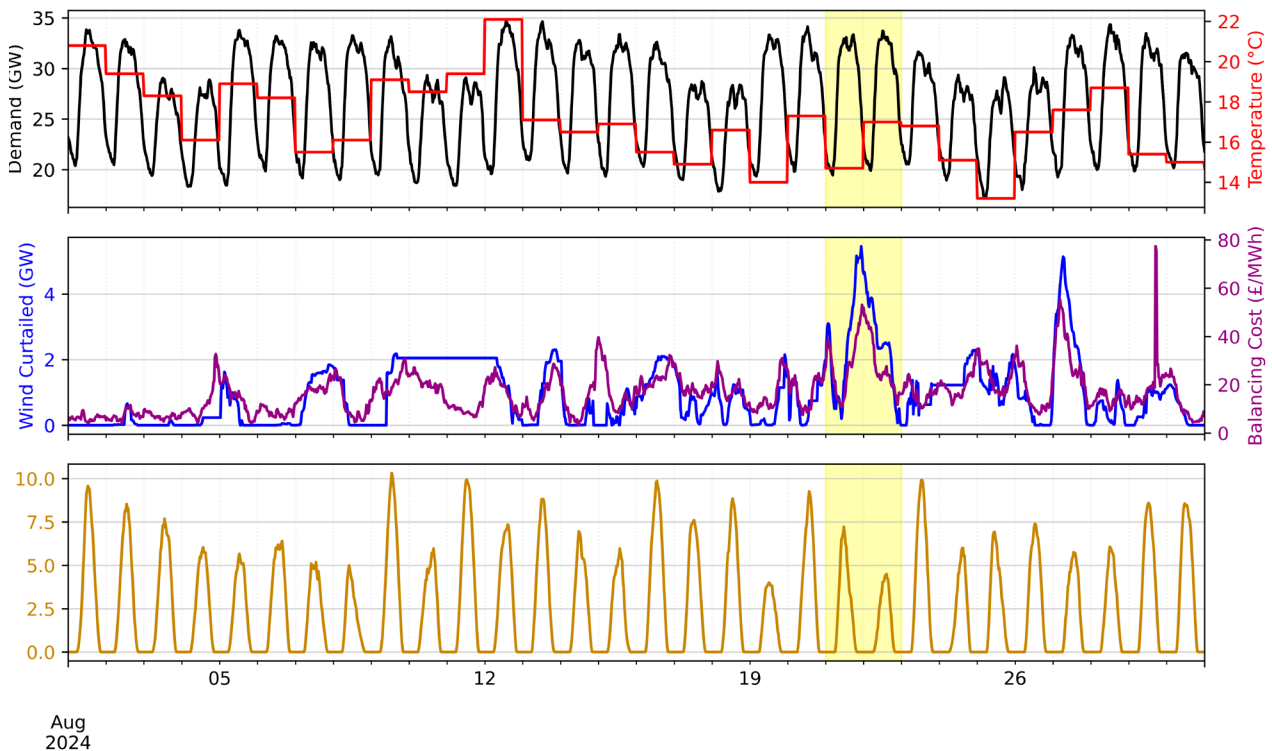


Figure 2-7: Hourly electricity demand, daily mean temperature, hourly wind power curtailment, balancing cost, and solar generation for GB during August 2024. The event period is highlighted in yellow. Hourly energy, curtailment and price data from Drax Electric Insights / Elexon Portal.

In August 2024, Britain experienced high renewable power generation, coupled with modest summer electricity demand. This led to wind curtailment and increased balancing costs. Although electricity demand in August (Figure 2-7a) was about average for this time of year, this is still well below winter demand (Figure 2-1b). This period of low demand was coincident with higher than average wind power production (Figure 2-7b), and solar generation that was slightly above average (Figure 2-1c). The net impact was a prolonged period – around two and a half weeks – of lower than average demand-net-renewables, visible as the green troughs in Figure 2-2a.

During these periods, wind power generation exceeded system demand requirements (including exports, storage and reserve margins) or network congestion prevented transmission from locations of generation to high demand areas. To maintain balance, NESO instructed wind farm operators to curtail their output. Wind generators are compensated for the curtailed energy, with this curtailment contributing to overall balancing costs, which may ultimately tend to increase consumer bills.

Between 21 and 26 August, wind power curtailment and balancing costs were notably above average. The largest curtailment event, peaking at 5 GW, was caused by sustained high wind speeds associated with Storm Lillian between 21 and 23 August (indicated in yellow on Figure 2-7). This curtailment led to the spike in balancing costs seen in Figure 2-7b. Transmission limitations meant that some wind power from the north of England and Scotland could not be exported to demand centres in southern England, necessitating gas-fired generation instead and further increasing balancing costs.

The meteorological conditions throughout August can be seen in Figure 2-8. Low pressure over Iceland and high pressure over continental Europe led to elevated wind speeds over the Irish and North Seas, particularly in the north. Temperatures were close to average. On 21 and 22 August, Storm Lillian passed across northern England and Wales, bringing strong winds to these areas and further increasing wind power production in the North Sea (Figure 2-2).

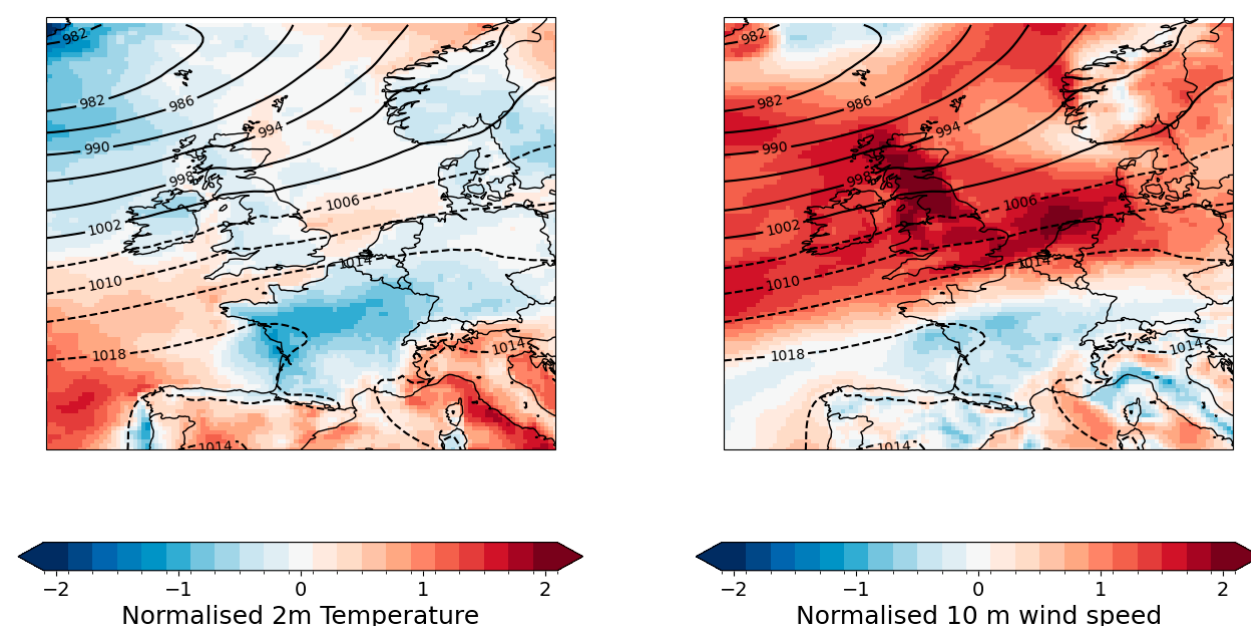


Figure 2-8: Temperature (left) and 10m wind speed (right) anomalies for 20-21 August 2024. Labelled contours for mean sea level pressure (hPa) during this period are superimposed. Normalised anomalies are calculated relative to a daily climatology for the period 1992-2022 and normalised by the mean and standard deviation. Values taken from ERA5 reanalysis datasets (Hersbach et al., 2020).

2.4. Sensitivity to possible future electricity system scenarios

Section 1.4 outlined that both the underlying climate and the GB energy system are in a period of rapid transition. Table 1 introduces potential scenarios for a changing GB power system composition (based on Bloomfield, 2025).

	Present Day	2035 Scenario	2050 Scenario
Mean Demand (GW)	32.5	52	70
Onshore Wind Capacity (GW)	14.5	27.8	31.0
Offshore Wind Capacity (GW)	11.3	60.0	115.0
Solar Power Capacity (GW)	13.9	70.0	106.4

Table 1: A summary of energy assumptions for three future energy scenarios, based on scenarios described in Bloomfield (2025). In these example scenarios, it is assumed that heating electrification contributes to an increase in demand, and that there are large increases in wind and solar built capacities.

In Figure 2-9, these energy scenarios are applied to the weather of January 2025 to show how a changing GB power system composition may impact the tight margins seen for the January 2025 case study. Keeping the weather conditions constant and only changing the power system setup allows for the resilience of future decarbonisation pathways exploration to be compared to present day weather challenges.

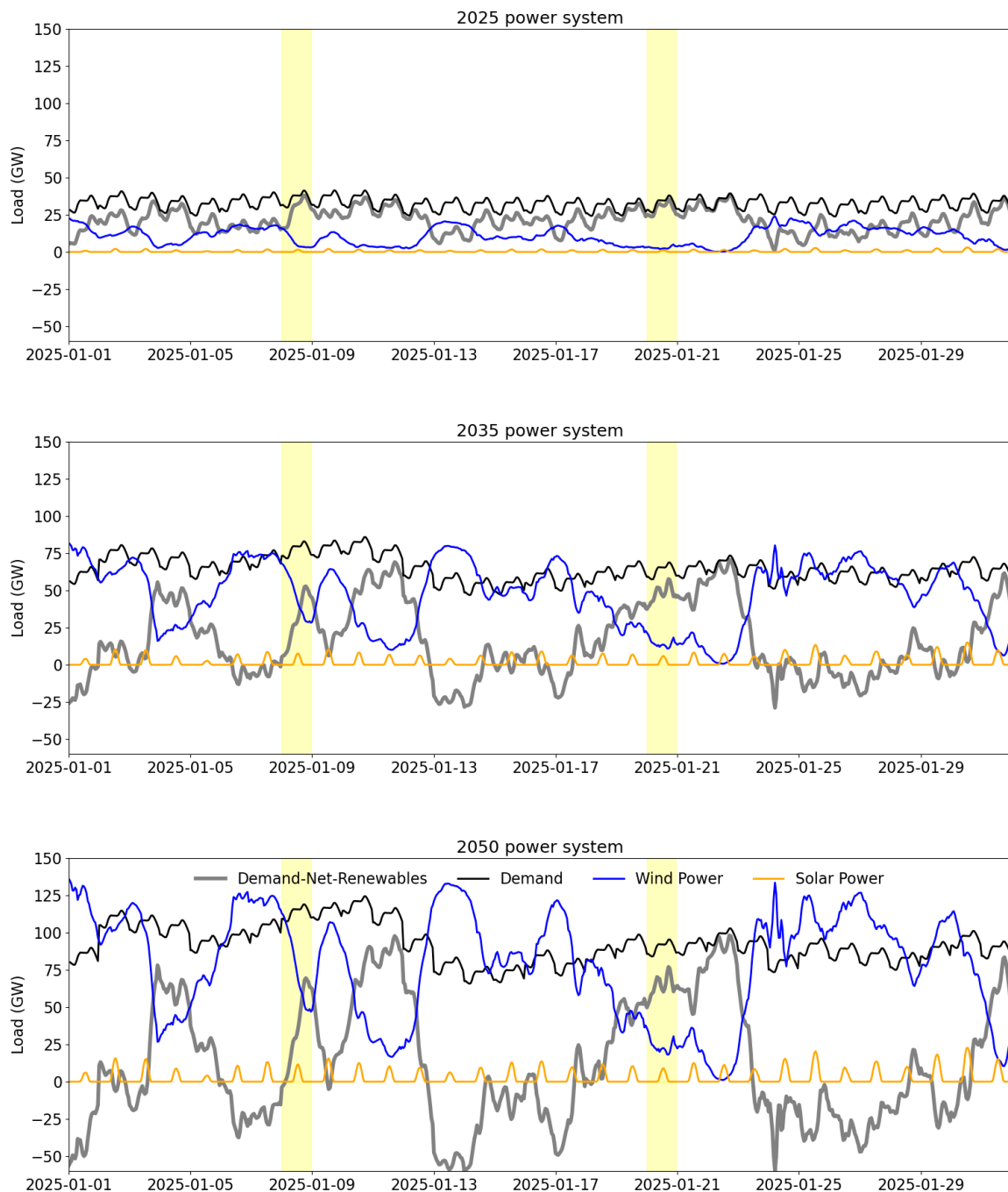


Figure 2-9: Hourly Demand-net-renewables (grey) demand (black) wind power (blue) and solar power (yellow) for the January 2025 case study period under three power system decarbonisation scenarios from Bloomfield, (2025) (a) 2025 (b) 2035 (c) 2050. Axes are kept the same in all subplots to emphasise changes in power system composition.

In the 2035 and 2050 scenarios, the increased demand (associated with heat electrification) is clearly visible in Figure 2-9 (black lines). Wind power generation also sees substantial increases with periods of over 125 GW of wind generation. As this is the mid-winter period, where climatologically solar potential is at its lowest, there is still very little contribution from solar PV during this period, even with >100 GW installed.

The demand-net-renewables time series in Figure 2-9 shows that in the 2035 and 2050 power system scenarios, there are often long periods where there is more renewable generation (predominantly from wind) than demand. In these periods, there is potentially an opportunity to store wind energy to be released during some of the more challenging days (such as the highlighted case study days).

By 2050, in the power system scenario explored, it is very common for renewable generation to exceed demand (particularly in summer, not shown). When comparing the subplots of Figure 2-9, it is clear that even with larger installed capacities of wind and solar, the system will need to rely on other sources of electricity, and provides real-world context for the scale of other electricity sources needed. There are still 5 periods in Figure 2-9c where demand-net-renewables is positive for multiple days because the area over which these high pressures extend is much larger than the areas of the North and Irish sea regions available to build wind farms. These events often extend across Central Europe (van Duinen et al., 2025) but it is very rare for a renewable energy drought to cover the whole continent. Therefore, additional technologies and having a variety of generation sources are important for ensuring the future resilience of the system.

3. Infrastructure impacts 2024-25

Physical energy infrastructure is vulnerable to weather-driven hazards. This can cause faults in transmission and distribution networks, disrupting electricity supply and, more rarely, gas supply to customers. Given the greater weather dependence of the electricity supply to weather hazards, this is the focus of the follow analysis. Distribution Network Operators (DNOs) are responsible for delivering electricity supply to consumers. DNOs use weather forecasts and vulnerability assessments to anticipate upcoming weather-driven hazards and, where possible, take measures to reduce outages.

Whilst some outages are inevitable, constant monitoring of potential hazards and network vulnerability across a range of temporal and spatial scales helps DNOs minimise the number of outages from a given extreme weather event. This includes developing and testing proportionate emergency response plans, as well as designing assets to be adequately weather resistant. As climate change influences the frequency, severity and timings of storms (Manning et al., 2023) and extreme heat (Kennedy-Asser et al., 2021), companies are increasingly choosing – and becoming obliged – to implement adaptation measures to ensure the future energy system is climate resilient (Ofgem, 2025).

This report considers the physical impacts of winter storms by exploring wind and precipitation related faults, as identified and recorded by DNOs over the period. A full methodology describing the fault data from DNOs is provided in Appendix B. Additionally, the report considers lightning strike density and lightning-related faults over the summer. Finally, it discusses several case studies of climate change adaptation measures being taken by the sector.

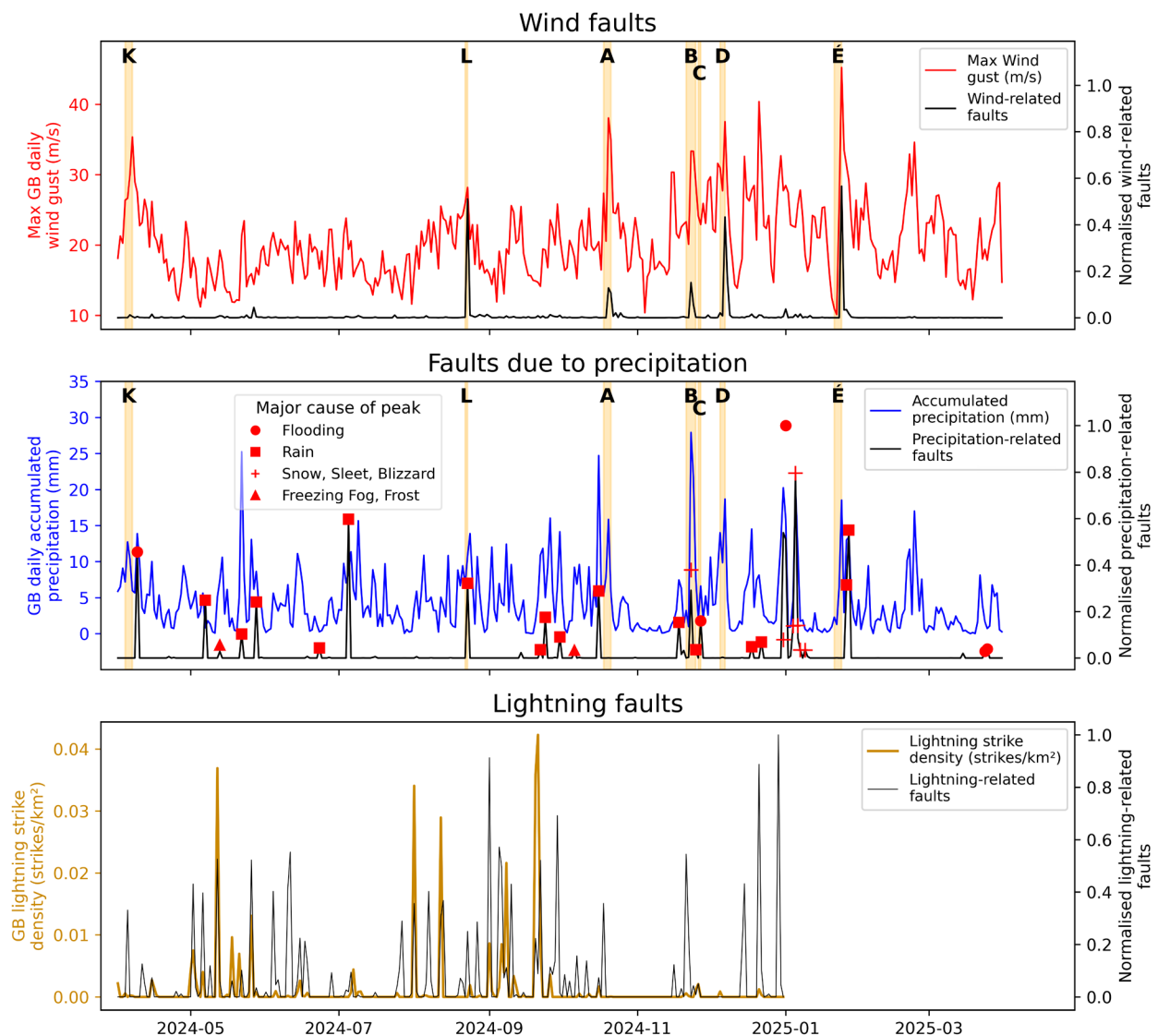


Figure 3-1: Top: Daily maximum 10 m wind gust (red) and normalised population-weighted wind-related electricity network faults as provided by DNOs (black) for Great Britain, from April 2024 to March 2025. Middle: Average daily accumulated precipitation (blue) and normalised population-weighted precipitation-related electricity network faults (black) for Great Britain, from April 2024 to March 2025. The red symbols at the top of the fault peaks show whether the major cause of the peak was from flooding, rain, snow or fog/frost. Bottom: Daily average lightning strike (orange) and normalised population-weighted lightning-related electricity network faults (black) for Great Britain, from April 2024 to January 2025. Wind and precipitation data is from ERA5 (Hersbach et al., 2020), and lightning strike data is from the Worldwide Lightning Network (Kaplan & Lau, 2021, data available at <https://zenodo.org/records/10246857>).

Storms of interest are highlighted in orange in the first two subplots: Kathleen (K), Lillian (L), Ashley (A), Bert (B), Connall (C), Darragh (D), and Éowyn (É). DNO data sub-divided by fault code was not available for all regions, so only data from SSEN (Southern England, Northern Scotland), ENWL (North Western England) and NPG (North Eastern England, Yorkshire) are included in the GB average fault data shown here.

3.1. Storms

There were seven named storms between April 2024 and March 2025, two in the 2023-24 storm season (September 2023 – August 2024) and five in the 2024-25 storm season (September 2024 – August 2025). These storms brought powerful winds and heavy rain to the UK, with significant impacts on electricity distribution and transmission networks.

Risks to the energy sector can be determined by combining the hazard, the exposure and the vulnerability (Cardona et al., 2012). In this specific case:

- The severity of the storm.
e.g. How strong are the wind speeds and gusts? What is the density of lightning strikes? What is the rate and total amount of precipitation?
- The exposure to the storm.
e.g. Does the track of the storm, or the location of other hazards, cover an area with lots of energy infrastructure and high population density?
- The vulnerability of assets.
e.g. Are the exposed assets adequately prepared to withstand extreme weather events, for example flood defences?

The largest impacts came from Storms Darragh and Éowyn in December 2024 and January 2025, respectively. The specific characteristics and impacts of all named storms are discussed below.

The top panel of Figure 3-1 shows normalised, population-weighted DNO faults (based on customer minutes lost, the sum of the amount of time each disconnected customer was without power for), attributed to wind damage, aggregated across Great Britain (solid black line), alongside the maximum wind gusts recorded on that day (solid red line). The relationship between the strength of the wind gusts and wind-related electricity network faults is clear: strong wind gusts are associated with increased faults, and therefore power outages.

Similarly, the relationship between daily accumulated precipitation (blue line) and precipitation-related faults (black line) is shown in the middle panel of Figure 3-1. The link between accumulated precipitation and faults is more complex: since many factors impact the potential for a region to flood. For pluvial (flooding from extreme precipitation events), these include land use, soil type, and the ability to absorb rainfall, whereas for fluvial flooding (from rivers), the associated catchment size and residence time are important. The rate of rainfall is also important: if most of the rain falls in just a few hours, this makes flash flooding more likely. However, there is still a robust relationship between days with increased rainfall and precipitation-related faults, and flooding faults often arise after several days of above-average precipitation.

Figures 3-2 shows maps, for each named storm, of the maximum wind gust in the 72-hour period centred around the storm; Figure 3-3 shows precipitation accumulated over the same period. The track of the storm's low-pressure centre is superimposed in magenta on each plot. These figures demonstrate the severity of each storm's wind and precipitation, and the locations at which each was most extreme. They also demonstrate several compound events with high winds and rainfall, particularly storms Bert, Lilian, and Éowyn. This can also be seen in the fault data in Figure 3-1.

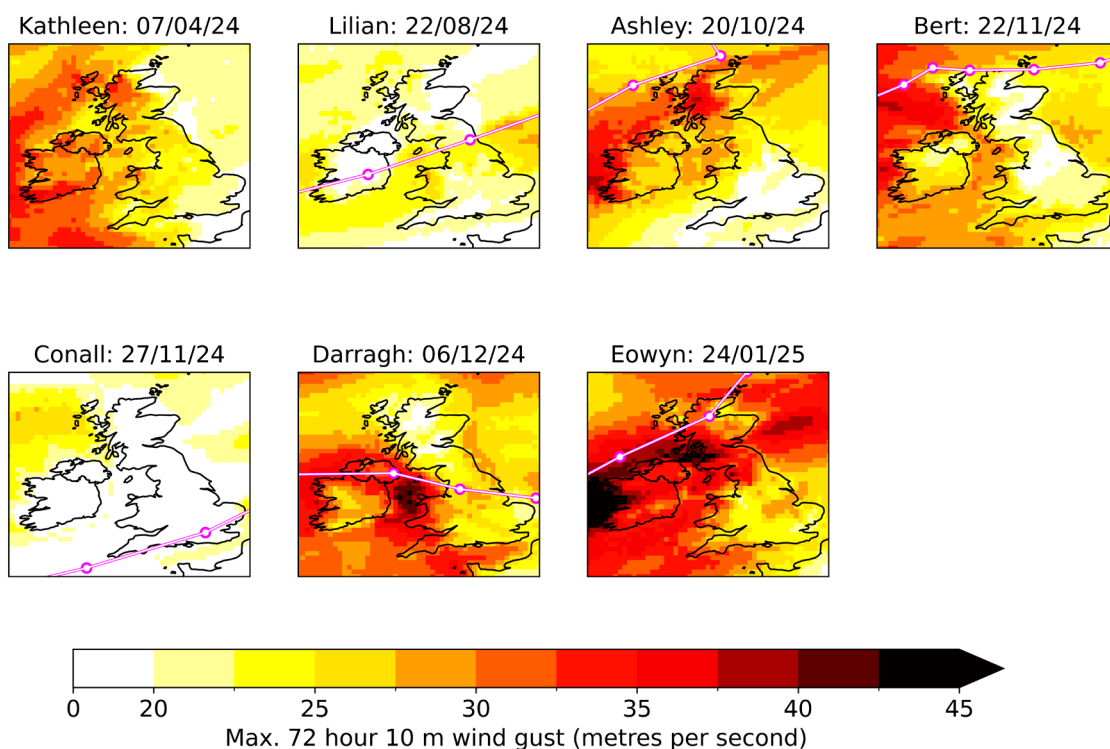


Figure 3-2: Storm footprints for named storms during the 2024-2025 storm season, defined as the maximum 3-second 10 m gust (m/s) at each grid point over a 72-hour period (gust data from ERA5). The 72-hour period is defined as the 36 hours either side of 1200 GMT the day the named storm impacted the UK. Each footprint is labelled with the name and central date of impact of the storm used to create the footprints. The magenta lines show the 6-hourly track of each storm according to its mean sea level pressure centre.

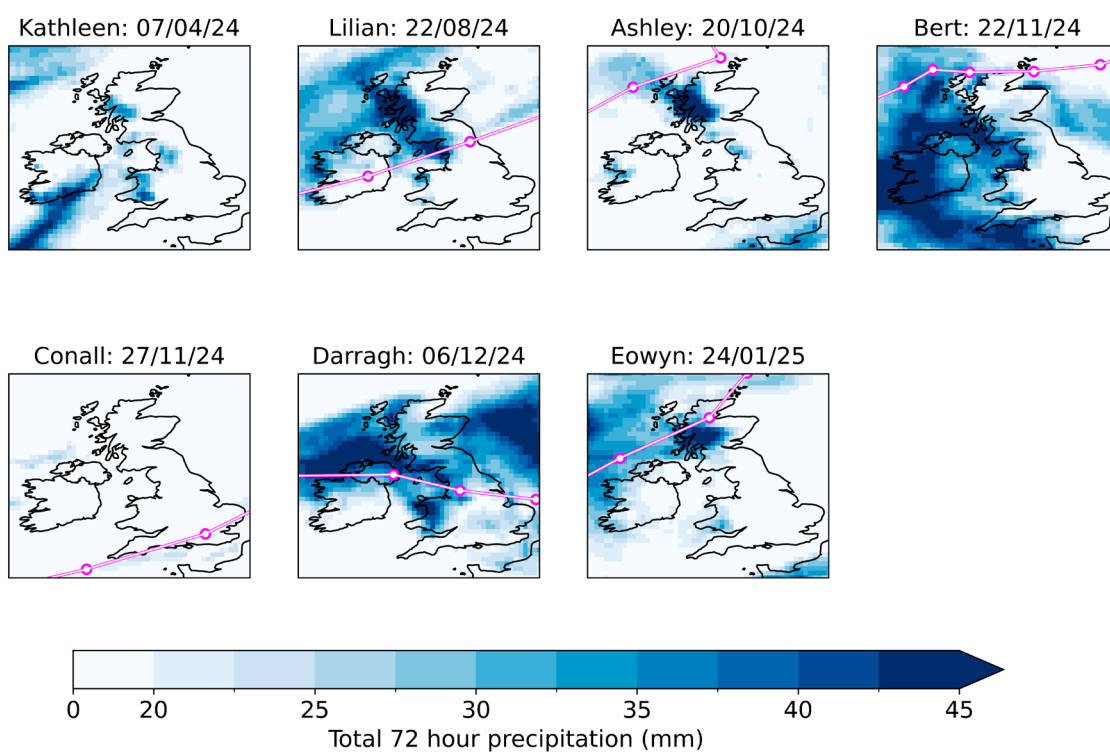


Figure 3-3: Storm footprints for notable named storms during the 2024-2025 storm season, defined as the total accumulated precipitation (mm) at each grid point over a 72-hour period. The 72-hour period is defined as the 36 hours either side of 1200 GMT the day the named storm impacted the UK. Each footprint is labelled with the name and central date of impact of the storm used to create the footprints. The magenta lines show the 6-hourly track of each storm according to its mean sea level pressure centre.

Figure 3-4 shows the impact of all weather-related faults (all faults for SPEN regions), as normalised number of customers affected, in each region where DNO data was available. Dates of named storms are superimposed. Along with Figure 3-2 and 3-3, this shows which storms were most damaging to each region.

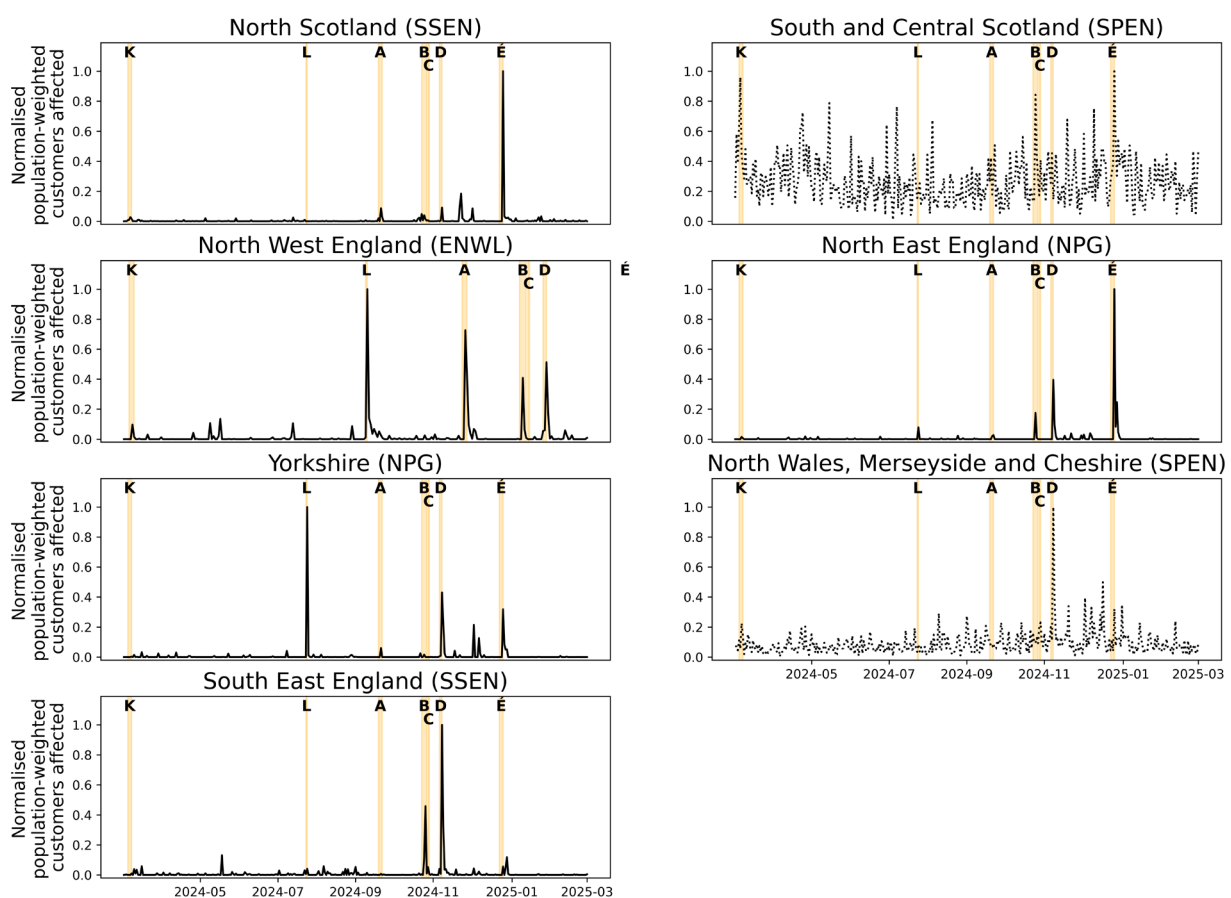


Figure 3-4: Weather related faults separated by distribution region. Titles of subplots show the region, with the relevant Distribution Network Operator in brackets afterwards. Storms of interest are highlighted in orange in the first two subplots: Kathleen (K), Lillian (L), Ashley (A), Bert (B), Connall (C), Darragh (D), and Éowyn (É). For all DNOs except SPEN (solid lines), fault data is limited to faults with weather-related fault codes. SPEN panels (dotted lines) show all faults. No data was available for NGED or UKPN, and only to 31/12/24 for ENWL.

Below, we identify the most impactful winter storms, and the effects they had on the energy network infrastructure.

Storm Kathleen (6-7 April 2024)

Kathleen was wet and windy, an ‘unusually severe storm for this time in spring’ (Met Office, 2024b). The storm tracked to the west of the UK, meaning that impacts on the GB energy sector were relatively low, despite wind gusts of up to 56 mph in some areas. Increased faults in South and Central Scotland can be seen in Figure 3-4, close to Éowyn in terms of number of customers affected. More severe impacts were experienced in Ireland and Northern Ireland (BBC News, 2024a).

Flooding in the aftermath of Kathleen in West Sussex on 8 April caused the highest level of precipitation-related electricity faults in Southeast England in the last year, clearly seen in Figure 3-1b. However, despite the high relative impact, the absolute impact was low.

Storm Lilian (23 August 2024)

Lilian was the most significant August windstorm since 2020, and it is rare for named storms to occur this late in the storm season. The storm tracked over northern England and Wales, with most impacts confined to these areas. Figure 3-4 shows that this event affected customers in the North-West England and Yorkshire regions the most in 2024-25 (noting that ENWL data stops on 31 December 2024, so excludes Éowyn).

Figure 3-3 shows Lilian had low levels of precipitation over land, with most precipitation falling off the west coast of Scotland. Thus, most faults in Figure 3-1 are wind-related, many due to fallen trees, which are more vulnerable when in full leaf, rather than precipitation-related.

The Energy Networks Association reported that over 60,000 customers, mostly in Northeast England, lost power. Over one third were re-connected within 24 hours (ENA, 2024a).

Storm Ashley (20-21 October 2024)

Ashley, the first named storm of the 2024-25 season, did not significantly impact the sector according to the DNO fault data that was analysed, despite wind gusts of up to 80 mph over Scotland (Met Office, 2024b). A small peak in faults can be seen over North Scotland (Figure 3-4), but the storm’s path north of Scotland meant that impacts were localised. Faults were quickly dealt with, because DNOs increased staffing in call centres and operational teams (ENA, 2024b).

Storm Bert (22-25 November 2024)

Storm Bert caused power outages for tens of thousands of customers throughout the country, including nearly 25,000 in Northern Powergrid's regions of Northeast England and Yorkshire (Northern Powergrid, 2024).

Wind-related faults were low, due to the storm's relatively low intensity over the UK, and its track over the north of Scotland. There was, however, extreme rainfall: 23 November 2024 had the highest UK-total rainfall since 3 October 2020 (Met Office, 2024b). This resulted in rain- and flooding-induced electricity faults that can be seen in Figure 3-1b, with localised flooding in central and eastern England persisting for several days after the event.

Finally, Bert brought significant amounts of snow to North England and Scotland, including over 20 cm in County Durham in the morning of 23 December. This resulted in the snow-related faults which can be seen in Figure 3-1b with the '+' topped peaks, from snow weight on overhead lines and roofs, melting snow causing water damage, and icing of cables. This amounts to the largest snow/ice impact on the energy sector in 2024-25.

Storm Conall (27 November 2024)

The footprints in Figure 3-2 and Figure 3-3 show that Conall brought less extreme wind gusts and precipitation than most other named storms in 2024-25. This meant that direct impacts were low. There are no clear peaks in wind-related faults in Figure 3-1, and a small peak in flooding related faults. Flooding related faults are likely related to precipitation accumulated across Bert and Conall, which occurred less than 48 hours apart.

Storm Darragh (6-7 December 2024)

Darragh brought extremely strong winds of up to 96 mph across Great Britain. This was accompanied by heavy rainfall with over 75 mm widely, and up to 100 mm in western Wales, in less than 48 hours (Met Office, 2024b). Its path across populated areas of Wales and central and northern England amplified its impacts on the energy sector: it was the storm which caused the most faults in 2024-25. For many affected areas, it was the biggest storm experienced in decades (Met Office, 2024b).

Over 2.3 million customers lost power during the storm (ENA, 2024c). The increase in wind-related faults is clear in Figure 3-1. This is supported by the regional breakdown in Figure 3-4: Darragh was by far the worst event, affecting the most customers, in 2024-25 in North Wales, Merseyside and Cheshire (despite not being able to separate weather-related faults). There were also large impacts across North-East England, North-West England, Yorkshire, and South-East England.

Extreme precipitation and winds were also experienced in South Wales, causing significant faults in this area (Hi West, 2024). There was also flooding along the River Severn. We could not access DNO fault data for these areas, so these precipitation-related faults do not appear in Figure 3-1. It is likely that Darragh had an even more significant impact than the available data suggest.

Recovery efforts from Darragh were efficient: 88% of customers were restored by 9am on 7 December, and 99% by 10 December. These efforts were helped by proactive actions from DNOs in the affected areas. National Grid Electricity Distribution (NGED), for example, provided 201 mobile generators and 14 food and drink welfare vehicles to maintain power in essential locations and assist those without power (National Grid, 2024).

Storm Éowyn (24 January 2025)

Éowyn was the UK's 'most powerful windstorm for over a decade' (Met Office, 2025b) and had widespread impacts on the energy sector, despite tracking over northern Scotland. Over one million customers suffered power outages (ENA, 2025). From Figure 3-4, Éowyn was the most impactful event in the North Scotland, South and Central Scotland, and North-East England regions.

Figure 3-1 shows that most outages were related to the strong winds – a maximum wind gust of 100 mph was recorded in Lanarkshire (Met Office, 2025b). This is supported by Figure 3-2 and 3-3, which show high winds over Scotland, Wales and North England, but large amounts of rainfall only over western Scotland. There were also a high number of outages in North-West England, which are not shown in Figure 3-1 as ENWL's data ends on 31 December 2024 (ENWL, 2025).

Whilst total customer minutes lost were lower in the SPEN region than for Darragh in the data available, the average time customers were disconnected for was longer. This is because recovery efforts were hampered by prolonged high winds, which stopped DNOs assessing and repairing damage (SPEN, 2025).

AECOM Insights on the impact of Storm Bert and Storm Connall

The impacts of Storms Bert and Connall on UK energy distributors was significant, with many companies reporting damage to overhead lines and transformers from flying debris, falling trees, snow/ice accumulation, heavy rain and flooding. The resulting power cuts affected more than 300,000 customers in National Grid supply areas, more than 11,000 homes in Cumbria and the northwest (Electricity North West), and over 2,400 homes in the UK Power Networks East of England supply area.

National Grid Electricity Distribution dealt with around 2,500 incidents over 72 hours and restored power to more than 300,000 customers, largely related to issues such as fallen trees and transformer damage (National Grid Electricity Distribution, 2024), while Electricity North West reported damage to overhead lines in Cumbria and the Northwest due to 'flying debris and ice accumulation'. They restored power to 11,000 homes (BBC News, 2024c).

In the East of England, UK Power Networks reported unplanned outages affecting almost 800 homes in Hertfordshire, with more than 1,000 homes in Norfolk without power, with several localized outages due to overhead cable faults (BBC News, 2024d). UK-wide outages affected nearly 27,000 homes in the North East, Yorkshire, and North Lincolnshire, plus 4,000 more in the Midlands, South West England, and South Wales (Euronews, 2024).

SEEN (Scottish and Southern Electricity Networks) activated contingency plans ahead of the storm to deal with flooding, wind gusts exceeding 60 mph, and snow which caused damage to overhead infrastructures. They deployed extra response teams, welfare support, and customer communication (SEEN, 2024a). Northern Powergrid, with support from Integrated Utility Services (IUS), restored power to over 30,000 customers in Northumberland, County Durham, and Tyne & Wear by early the next day (IUS, 2024).

The severe weather across the UK, including heavy rain, snow, and strong winds—led to fallen trees, transformer damage, fallen lines, blocked access routes, and widespread flooding, complicating repair efforts. Staffing was increased in control rooms and contact centres, and field operations teams were put on standby (SPEN, 2024), using automatic restoration systems where possible. Many electricity networks reached out to customers on Priority Services Registers. For example, SEEN sent 750,000 text messages ahead of the storm (SEEN, 2024b).

3.2 Flooding

Aside from flooding associated with the named storms, outlined above, power outages were associated with other flooding events throughout the year. This can be due to precipitation accumulating over several days, weeks, or months, and causing fluvial (river) flooding, or due to tidal surges, as opposed to the pluvial or flash flooding caused by storms.

Northern England experienced over 90 mm of rain in a 24-hour period over 31 December 2024 and 1 January 2025 (BBC News, 2025a). This caused widespread flooding across North-West England, and an increase in flooding-related electricity system faults as seen in Figure 3-1b.

3.3 The impacts of lightning

The relationship between lightning-induced electricity faults and lightning strike density is not simple. An increased number of thunderstorms and lightning strike density (usually measured in strikes each day per km²) increases the likelihood of a strike hitting equipment and causing surges that damage or destroy components. However, just one isolated lightning strike has the potential to cause outages for many customers if it damages a key piece of equipment or not correctly cleared as a transient fault. For example, in 2019 a single strike hit a transmission line and led to a series of cascading effects that resulted in a widespread power outage including two large generators going offline (Ofgem, 2019).

Lightning was particularly prevalent and impacting on energy infrastructure and operations in May and September 2024: Figure 3-1c shows a high number of normalised customer minutes lost for these months, along with high lightning strike densities. There was high thunderstorm activity in May, with 9,576 strikes (including cloud-to-cloud strikes) recorded on 12 May (BBC News, 2024b). September 2024 had the second-most lightning strikes on record for September across 18 thunder days (Meteorage, 2024). This activity was most concentrated in the South England, especially Gloucestershire, Surrey and East Sussex; this shows up in the SSEN fault data for South-East England (Figure 3-4)

There were also several more isolated lightning events affecting the GB energy sector during the year. Scotland typically has a secondary peak of lightning activity during the winter, particularly around NW-facing coastlines (Hayward et al., 2022). In December, January and February, lightning strikes in North Scotland led to power outages and cause the peaks in faults shown in Figure 3-1c.

4. Conclusions and outlook

This report has given an overview of extreme weather events that impacted the UK energy sector between April 2024 and April 2025, focusing on several case studies to demonstrate how weather has the potential to disrupt the electricity system. Here, the impacts are divided into two categories: (1) events where there was a large imbalance between renewable generation and GB demand, and (2) events that damaged grid infrastructure.

In two separate events in January 2025 there were periods of high demand-net-renewable generation, requiring NESO to rely more heavily on conventional generation (e.g. gas fired power stations) to balance the system. Both events occurred because simultaneously renewable production decreased, and demand increased. On 8 January, a sudden drop in the availability of wind was compounded by interconnector maintenance and limited non-renewable production. The response, whilst significantly increasing the real-time price of electricity, ensured that system stability was maintained. On 20 January, sufficient additional generation sources were prepared, meaning that there was a very limited impact on the real-time price of electricity. This highlights the importance of accurately forecasting these events in advance but also shows that responses taken by NESO are effective and can maintain the system. Ongoing efforts to improve energy-relevant forecasts and optimise their use include full utilisation of probabilistic forecasting to provide better uncertainty quantification, particularly during times of high uncertainty.

By comparison, significant renewable production during August occurred when there was limited demand, leading to a large curtailment event. High winds from Storm Lillian, coupled with plentiful solar availability, led to large amounts of renewable generation. Low demand, lack of available storage, and locational mismatches between generation and demand meant that 3-4 GW was curtailed, even while flexible generation was needed in south England. These events suggest the continued importance of weather on energy and that the interaction of weather/climate with potential energy-system solutions such as emerging energy-storage, demand flexibility, interconnectors, and gas-fired generation needs to be fully evaluated.

It is also highlighted that the impact of a windstorm is not just a function of its severity because the track of the storm, time of year, and associated extreme weather also affect exposed energy infrastructure. Storm Darragh had significant impacts on the energy sector, because it brought high winds and heavy rain which affected large parts of Wales and Northern and Central England. Storm Éowyn, despite being the UK's worst windstorm in a decade, had a lesser impact as it passed over less densely populated Scotland. Storm Lillian, although much weaker than Éowyn, also showed significant impacts due to its track over densely populated regions and summer timing.

Storm damage to the energy system was mostly limited by accurate forecasting and good communication between the weather sector and energy sector. DNOs responded swiftly so that most customers who experienced connection issues were reconnected quickly. An exception to this was during Éowyn, when high winds persisted, preventing rapid deployment of engineers to fix damaged infrastructure. Additional infrastructure damage occurred in May and September due to lightning strikes from a series of thunderstorms. The sporadic nature of both thunderstorms and lightning strikes themselves and the unpredictable cascading impacts that can occur from single points of failure mean that impacts from such events is much harder to anticipate.

The UK energy system and climate are rapidly evolving, impacting future energy security. Using 2025 weather conditions and plausible near-future power system scenarios, the report's analysis suggests that many challenges remain if the UK is to meet significantly increasing demand using predominantly wind and solar power. This report emphasises the need for collaboration between disciplines to improve understanding of the impact of a changing climate on individual energy system components. It also emphasises the need to consider the impact of climate on an integrated energy system that uses multiple technologies to achieve secure, reliable and affordable energy supplies into the future.

Acknowledgements

DNOs for fault data

Drax Electric Insights/Iain Staffell for price/energy data

AECOM for sector-based insights

RMetS Energy SIG members contributing feedback to the report

Dr Duncan Ackerley for the storm tracks

References

Agora Energiewende, 2025. Current and historical as well as modelled locational and future representation of the situation in the electricity system with generation, consumption and prices, Agorameter – Available at https://www.agora-energiewende.org/data-tools/agorameter/live/chart/power_import_export/01.11.2024/15.11.2024/hourly

Bloomfield, H.C., and Brayshaw, D.J., 2021. ERA5 derived time series of European aggregated surface weather variables, wind power, and solar power capacity factors: hourly data from 1950-2020. University of Reading. Dataset. <https://doi.org/10.17864/1947.000321>

Bloomfield, H.C., Brayshaw, D.J., Deakin, M. and Greenwood, D., 2022. Hourly historical and near-future weather and climate variables for energy system modelling. *Earth System Science Data*, 14(6), pp.2749-2766. <https://doi.org/10.5194/essd-14-2749-2022>

Bloomfield, H.C, 2025. Reasonable worst-case stress-test scenarios for the UK energy sector in the context of the changing climate. *Newcastle University/ Climate Change Committee* <https://www.theccc.org.uk/wp-content/uploads/2025/02/Reasonable-worst-case-stress-test-scenarios-for-the-UK-energy-sector-in-the-context-of-the-changing-climate-Bloomfield.pdf>

BBC News, 2024a. “Storm Kathleen brings trees down and power outages” April 2024, accessed 01/08/2025 at <https://www.bbc.co.uk/news/uk-northern-ireland-68746898>

BBC News, 2024b. “Thunderstorms and heavy rain sweep parts of UK”. Accessed 01/08/2025 at <https://www.bbc.co.uk/news/articles/cp8lqjy8p7po>

BBC News, 2024c. “Storm Bert causes power cuts and travel disruption”. Accessed 23/09/2025 at <https://www.bbc.co.uk/news/articles/cvgel4rq8eyo>

BBC News, 2024d. “Hundreds of homes without power in Storm Bert”. Accessed 23/09/2025 at <https://www.bbc.co.uk/news/articles/cd6v8yqj5j7o>

BBC News, 2025a. “Homes flooded in Greater Manchester as storms hit New Year’s Day”. Accessed 01/08/2025 at <https://www.bbc.co.uk/news/articles/cvgm5krp25o>

Cardona, O.D., M.K. van Aalst, J. Birkmann, M. Fordham, G. McGregor, R. Perez, R.S. Pulwarty, E.L.F. Schipper, and B.T. Sinh, 2012. Determinants of risk: exposure and vulnerability. In: *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 65-108.

Department for Energy, Security and Net Zero, 2024. Clean Power 2030 Action Plan. *Presented to Parliament pursuant to Section 172 of the Energy Act 2004*, Available at: <https://www.gov.uk/government/publications/clean-power-2030-action-plan>

Department for Energy, Security and Net Zero, 2025. Average daily sun hours and deviations from the long term mean. *Published by the National Statistics Energy Trends Publication*. Available at <https://www.gov.uk/government/collections/energy-trends>

Drax & LCP, 2022. Renewable Curtailment and the role of long duration storage, available at: <https://www.drax.com/wp-content/uploads/2022/06/Drax-LCP-Renewable-curtailment-report-1.pdf>

Drax, 2024a. Shaping tomorrow's energy landscape. Drax Group plc Annual report and accounts, 2024. Available at: https://www.annualreports.com/HostedData/AnnualReports/PDF/LSE_DRX_2024.pdf

Drax, 2024b. Drax group – Benefiting from Dunkelflaute. Available at https://www.research-tree.com/companies/uk/generic-electricity/drax-group-plc/research/longspur-clean-energy/drax-group-benefiting-from-dunkelflaute/59_92b735fb-7b19-43b5-873e-3a098bd43f40

Drax, 2025. UK urgently needs more energy storage to avoid wasting wind power – report, Drax Press Release, Available at: https://www.drax.com/press_release/uk-urgently-needs-more-energy-storage-to-avoid-wasting-wind-power-report/

Drew, D.R., Coker, P.J., Bloomfield, H.C., Brayshaw, D.J., Barlow, J.F. and Richards, A., 2019. Sunny windy Sundays. *Renewable Energy*, 138, pp.870-875.

Electric Insights, 2024. Wind Becomes Britain's Largest Source of Electricity in 2024, *EI Quarterly Reports*, available at: <https://reports.electricinsights.co.uk/q4-2024/wind-becomes-britains-largest-source-of-electricity-in-2024/>

Elexon Portal, 2025. Elexon portal Operational and Grid Data. Available at <https://www.elexonportal.co.uk/news/latest?cachebust=mdewiab7xm>

Energy Network Association, 2024a. "Storm Lilian – latest update", access 01/08/2025 at <https://www.energynetworks.org/newsroom/storm-lilian-electricity-networks-reconnect-20-000-customers>

Energy Network Association, 2024b. "Energy network operators issue storm advice ahead of strong winds this weekend", accessed 01/08/2025 at <https://www.energynetworks.org/newsroom/storm-ashley-energy-networks-issue-storm-advice>

Energy Network Association, 2024c. "Storm Darragh updates" accessed 01/08/2025 at <https://www.energynetworks.org/newsroom/storm-darragh-latest-from-energy-networks>

Energy Network Association, 2025. "Storm Éowyn power cut information" accessed 01/08/2025 at <https://www.energynetworks.org/newsroom/storm-eowyn-power-cut-information>

ENWL, SP Electricity North West, 2025. "Engineers restore power to more than 66,000 properties". Accessed on 01/08/2025 at <https://news.enwl.co.uk/news/engineers-restore-power-to-more-than-66-000-properties>

Euronews, 2024. “Thousands across the UK battle floodwaters after Storm Bert causes widespread disruption”. Accessed 23/09/2025 at <https://www.euronews.com/my-europe/2024/11/25/thousands-across-the-uk-battle-floodwaters-after-storm-bert-causes-widespread-disruption>

Foresight Environmental Infrastructure Limited (FGEN), 2025. Annual Report 2025. Available at: https://media.umbraco.io/foresight/srqnc5e/web_fgen_ar25.pdf

Giddings, J., Bloomfield, H., James, R. and Blair, M., 2024. The impact of future UK offshore wind farm distribution and climate change on generation performance and variability. *Environmental Research Letters*, 19(6), p.064022. Hayward, L., Whitworth, M., Pepin, N. and Dorling, S., 2022. A regional lightning climatology of the UK and Ireland and sensitivity to alternative detection networks. *International Journal of Climatology*, 42(15), pp.7839-7862. <https://rmets.onlinelibrary.wiley.com/doi/10.1002/joc.7680>

Hersbach, H., Bell, B., Berrisford, P., Hirahara, S., Horányi, A., Muñoz-Sabater, J., Nicolas, J., Peubey, C., Radu, R., Schepers, D. and Simmons, A., 2020. The ERA5 global reanalysis. *Quarterly journal of the royal meteorological society*, 146(730), pp.1999-2049.

Hi West, 2024. “Storm Darragh Wreaks Havoc as UK’s Infrastructure Tested To The Limit” accessed 01/08/2025 at <https://www.hiwest.com/insights-news/storm-darragh-wreaks-havoc-as-uk-s-infrastructure-tested-to-the-limit/>

International Energy Agency, 2025. Electricity 2025: Analysis and forecast to 2027, 2025, IEA, available at <https://www.iea.org/reports/electricity-2025/reliability>

IUS, 2024. “IUS News – Major Incident Response to Storm Bert”. Accessed 23/09/2025 at <https://www.ius.co.uk/major-incident-response-storm-bert>

Kaplan, J.O. and Lau, K.H.K., 2021. The WGLC global gridded lightning climatology and time series. *Earth System Science Data*, 13(7), pp.3219-3237.

Kendon, M., Doherty, A., Hollis, D., Carlise, E., Packman, S., Jevrejeva, S., Matthews, A., Williams, A., Garforth, J., and Sparks, T., 2025. State of the UK Climate 2024. *International Journal of Climatology*, 45, pp.1-72. <https://rmets.onlinelibrary.wiley.com/doi/epdf/10.1002/joc.70010>

Kennedy-Asser, A.T., Andrews, O., Mitchell, D.M. and Warren, R.F., 2021. Evaluating heat extremes in the UK Climate Projections (UKCP18). *Environmental Research Letters*, 16(1), p.014039.

Khosravi, F., Lowes, R. and Ugalde-Loo, C.E., 2023. Cooling is hotting up in the UK. *Energy Policy*, 174, p.113456.

Lopez, P., 2018. Promising results for lightning predictions. *ECMWF Newsl*, 155, pp.14-19. <https://www.ecmwf.int/en/newsletter/155/meteorology/promising-results-lightning-predictions>

MacIver, M., and Bell, K., 2025. Transmission Network Unavailability – the Quiet Driving Force Behind Rising Curtailment Costs in Great Britain, *UK Energy Research Centre*, Available at: <https://ukerc.ac.uk/news/transmission-network-unavailability-the-quiet-driving-force-behind-rising-curtailement-costs-in-great-britain/>

Manning, C., Kendon, E.J., Fowler, H.J. and Roberts, N.M., 2023. Projected increase in windstorm severity and contribution from sting jets over the UK and Ireland. *Weather and Climate Extremes*, 40, p.100562.

McGuire, C., Naderi, Y.N., Gardner, A., Sharma, M., Solanki, L., Jenssen, O., Page, B., Long, F., Adams, M., Evangelides, C., Hamilton, N., and Hogarth, R., 2025. CS-N0W WPG8 Impacts on energy assets from extreme heat and heatwaves: Final Report. Available at: <https://assets.publishing.service.gov.uk/media/680b9d79521c5b6f2883cca1/impacts-on-energy-assets-from-extreme-heat-and-heatwaves.pdf>

Met Office, 2024a & 2025a. Monthly and Seasonal Weather reports (November 2024, January 2025, February 2025, March 2025, April 2025, Winter 2025). Available at: <https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/weather/learn-about/uk-past-events/summaries>

Met Office, 2024b & 2025b. Learn About UK past events (Storm Kathleen, Storm Lillian, Storm Ashley, Storm Bert, Storm Darragh, Storm Éowyn) https://weather.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/weather/learn-about/uk-past-events/interesting/2024/2024_04_storm_kathleen.pdf; https://weather.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/weather/learn-about/uk-past-events/interesting/2024/2024_06_storm_lillian.pdf;

https://weather.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/weather/learn-about/uk-past-events/interesting/2024/2024_08_storm_ashley.pdf;

https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/weather/learn-about/uk-past-events/interesting/2024/2024_09_storm_bert.pdf;

https://weather.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/weather/learn-about/uk-past-events/interesting/2024/2024_10_storm_darragh_v1.pdf;

https://weather.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/weather/learn-about/uk-past-events/interesting/2025/2025_02_storm_eowyn.pdf

Meteorage, 2024. “UK 2024 lightning and thunderstorm report”. Accessed 23/07/2025 at <https://www.meteorage.com/thunderstorm-report/lightning-thunderstorm-2024-report/>

Montel Energy, 2025. Lessons from the recent GB market crunch. Available: <https://montel.energy/commentary/lessons-from-the-recent-gb-market-crunch>

National Grid, 2024. “Storm Darragh Summary” Accessed on 01/08/2025 at <https://powercuts.nationalgrid.co.uk/storm-summary>

National Grid Electricity Distribution, 2024. “Teams tackle 72 hours of Storm Bert disruption”. Accessed on 23/09/2025 at <https://commercial.nationalgrid.co.uk/mp-hub-news-and-events/display/teams-tackle-days-of-storm-bert-disruption>

National Grid Electricity Transmission, 2024. Climate Change Adaptation Report for ARP4, National Grid, <https://www.nationalgrid.com/document/357171/download>

- NESO, 2022. Demand Flexibility Service, available at: <https://www.neso.energy/industry-information/balancing-services/demand-flexibility-service-dfs>
- NESO, 2024. Britain's Electricity Explained: 2024 Review: Available at <https://www.neso.energy/news/britains-electricity-explained-2024-review>
- NESO, 2025a. Historic GB Generation Mix, available from https://www.neso.energy/data-portal/historic-generation-mix/historic_gb_generation_mix
- NESO, 2025b. What happened with margins on 8 January?, National Energy System Operator Available at: <https://www.neso.energy/news/what-happened-margins-8-january>
- NESO, 2025c. Winter Review and Consultation 2024/2025. Available at: <https://www.neso.energy/document/362981/download>
- Northern Powergrid, 2024. "We're here for our customers whatever the weather through Storm Bert" accessed 01/08/2025 at <https://www.northernpowergrid.com/news-and-events/were-here-our-customers-whatever-weather-through-storm-bert>
- Ofgem, 2019. Investigation into 9 August 2019 power outage, Available at: <https://www.ofgem.gov.uk/publications/investigation-9-august-2019-power-outage>
- Ofgem, 2022. Storm Arwen Report. Available at: <https://www.ofgem.gov.uk/publications/storm-arwen-report>
- Ofgem, 2025. Ofgem climate resilience report – fourth round reporting, Ofgem <https://www.ofgem.gov.uk/sites/default/files/2025-04/Ofgem-climate-resilience-report-ARP4.pdf>
- Scottish Power Energy Network (SPEN), 2024. "Engineers on standby for Storm Bert" Accessed on 23/09/2025 at <https://news.enwl.co.uk/news/engineers-on-standby-for-storm-bert>
- Scottish Power Energy Network (SPEN), 2025. "Storm Éowyn bring winds of almost 90mph" Accessed 01/08/2025 at https://www.spenergynetworks.co.uk/news/pages/storm_eowyn.aspx
- Souto, L., Neal, R., Pope, J.O., Gonzalez, P.L., Wilkinson, J. and Taylor, P.C., 2024. Identification of weather patterns and transitions likely to cause power outages in the United Kingdom. *Communications Earth & Environment*, 5(1), p.49.
- SSE, 2025. SSE Strategic Report AR25. Available here: https://www.sse.com/media/k1yow1co/sse_strategic_report_ar25-1.pdf
- SSN, 2024a. "Storm Bert: Sunday 24 November". Accessed 23/09/2025 at <https://www.ssen.co.uk/news-views/2024/Storm-Bert-Update-Sunday-24-November-AM/>
- SSN, 2024b. "Weather Warning – Storm Bert: Saturday 23 and Sunday 24 November" Accessed 23/09/2025 at [https://www.ssen.co.uk/news-views/2024/Weather-Warning-Storm-Bert/](https://www.ssen.co.uk/news-views/2024/Weather-Warning-Storm-Bert/Staffell, I., Pfenninger, S. and Johnson, N., 2023. A global model of hourly space heating and cooling demand at multiple spatial scales. Nature Energy, 8(12), pp.1328-1344.)

Thornton, H.E., Scaife, A.A., Hoskins, B.J. and Brayshaw, D.J., 2017. The relationship between wind power, electricity demand and winter weather patterns in Great Britain. *Environmental Research Letters*, 12(6), p.064017.

Van der Wiel, K., Stoop, L.P., van Zuijlen, B.R.H., Blackport, R., van den Broek, M.A., and Selten, F.M., 2019. Meteorological conditions leading to extreme low variable renewable energy production and extreme high energy shortfall, *Renewable and Sustainable Energy Reviews*, 111, pp261-275, <https://doi.org/10.1016/j.rser.2019.04.065>

van Duinen, B., van der Most, L., Baatsen, M.L. and van der Wiel, K., 2025. Meteorological drivers of co-occurring renewable energy droughts in Europe. *Renewable and Sustainable Energy Reviews*, 223, p.115993. <https://www.sciencedirect.com/science/article/pii/S1364032125006665>

Watt-Logic, 2025. Blackouts near miss in tightest day in GB electricity market since 2011. Available at: <https://watt-logic.com/2025/01/09/blackouts-near-miss-in-tighest-day-in-gb-electricity-market-since-2011/>

Wright, M., Hutchins, B., Fallon, J., and Bloomfield, H., 2024. State of the Climate for the UK Energy Sector 2023-24. *Royal Meteorological Society*, <https://www.rmets.org/news/state-climate-uk-energy-sector-2023-24>

Appendix A – Datasets

The ERA5 reanalysis dataset is used in this report for climate variables (Hersbach et al., 2020). By design ERA5 provides a best-estimate of meteorological fields smoothed over an approximately 30 km grid spacing. Therefore, the values presented in Figures 5 to 7 for 10 m wind gusts and accumulated precipitation may appear lower than the record-breaking events seen in observations from meteorological stations. Figures 5 to 7 are intended to be interpreted for context of where impacts occurred, rather than to over-interpret the magnitude of the meteorological hazards during the extreme events.

For energy variables, including weather-dependent electricity demand and wind power generation, the ERA5-derived time series from CLEARHEADS are used. These use the locations of wind farms operational in April 2021 combined with known physical relationships between wind speed and wind power to quantify wind power generation (given wind speeds from ERA5). By quantifying heating degree days and cooling degree days from ERA5 and using a linear regression fit to observed demand time series, the weather-dependent electricity demand is calculated. We note that the relationship between electricity demand and cooling degree days was weak at the time of making the model, but this weather-sensitivity is likely to increase substantially in the future. These ERA5-derived time series have been verified against observed time series of relevant energy variables, and details of this are available in Bloomfield et al., (2022).

Appendix B – Fault Codes

Data

Fault data was obtained from the following DNOs:

- Scottish and Southern Electricity Networks (SSEN)
- Scottish Power Electricity Networks (SPEN)
- Northern Power Grid (NPG)
- Electricity North West (ENWL)

Wind gust and accumulated precipitation data is from ERA5 (see Appendix A).

Lightning data was obtained from the World Wide Lightning Location Network (WWLN, <http://wwlln.net>): a gridded product for 2025 was downloaded from <https://zenodo.org/records/10246857> on 31/07/2025.

The weather data was cropped to the DNO regions (described below) and averaged to produce regional mean values.

Fault codes

NAFIRS fault codes, where available from DNO data, are used to classify faults into various weather-related categories.

- Wind-related faults are defined as those due to 'Wind & gale' (06), 'Windborne material' (21), 'Falling live trees (not felled)' (23), and 'Falling dead trees (not felled)' (24).
- Precipitation-related faults are defined as those due to 'Rain' (02), 'Snow, sleet & blizzards' (03), 'Freezing fog & frost' (04) and 'Flooding' (18).
- Lightning-related faults are defined as those due to 'Lightning' (01)

Regions

Regions are defined based on industry standards, as described at www.eaguk.org/distribution-network-operator-dno/ . This means that one DNO can have multiple regions, and data is subdivided into these regions where possible to produce the figure with faults by region, and during the normalisation process (see below).

Normalisation of DNO data

Raw customer minutes lost (CML) data is processed as follows to get normalised, population-weighted, relative severity indices for each weather-related fault category:

1. Weight by the (cosine-weighted) population of each region to standardise into CML per person (using DNO shapefiles from NESO and UK population data from humdata.org)
2. Sum up all CML per person for each day in the period, for each region
3. In each region, normalise by dividing daily CML per person, by the maximum CML in the whole period in that region – to give normalised, population-weighted CML for each day, for each region.
4. For UK-average plots: average across the regions to get a UK-mean normalised, population-weighted CML.
5. For plots split by precipitation-related fault code: repeat normalisation process for each fault code individually, to estimate relative contributions of each fault code.

Note: for the regional subplots, customers affected is used in place of CML, due to data availability.