ACCELERATED

NIA Project Closedown Report

May 2023

Electricity Distribution

nationalgrid

Version Control

Issue	Date
Draft 0.1	17/03/2023
Draft 0.2	19/04/2023
Draft 0.3	26/04/2023
Final	19/05/2023

Publication Control

Name	Role
David Thorn, Liza Troshka	Author
Jenny Woodruff	Reviewer
Jenny Woodruff	Approver

Contact Details

For further information, please contact:

nged.innovation@nationalgrid.co.uk

Postal

Innovation Team
National Grid Electricity Distribution
Pegasus Business Park
Herald Way
Castle Donington
Derbyshire DE74 2TU

Disclaimer

Neither National Grid, nor any person acting on its behalf, makes any warranty, express or implied, with respect to the use of any information, method or process disclosed in this document or that such use may not infringe the rights of any third party or assumes any liabilities with respect to the use of, or for damage resulting in any way from the use of, any information, apparatus, method or process disclosed in the document.

Contents

1 Executive summary

Climate change is expected to result in changes to the patterns of weather experienced around the world. In the UK we are expecting an increase in the number and severity of storms. The higher wind speeds associated with more severe storms are more likely to cause damage to our overhead network directly and by causing greater volumes of windborne debris. Similarly climate change is expected to result in more intense periods of rainfall which is also known to trigger faults. Network Innovation Allowance (NIA) 'Assessment of Climate Change Event Likelihood Embedded in Risk Assessment Targeting Electricity Distribution (ACCELERATED)' project was in response to the need for Distribution Network Operators (DNOs) to determine the impact of Climate Change on the future reliability of the network. This involved the provision of reliable climate change data and analytical techniques to determine the likely impact so that DNOs can determine how they will change how they operate and manage the network in the future as the climate change impacts materialise.

The project was delivered in collaboration with Newcastle University and GHD consultancy. The total budget for the project was £240,923.

The project comprised four work packages which were;

- WP1 Identification of historic severe weather impacts and at-risk asset groups.
- WP2 Projecting future impacts of severe weather and climate change.
- WP3 Projecting climate change impacts on embedded generation and consumption patterns.
- WP4 Climate Change Impact Assessment Procedure.

The project focussed on the following weather groups: wind, rain, lightning, flooding, high and low temperatures. The following assets groups from all voltage levels were included in the analysis:

- Overhead mains and overhead service
- Underground mains and underground service
- Ground mounted and pole mounted transformers
- Switchgear and protection equipment

The main findings of the study can be summarised as follows:

1) Historically wind has been the main driver of the faults across NGED licence areas (approximately 78% of all weather related faults). Extreme wind related faults predominantly occur in South West licence area. Few faults occur below a wind speed of 30 m/s however this significantly ramp up after 35m/s causing damage primarily to overhead network. No obvious historic trend of the faults to increase or decrease over time was observed. There is a high confidence that extreme windstorms are more likely to occur in the future, specifically exposing coastal locations and north-western areas of the UK. South Wales is likely to see the biggest increase in the frequency of windstorms in far future (2061-2080) with a 1 in 50 year return period storm occurring on average every 20 years (or a 30% increase in the number of faults). The impact of windstorms in East Midlands is projected to decrease over time.

2) Climate change demand half-hourly adjustment factors developed for each representative day for a selected types of substations were relatively small and didn't illustrate a noticeable decrease in demand profiles due to change in temperature over time (compared to unadjusted profiles). Distributed generation climate change adjustment factors have shown a mixed results. For example: up to 25% increase in solar outputs in 2050 for Bodmin primary; and approximately 15% decrease in wind generation in South Molton (compared to unadjusted profiles).

The outputs from the project comprise tools for improved analysis and visualisation of the impact of climate change, both in terms of the projections of the number and impact of faults on the network and the changing half-hourly profiles of demand and distributed generation (DG) output.

The improved analysis of the nature and impact of climate change will enable informed and future-proof investment decisions to be made for network construction standards and policies, as well as identification of at-risk hotspots so that design, reinforcement and maintenance activities can be optimised.

2 Project Background

The latest ‘Progress in Adapting to Climate Change’ report[1] from the Climate Change Committee (CCC), published in 2021, states that national progress in planning and delivering adaptation is not keeping up with increasing risk from climate change. This implies that the UK is less prepared for the changing climate now than it was when the previous risk assessment was published five years ago. As a result the CCC recommended that the energy industry work to make monitoring and data analysis of climate risks more accessible, alongside better digitisation of past records (e.g. historic faults). Specifically, the report states that ‘a major gap is lack of projections of impacts in 2°C and 4°C scenarios; this needs addressing as an urgent priority’. Moreover, recent experience in dealing with extreme weather events revealed the need to improve sharing of information on climate risks to infrastructure, especially for electricity networks and including interdependencies at a local level.

NGED has a dedicated Climate Resilience Strategy[2], which aims to plug the major gap identified by the CC by improving our understanding of the likely environmental effects of climate change, while continuing to assess risks and impacts associated with climate change and subsequent adaptation pathways and resilience initiatives.

The ACCELERATED project was undertaken to equip DNOs with

1) Reliable climate change data.
2) Analytical techniques to assess the impact of different climate change scenarios.

The results of the analysis would then inform the DNOs enabling them to put in place appropriate mitigation strategies allowing them to effectively operate and manage the network in view of the increasing risk of climate change. Furthermore, through development of a GIS tool the project provides climate change data “at a glance” to ensure streamlined information sharing with all relevant internal stakeholders across all four licence areas operated by NGED.

The project has been delivered in collaboration with Newcastle University and GHD and involved the following:

- Quantifying the impact of weather conditions on the distribution network based on historic weather observations and fault report data.
- Defining relationships between weather hazard intensities and faults for different asset types, where possible.
- Using climate modelling to produce projections of future weather conditions and associated faults to account for the impact of climate change.
- Building a GIS model based on the findings of WP1 and WP2. The tool will summarise both the historical and projected impact of weather hazards on the distribution network.
- Quantifying the impact of climate change on demand and DG output profiles.
- Providing recommendations for the integration of the above analysis into NGED processes in the form of a climate change impact assessment procedure.

The outputs from the project comprise tools for improved analysis and visualisation of the impact of climate change, both in terms of the projections of the number and impact of faults on the network and the changing half-hourly profiles of demand and DG output.

The analysis undertaken can be expanded in response to improvements in climate science and data availability in future. The improved analysis of the nature and impact of climate change will enable informed and future-proof investment decisions to be made, as well as identification of at-risk hotspots so that design, reinforcement and maintenance activities can be optimised.

[1] https://www.theccc.org.uk/wp-content/uploads/2021/06/Progress-in-adapting-to-climate-change-2021-Report-to-Parliament.pdf
[2] https://yourpowerfuture.nationalgrid.co.uk/downloads-view/41106

3 Scope and Objectives

The ACCELERATED project looked to understand the impact of climate change on distribution networks through analysing the historical relationships between weather variables (rainfall, wind speed etc.) and consequential faults on assets. In addition, the impact of climate change on the half-hourly demand and DG output profiles was determined based on long-term historical relationships. NGED improved its understanding of the quantitative relationships between weather events and faults, including associated Customer Minutes Lost (CML) by analysing historical data. These relationships were applied to climate projections based on the worst-case climate change outlook.

Table 1 provides a summary of the main objectives and their status following completion of the project. Further details explaining how these objectives were met can be found in Section 6.2.

Table 1 ACCELERATED project objectives

Objective	Status
To provide a visual representation of NGED historic weather impacts and climate change projections within different timeframes and spatial resolutions.	✓
To establish an up-to-date understanding of the potential impacts of projected climate change on the NGED's assets performance and functionality.	✓
To establish an understanding of climate change impacts on embedded generation and consumption patterns.	✓
To develop a climate change impact assessment procedure and to trial it across the business.	✓

4 Success Criteria

The project successfully met the criteria specified in the original "NIA Project Registration and PEA document" dated December 2021. The success criteria for the project are summarised in Table 2 and further details explaining how these criteria were met can be found in Section 6.3.

Table 2 ACCELERATED Success Criterion

Success Criterion	Status
Climate impacts on asset groups established and documented	✔
Impacts on embedded generation and future demand modelled and documented	✔
Climate change impact assessment procedure developed and verified within the business	✔

Notable learning has been generated following successful completion of the project. Further details are provided in Section 9 of this Closedown report.

5 Details of the work Carried Out

5.1 Introduction

The delivery of ACCELERATED was split into four separate Work Packages (WPs) as detailed in the Project Eligibility Assessment (PEA)[3] and summarised in Table 3. Further details on the individual WPs are provided within the following sections of this report.

Table 3 ACCELERATED Work Packages

Ref	Description	Delivered by
WP1	Identification of historic severe weather impacts and at-risk asset groups	Newcastle University
WP2	Projecting future impacts of severe weather and climate change	Newcastle University
WP3	Projecting climate change impacts on embedded generation and consumption patterns	GHD
WP4	Climate Change Impact Assessment Procedure	GHD

5.2 Work Package 1 – Identification of historic severe weather impacts and at-risk asset groups

In WP1, Newcastle University looked to establish the impact of historical severe weather events on the NGED network across all four licence areas. This activity is a precursor to the assessment of the future impact of climate change in WP2. As such, it aimed to achieve two main outcomes, summarised as follows:

1. Provide a baseline of current weather-related impacts (i.e. historical weather-related fault rates); and
2. Establish relationships between weather intensities and climate impacts (e.g. likelihood of a wind related fault occurring for a given wind speed) – this is referred to as “fragility”.

These outcomes were achieved by identifying historical climate impacts and at-risk asset groups and locations, and then correlating these with historical weather observations (where available).

The results were presented in the form of:

- A series of heatmaps of climate related impacts (in terms of number of faults) and consequences (in terms of Customer Interruptions – CIs - and Customer Minutes Lost - CML[4]) for different asset types and different categories of climate hazard.
- Fragility curves showing the relationships between the intensity of the climate variable and the probability that this intensity will result in faults, and severity of these (CIs and CML), for individual asset types and regions where possible (for faults attributed to wind)[5].

The heatmaps prepared enable the user to see areas where historically greater impacts and/or consequences have occurred, the asset type most likely to be affected and the climate variable most likely to have been the cause. Figure 1 provides an example heatmap showing the number of wind-related faults per primary substation area, from the historical fault data.

---

[3] www.nationalgrid.co.uk/downloads-view-reciteme/622017
[4] www.ofgem.gov.uk/sites/default/files/docs/2012/09/riioed1sconglossary.pdf
[5] For some of the climate variables (rain and flood, and temperature related faults) there is not enough data to reliably create fragility curves for individual asset types or regions. In these cases the data has been pooled for the regions and different assets to produce a fragility curve, which should be used with caution.

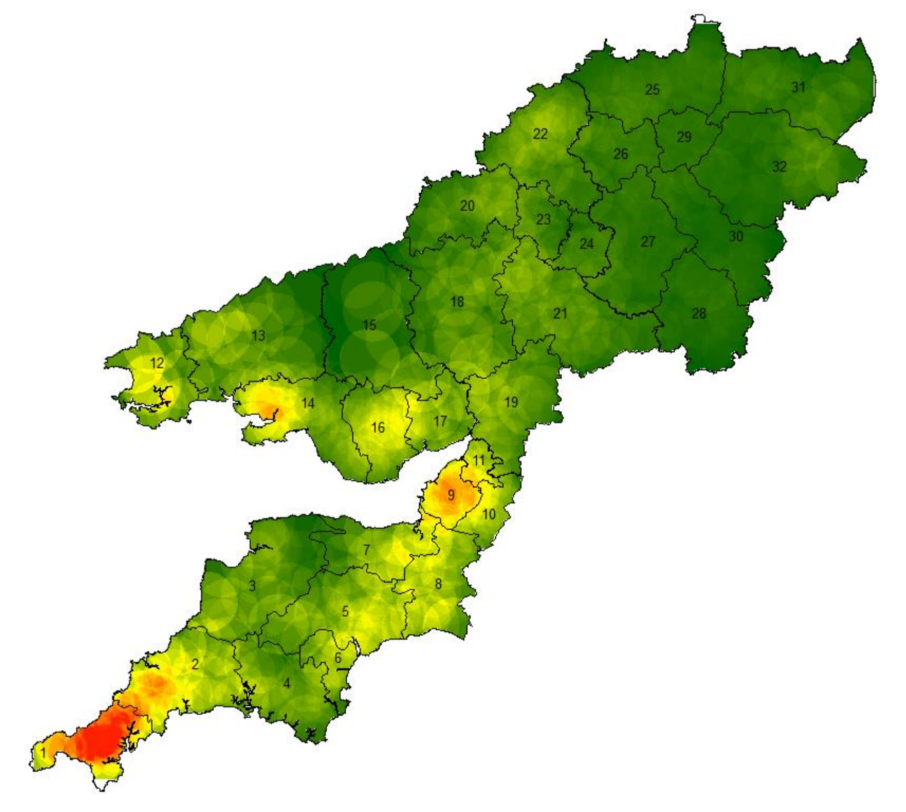

Figure 1 Example heatmap showing number of wind-related faults per primary substation shown on a red/green scale, where red indicates a high number of faults). The highest number of faults recorded is 283.

The fragility curves prepared can be used to understand how likely it is for faults to occur subject to a given intensity of weather variable, and the range of likely faults (number and severity) that may occur for that given weather intensity. Figure 2 presents example fragility curves showing the relationships between wind gust intensity and CML in a windstorm for each asset type considered.

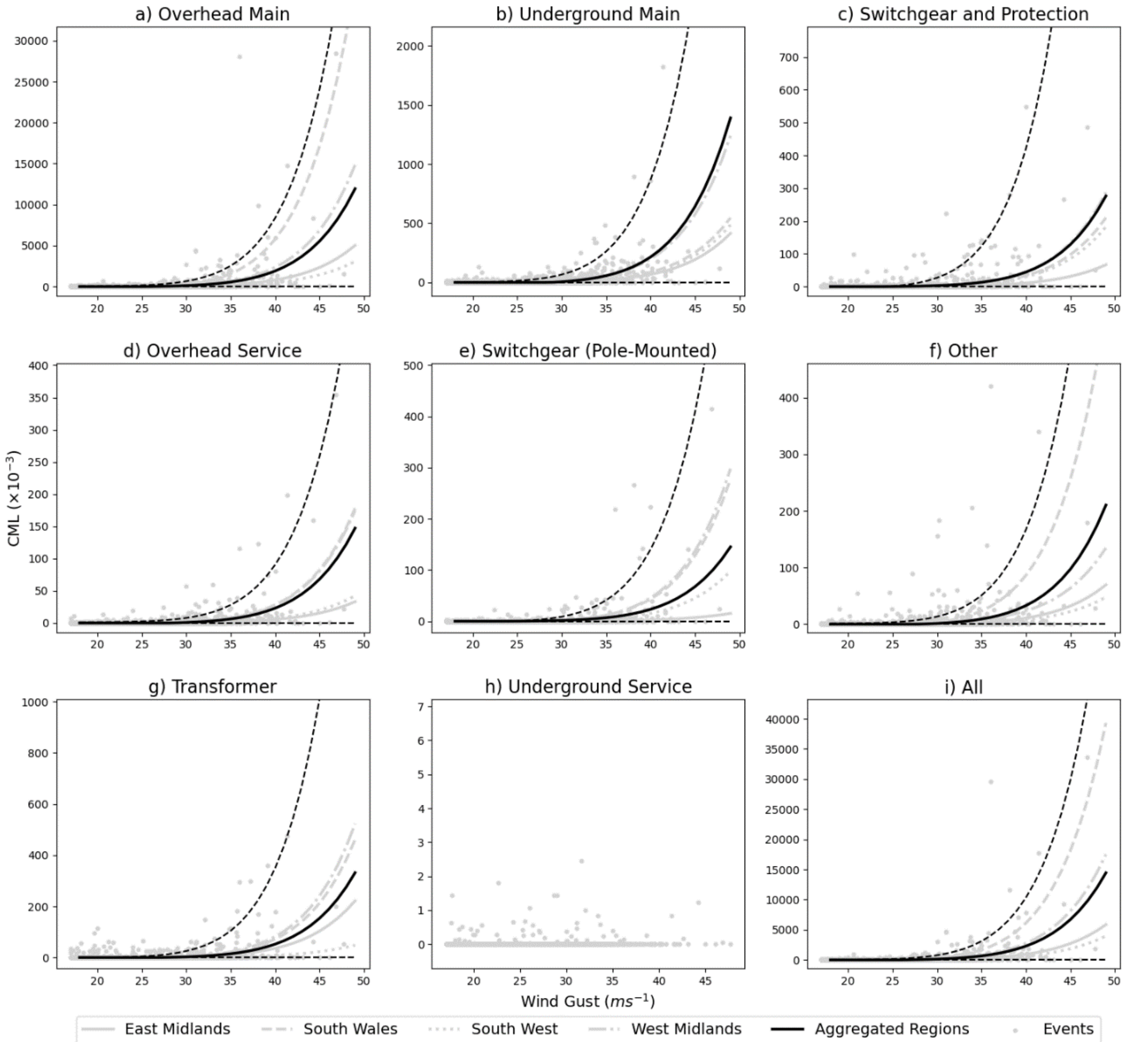

Figure 2 Example fragility curves showing the relationships between wind gust intensity and CML in a windstorm for each asset type.

Figure 4 shows that for most asset types the CML are fairly stable until wind gust speed exceeds 25 m/s. The assets in the South Wales area tend to have the highest levels of increased CML with the assets in the East Midlands tending to have the least increase in CML with increased windspeed. While, as expected, underground services are largely unaffected by windspeed there is an increase in the faults seen for underground mains which was not expected. This may be due to the generic difficulty in restoring faults when fault volumes are high and staff are stretched or might reflect locations where networks have both overhead and underground sections and the increase in faults on "underground" mains is really reflecting associated overhead line elements. Similarly, while an increase in pole mounted switchgear faults would be expected there is also an increase in ground mounted switchgear faults.

The regressions analysis undertaken in WP1 has provided an improved evidence base for the causality between weather variables and weather-related faults, based on real historical data, and quantified the impact of weather conditions on the distribution network. R^2 values (indication of how good the model was) were calculated for each fragility curve and varied for each hazard type, region, and impact type (i.e. fault rates and CML). The highest R^2 values were generally obtained for wind (0.67 to 0.91). The confidence can be drawn in the robustness of the wind results as the relationships were similar across each of the regions. Lower and more variable R^2 values were found for the other hazards, rainfall (0.19 to 0.99), high temperature (0.25 to 0.69) and cold temperatures (0.17 to 0.87).

A report has been prepared presenting the outputs from WP1 and is available upon request.

5.3 Work Package 2 – Projecting future impacts of severe weather and climate change

In WP2, Newcastle University sought to quantify the future impact of climate change on the network for the worst-case climate scenario, as well as to provide a tool for visualisation of the outputs from WP1-2.

Quantification of the future impact was achieved through combination of climate projection data with the fragility curves from WP1. The future weather intensity information was taken from the Met Office UKCP18 climate projections dataset. The climate model outputs are provided for three time slices (TSs): a control simulation (TS1: 1981-2000), and two future simulations (TS2: 2021-2040 and TS3: 2061-2080). These climate projection values have been used as inputs with reference to the fragility curves to calculate short, medium and long-term changes in expected climate related impacts and consequences (i.e. number of weather related faults and CML due to these faults).

The results of the analysis can be considered to represent the baseline level of resilience, and the impact of climate change on the distribution network should there be no significant change to the volume, specification or configuration of distribution network assets. Furthermore, the approach to adopt fragility curves can be applied in future through use of updated fragility curve parameters or estimates of future fault rates based on engineering judgements. Figure 3 presents an example plot of the projected number of faults attributed to warm spells, for temperature projections corresponding to return periods[6] in the range 1-50 years.

[6] Return periods provide a measure of the probably frequency for an event with a specified intensity. For example, an event with a return period of 5 years is expected to occur on average every 5 years. However, this does not mean that there are 5 years between each time such an event occurs, but that in a 100-year time period, the event has occurred at least 20 times.

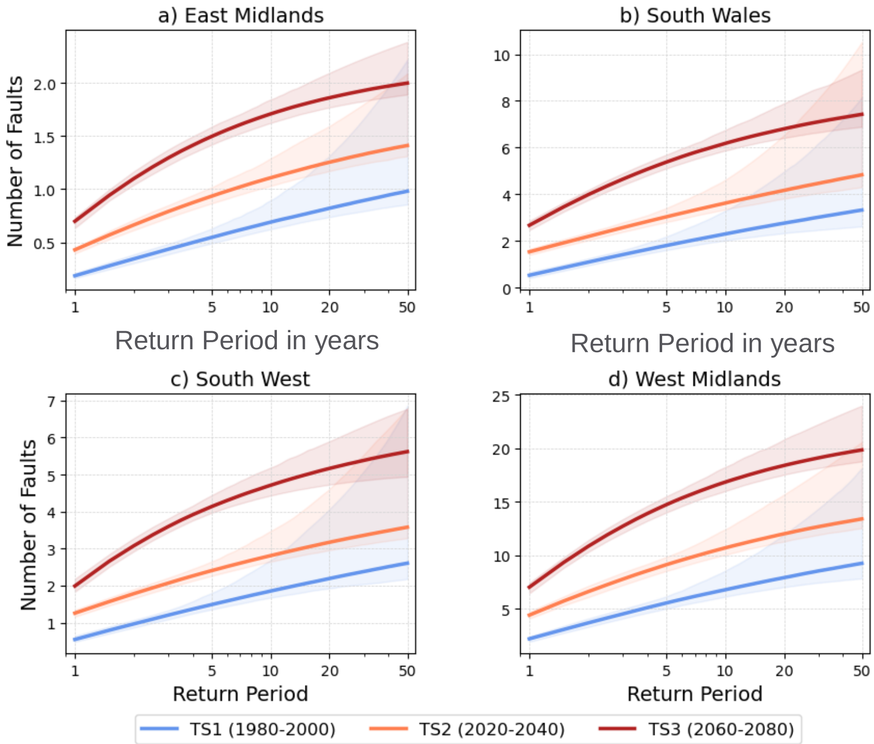

Figure 3 Example projections of the number of faults due to warm spells

Figure 5 illustrates that in the control climate (1980-2000) for West Midlands, for example, a 10-year event has 7 faults due to warm spells, meaning that there is an event every 10 years on average where there is a 50% chance of having more than 7 faults in West Midlands. The graph shows that the event with the same level of impact is expected to occur once every 2-3 years in TS2 (2020-2040) and every year in TS3 (2060-2080).

In addition, a GIS tool was developed as part of WP2 to provide visualisation of the results of the analysis in WP1 and WP2. The tool was developed in ArcGIS online, with screens showing the details identified in Table 4.

Table 4 GIS tool screens

Screen	**Data visualisation**
Display faults heatmap	No. faults per primary
Display faults and CML	No. faults and associated CML per primary
Hazards	Historic weather intensities per licence area
Future scenarios Hazards	Future weather intensities per licence area
Future scenarios CML	Future CML values per licence area

As indicated above, the GIS tool presents the results of the analysis for each primary substation area (historical faults) and each licence area (future projections), based on the available data.

Figure 4 illustrates the screen of the tool showing the location, number and severity (CML impact) of historical faults. Filters are applied such that the faults showing are faults on overhead main assets attributed to wind.

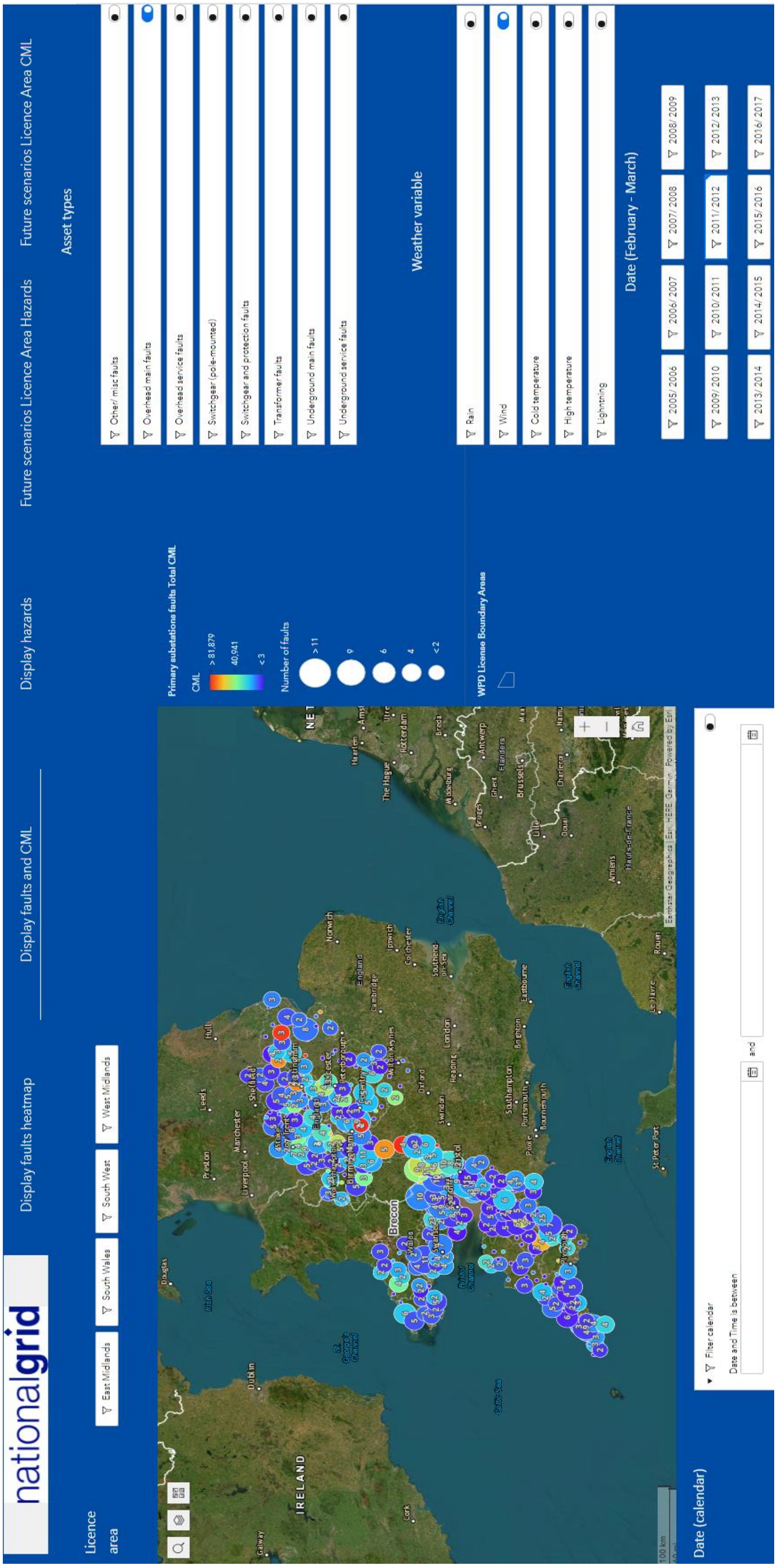

Figure 4 Illustration of GIS tool screen 2 - Display faults and CML (historical)

The analysis undertaken in WP2 has provided the ability to quantify the future impact of severe weather on the NGED network, based on real historical data for weather-related faults and data for the accepted worst-case climate projections.

A report has been prepared presenting the outputs from WP2 along with the GIS tool. The outputs of the WP2 can be made available upon request.

5.4 Work Package 3 – Projecting climate change impacts on embedded generation and consumption patterns

In WP3, GHD has developed and implemented a methodology to quantify the impact of climate change on half-hourly demand and DG output profiles[7], which impact the operation of the network and investment required to provide capacity with a suitable level of headroom. This approach has been developed to complement the analysis undertaken as part of the preparation of the annual Distribution Future Energy Scenarios (DFES) publication.

The methodology adopted in WP3 comprised the following steps:

- Assessment of the long-term trends observed from datalogger measurements in conjunction with historic weather observations;
- Identification of representative day profiles;
- Assessment of climate projections; and
- Modification of representative day profiles based on quantitative climate projections, implemented in an Excel spreadsheet.

It should be noted that the precise impact of future climate events on generation and consumption profiles will be subject to other factors in addition to climate change, as well as to uncertainty with respect to climate modelling. As described above, the analysis in this project has been undertaken based on real historical demand, DG output and weather observation data for specific locations. However, the principles can be applied to representative profiles, like the ones adopted for long-term planning purposes in DFES, as well as to specific ones. Details of how the approach can be applied are provided in WP4.

The methodology in WP3 was developed to analyse the "unmasked"[8] underlying demand, i.e. adjusting for the masked demand satisfied by embedded generation but excluding the impact of changes in customer behaviour (e.g. in response to tariff price signals) and uptake of new technologies, as far as possible. This is consistent with the approach to complement the DFES analysis[9], since these aspects are modelled separately by the NGED DSO team.

The analysis undertaken in WP3 has enabled real historical demand and DG output data to be used in conjunction with historical weather observations sourced from the Met Office (with 1 km resolution for temperature and rainfall, and 2km for wind) and climate projections (2.2 km resolution) to develop adjustment factors for future half-hourly profiles. For example, it has provided understanding of the impact of climate change on the demand profiles during different seasons of the year, including the range of reduction factors applied to historical demand profiles to reflect the projected temperature in 2050.

Figure 5 presents an example of the adjusted half-hourly demand profiles for Bodmin primary on winter season days. The adjustment factors have been applied to the unadjusted profile (dotted line) to give the black, red and green profiles representing the impact of climate change in 2030, 2040 and 2050, respectively.

---

[7] Based on datalogger measurements aggregated to the High Voltage (HV) feeder level (and higher voltages).
[8] Gross demand, which is supplied by a combination of local generation and from the upstream network.
[9] www.nationalgrid.co.uk/downloads-view-reciteme/620637

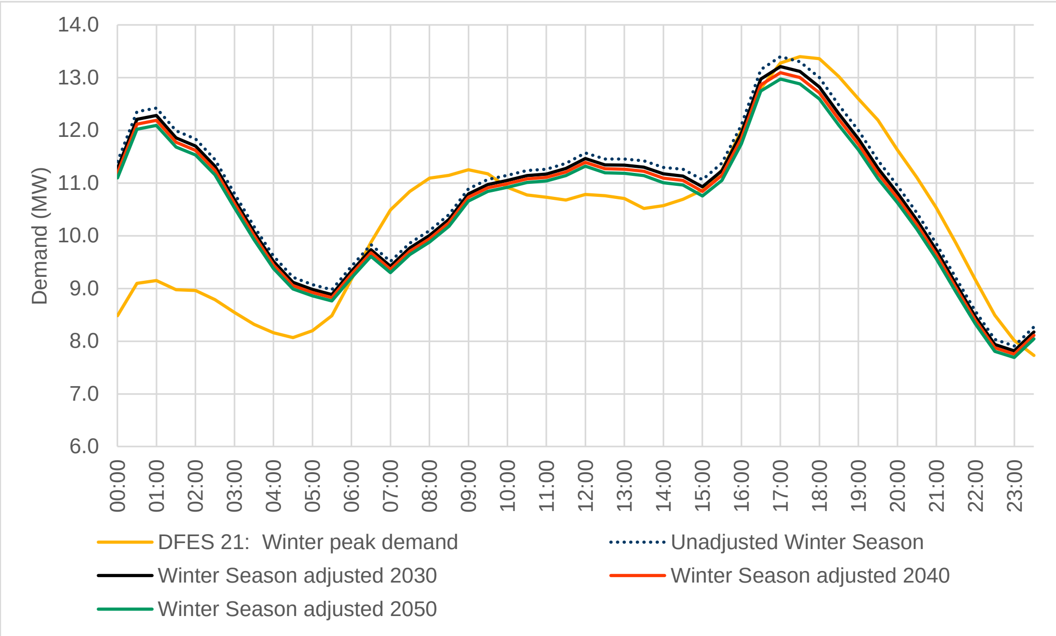

Figure 5 Example adjusted half-hourly demand profiles for Bodmin primary – winter season days

Figure 7 shows that the impact of climate change is to reduce the underlying winter season demand on Bodmin primary substation between now (unadjusted baseline shown as a dotted black line) and 2050 (green line), with the greatest reduction occurring during the evening peak period. The reduction in underlying demand is due to the projected increase in temperature resulting in a reduction in the heating load.

The future adjusted profiles are based on the unadjusted profile derived from historical data for Bodmin primary substation in the project. These are plotted alongside the DFES 21 winter peak demand profile for a rural primary substation, which is based on the average demand across a number of rural primary substations of which Bodmin is one. It can be seen that the specific profile for Bodmin primary deviates from the DFES 2021 average profile in the period from 00:00 to 05:00hrs in winter, which corresponds to overnight charging of electric storage heaters. As such, it is expected that Bodmin primary has a greater prevalence of electric storage heating compared with the average rural primary, which results in a more pronounced overnight demand.

A report has been prepared to summarise the methodology and the results gathered as part of WP3. The report is available upon request.

5.5 Work Package 4 – Climate Change Impact Assessment Procedure

In WP4, GHD prepared a procedure document based on the approaches adopted in WP1-WP3. This document has established a procedure for adopting the climate change impact assessment developed in this NIA project as part of NGED’s day-to-day activities and strategic planning. It aimed to provide a consistent and robust approach to assess and mitigate the impact of climate change.

The procedure document prepared in WP4 describes the following elements:

- Nature of analytical approaches developed:
  - GIS tool for visualisation of historical and projected impacts of weather-related faults; and
  - Spreadsheet analysis for adjustment of demand and DG output profiles based on long-term trends with weather variables;

- NGED internal teams affected by improved analysis of the impact of climate change;
- Identification of applications for the analytical approaches developed across the NGED business:
  - Application 1) ED3 Business Plan – consideration for additional climate resilience expenditure;
  - Application 2) ED2 expenditure – prioritise locations for Capex and Opex schemes;
  - Application 3) Feedback to Policy team – suitability of equipment specifications / selection of specifications under different conditions; and
  - Application 4) DFES preparation - generation and demand profile adjustment;
- Identification of how the approaches can be used to consider prospective climate change adaptation measures;
- Examples of how the analysis would be applied for each of the applications identified above; and
- Details of limitations, recommended developments and requirements for future updates to the analysis.

Figure 6 provides an example of the quantitative analysis for application 1 (ED3 Business Plan – justify additional climate resilience expenditure). This shows an indication of the potential financial penalty corresponding to the projected increase in CML under the medium and long-term climate projections, based on a 100 year return period. So in this case it shows that the biggest single risk is the additional CML penalty from Wind related faults in the South Wales region, but that East Midlands is expected to have very little additional CML penalty.

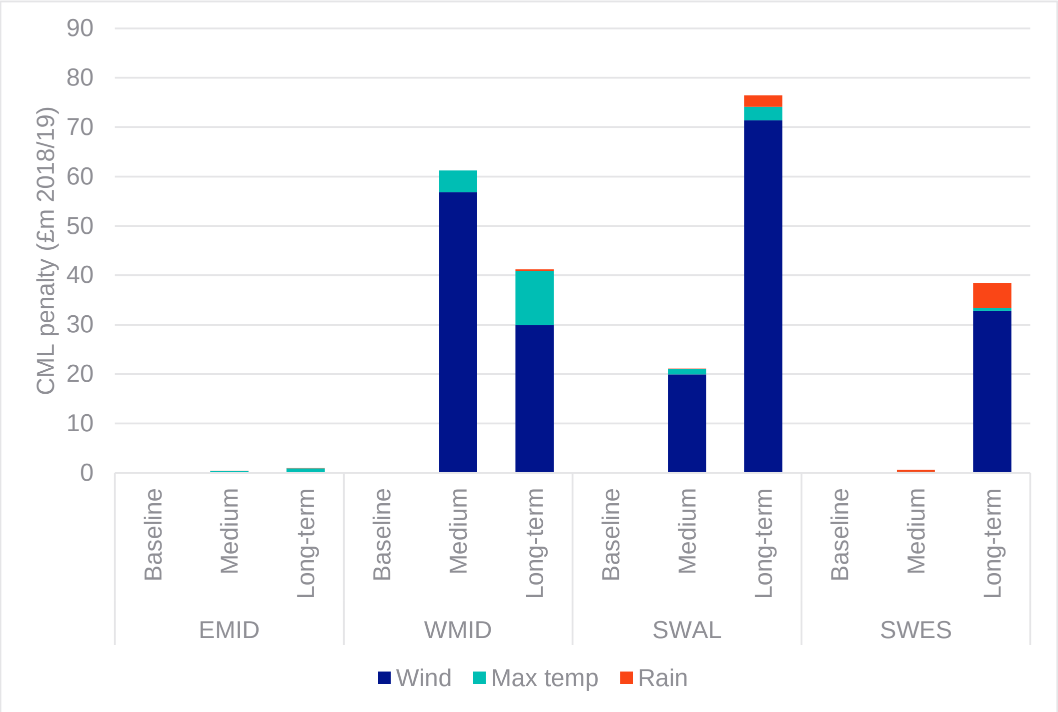

Figure 6 Example analysis showing indicative CML penalty corresponding to 100 year return period (£m 2018/19)

The output from WP4 was a procedure document that is available upon request.

6 Performance Compared to the Original Aims, Objectives and Success Criteria

6.1 Overview

ACCELERATED successfully delivered against all the original aims, objectives and success criteria that were set out at the start of the project.

The successful delivery of the project has:

- Provided an improved evidence base for the causality between historical weather variables and weather-related faults;
- Quantified the historical impact of severe weather conditions on the distribution network;
- Provided the ability to quantify the future impact of severe weather on the NGED network, based on the accepted worst-case climate projection;
- Provided GIS visualisations of the above outputs; and
- Enabled adjustment factors to be developed for the impact of climate change on half-hourly demand and DG output profiles, based on historical trends.

6.2 Project Objectives

The project successfully met all the original objectives as detailed in Table 5.

Table 5 Project objectives

Objective	Status	Performance
To provide a visual representation of NGED historical weather impacts and climate change projections within different timeframes and spatial resolutions.	✔	Heatmaps and fragility curves prepared as part of historical assessment in WP1, and incorporated into the GIS tool developed as part of the project.
To establish an up-to-date understanding of the potential impacts of projected climate change on the NGED's assets performance and functionality.	✔	Future impact of weather-related faults quantified through application of climate projections to fragility curves in WP2, and presented in GIS tool visualisations.
To establish an understanding of climate change impacts on embedded generation and consumption patterns.	✔	Methodology implemented in WP3 to quantify the impact of climate change on half-hourly demand and DG output profiles, providing adjustment factors in an Excel spreadsheet that can be used to complement the DFES analysis undertaken by the NGED DSO team.
To develop a climate change impact assessment procedure and to trial it across the business.	✔	Procedure document prepared in WP4 for adoption of the climate change impact assessment developed in this NIA project as part of NGED's day-to-day activities and strategic planning.

6.3 Success Criteria

The project delivered against the success criteria as detailed in Table 6

Table 6 Project success criteria

Success Criterion	Status	Performance
Climate impacts on asset groups established and documented.	✔	In addition to the internal project reports, the GIS tool effectively documents the results from WP1 and WP2: • Heatmaps and fragility curves showing the historical impact of severe weather on network assets; and • Projected impacts of weather-related faults under the worst-case climate scenario.
Impacts on embedded generation and future demand modelled and documented.	✔	The internal project report prepared in WP3 documents the methodology and results of the analysis of the impact of climate change on half-hourly demand and DG output profiles, which have been developed to complement the DFES analysis undertaken by the NGED DSO team.
Climate change impact assessment procedure developed and verified within the business.	✔	Document prepared in WP4 provides procedure for adoption of the climate change impact assessment developed in this project as part of NGED's day-to-day activities and strategic planning. This report has been verified through a workshop and review by the NGED Climate Resilience Lead.

7 Required Modifications to the Planned Approach during the Project

Several change requests were approved during the course of the project reflecting slight delays to deliverables compared with the project programme. These changes were minor and mitigated to ensure that the project was completed before the end of March 2023.

8 Project Costs

Table 7 outlines the spend on the project against the project budget.

Table 7 Project finances

Activity	Budget (£)	Actual (£)	Variance (£)
Project Management	£40,588	£60,453	£19,865
Newcastle University	£78,570	£78,570	£0
GHD	£103,125	£101,900	£1,225
Total before contingency	£222,283	£240,923	£18,640
Contingency	£22,228	Included in actuals £18,640	Remaining £3,588
Totals	**£244,511**	**£240,923**	**£3,588**

Comments around variance

The project costs are within the total costs including contingency, though the project management budget has been overspent. The project management costs were higher than expected because a significant resource was required during the mobilisation, data gathering and stakeholder engagement stages of the project. The need for extra project management time was not expected during the scoping phase of the project and, therefore, the contingency funds were released to cover the gap.

9 Lessons Learnt for Future Projects

The project team ensured that lessons from the project were captured on a monthly basis. Table 8 details the key learning that was generated from the project.

Table 8 Lessons Learnt

Ref	Area	Description
1	WP1 – Nature of historical faults	Wind is the main driver of the faults and extreme wind related faults predominantly occur between November and March, but are present throughout the year. Wind related faults are also predominantly in the South West licence area. For the different years there are clear spikes in wind related faults in the years 2006, 2007, 2008, 2009 and 2014 for the South West. East Midlands wind related faults are generally lower than other regions (in all months/years). Additionally, no obvious trend of these faults increasing or decreasing has been observed over the time frame. The analysis also shows that few faults occur below a wind speed of 30m/s, however, this starts to ramp up significantly after 35m/s.
2	WP1 – Nature of historical faults	Lightning is the second most prevalent fault, but this and the other categories result in far fewer faults than wind. In the case of lightning, faults are far more prevalent from June to August and occur most frequently in the South West and East Midlands. The South West is unusual in that it also records a significant number of lightning faults for the duration of the year. 2005 and 2006 were particularly bad years for lightning.
3	WP1 – Nature of historical faults	For cold weather, as expected, faults occur during November to April and there is a higher proportion of faults for South West and West Midlands (in December only). The majority of cold weather faults, for all regions, is caused by Snow, Sleet & Blizzard, with 2009 being a bad year for the South West, 2017 for the West Midlands and 2018 for the South West.
4	WP1 – Nature of historical faults	For heat related faults (cause category Solar Heat), unsurprisingly most faults occur between April and August. East Midlands experiences a low number of faults compared to the other regions. This is the only climate variable where we may be seeing an increasing trend in the number of faults for the past 4 years but only in the West Midlands (there is not enough data to be sure of this).
5	WP1 – Fragility curves	Apart from wind, for some of the other climate variables there is not enough data to reliably create fragility curves. In these cases the data has been pooled for the regions and the different asset types to produce fragility curves. These fragility curves should be used with more caution as the relationships between climate intensity and fault probability are not strong.

Ref	Area	Description
6	WP1 – Fragility curves	Fragility curves are useful for two things: the first is to understand how likely it is for a fault to occur subject to a given intensity of weather variable and the second is to understand the range of likely faults that may occur for that given weather intensity value. For example, if a 38m/s wind was to occur in the East Midlands, on average we would expect approximately 75 faults to occur in overhead lines, however, for every 100 of these storms that did occur we could expect 5 of them to have in excess of 350 faults. However, the statistical value of these findings should be noted because, whilst a significant number of storms have been analysed, for these very large events there is not much data hence this figure of 350 is subject to a lower level of confidence.
7	WP2 – Projected climate impact	Extreme windstorms are likely to increase in frequency and intensity over the UK. Within the NGED licence areas, the projections are less certain, partially due to random variability regarding exactly where is worst affected by individual storms. However, it is expected that South Wales and the South West licence areas will be worst affected, particularly exposed coastal regions. In particular, in South Wales, the biggest increase in the frequency of windstorms is likely to be in the far future TS3 (2061-2080) with a 1 in 50 year return period storm resulting in a 30% increase in the number of faults and a current 1 in 50 year event (620 faults) occurring on average approximately every 20 years. Similar percentage increases are expected for CML with a 1 in 50 year event causing a little less than $7x10^6$ CML in South Wales for TS3 (2061-2080), assuming the same plant and equipment standards.
8	WP2 – Projected climate impact	Extremely hot temperatures are very likely to increase in their intensity and frequency in the future in all four licence areas (there is high confidence in this as it is consistent with historical trends). As a result, NGED is likely to experience impacts due to high temperatures more frequently in the future, with a current 1 in 50 year event occurring, on average, every 5 to 10 years for the TS2 (2020-2040) time slice and occurring on average every 1 to 2 years for the TS3 (2061-2080) time slice. This means that heat related CML are set to increase by approximately 30-40% for the TS2 (2020-2040) time slice and double by TS3 (2061-2080). Similar percentage increases are expected for number of faults.
9	WP2 – Projected climate impact	Extremely cold temperatures are likely to decrease in their intensity and frequency in the future, following historical trends. As a result, NGED is likely to experience cold temperatures impacts less frequently in the future.

Ref	Area	Description
10	WP2 – Projected climate impact	Rainfall extremes are very likely to increase in their intensity and frequency in the future, and subsequent flooding. It is expected that winters will be wetter with more short duration (1-hour) intense rainfall events. As such, greater impacts due to wet periods may be expected in the future, particularly in South Wales and the South West. For instance, a 10-year event in TS1 (current climate) is projected to occur every 5 years in TS3 (2061-2080). Faults associated with wet spells are projected to increase by approximately 60% in the South West and 80% in South Wales for this time slice. In contrast, no significant change was observed in the East or West Midlands licence areas.
11	WP1 and WP2 – Fragility curves	WP1 showed considerable spread in the relationships indicating that additional influences are present in producing impacts to the distribution network. For instance, impacts from windstorms may also depend on the soil moisture, wind direction and time of year (trees and poles may be more likely to be dislodged/uprooted by a windstorm in wet conditions following a period of rainfall). Further work would be required to quantify the combined influence of these additional components.
12	WP3 - Data	Historical datalogger measurements have been used to obtain the best approximation of the underlying “unmasked” demand and DG output profiles. However, the following limitations should be noted: • Actual demand measurements include the effect of some technologies, e.g. overnight storage heating. There is no established method to cleanse the underlying demand, but more information about the nature of demand may be available in future; and • Profile data for the aggregate output from small behind-the-meter generators is not generally available. This means that it is difficult to determine the true “unmasked” demand.
13	WP3 – Alignment with DFES	The approach adopted in DFES is to use average profiles for each of three primary substation categories, for each of five representative days in the year. Work on this project has highlighted the importance of location specific factors that impact the demand/DG outputs at each particular location on the network. As such, the use of average profiles should be reviewed regularly, including the suitability for application to particular substations (e.g. morning peaking primaries dominated by industrial customers) and also the need to update them periodically.
14	WP3 – Historical long-term relationships	Whilst not always perfect, the non-linear sigmoid and logarithmic relationships between historical daily demand and daily maximum temperature appear to be suitable for modelling the impact of climate change on the demand and DG output profiles. In addition, it should be noted that the nature of the sigmoid relationships is such that the changes in demand are limited within reasonable bounds.

Ref	Area	Description
15	WP3 – Alignment with DFES	The historical relationships have been used to determine adjustment factors that have been applied to the historical profiles for specific substations, but they could also be applied to the average profiles adopted in DFES.
16	WP3 – Climate projections	In contrast to the WP1 and WP2 analysis that considered extreme weather variable values, this analysis uses average daily maximum values to understand the average impact that is relevant for application to the demand profiles. The projected increases in 2050 of the average daily maximum temperatures range from 1.4°C in winter to 2.6°C in summer. These correspond to maximum reductions in half-hourly demand between 0% and 9.6% in 2050 for the five primary substation areas considered.
17	WP3 – Adjustment to profiles	The greatest reductions in demand are seen in the periods of the year when intermediate temperatures are observed. This results from the historical relationships showing that the underlying demand converged on a finite maximum value at low temperatures and a finite minimum value at high temperatures (represented by sigmoid functions).
18	WP4 – Earlier climate adaptation activities	A key feature of the Adaptation Reporting Power (ARP) first and second round reports, and associated actions undertaken by NGED, was flood mitigation required due to increases in prolonged rainfall. As such, a substantial amount of progress has been made towards identifying and mitigating the impact of flooding on NGED assets. Additionally, earlier activities have worked to improve 'storm response efforts' (acknowledging that 'there is currently no strong signal within the climate projections for a change to future storm intensity') and specify 'lightning protection for pole mounted transformers.
19	WP4 – Earlier climate adaptation activities	The NGED Climate Resilience Strategy and ENA consolidated third round report highlight key areas where risk assessments are being updated and climate resilience initiatives are being considered to mitigate the following: • Extreme high temperatures causing expansion of overhead conductors and increases in ground temperature limiting the radiation of heat from underground cables; and • Heavy rainfall/drought cycles resulting in ground movement and increases in the soil resistivity and effectiveness of the earthing design parameters.

Ref	Area	Description
20	WP4 – Applications of the analytical approaches	The following applications have been demonstrated to be legitimate uses of the new analytical approaches, and examples of suitable analyses have been prepared: • ED3 Business Plan – consideration for additional climate resilience expenditure; • ED2 expenditure – prioritise locations for Capex and Opex schemes; • Feedback to Policy team – suitability of equipment specifications / selection of specifications under different conditions; and • DFES preparation - generation and demand profile adjustment.
21	WP4 – Climate risks	It should be noted that the ENA third round report largely disregards the impact of wind based on the statement that 'there is currently no strong signal within the climate projections for a change to future storm intensity' (or frequency). This is reflected in the long term projections for average daily wind speed. Whilst the projections for wind speed do not include any substantive change in the long-term, most of the historical weather-related faults are attributed to wind and, correspondingly, the projections developed by Newcastle University (both for number of faults and corresponding CML values) are also dominated by wind. The GIS tool allows the user to filter the fault causes such that wind-related faults may be included or excluded from the visualisations depending on the requirements of the assessment.

10 The Outcomes of the Project

ACCELERATED was delivered in four work packages as detailed in Section 5 of this report. The following sections outline the outcomes from each of the work packages.

10.1 Work Package 1 – Identification of historic severe weather impacts and at-risk asset groups

Figure 7 presents excerpts from the WP1 project report.

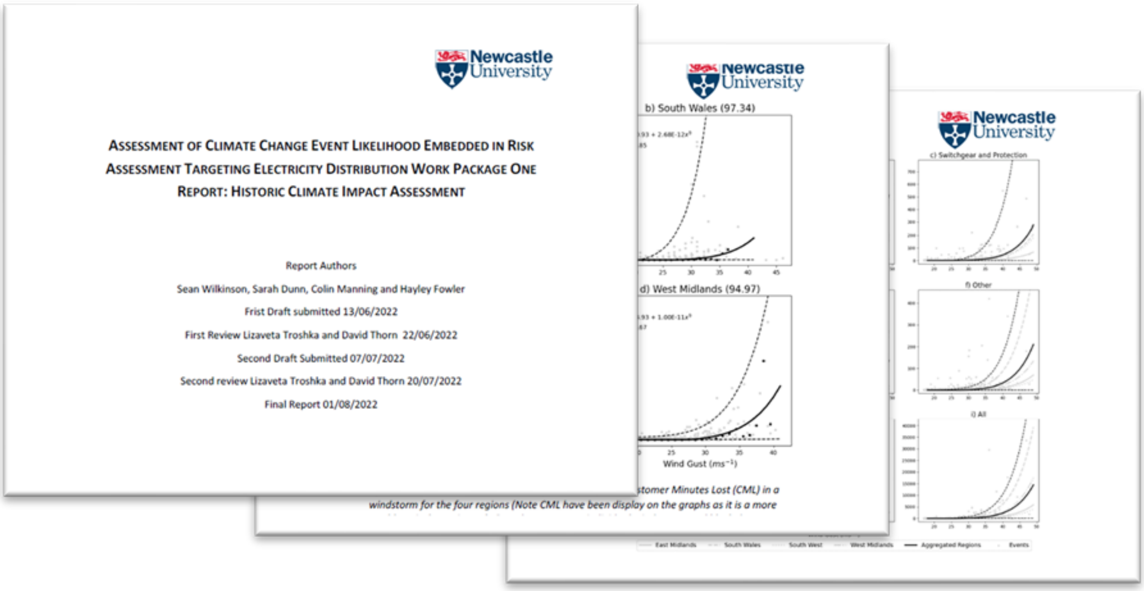

Figure 7 WP1 report excerpts

As discussed and illustrated in Section 5, this report presents the results of the analysis in two parts:

- Heatmaps of climate related impacts (in terms of number of faults) and consequences (in terms of CML) for different asset types and different categories of climate hazard; and
- Fragility curves for different assets and different climate variables (excluding flooding and lightning as no historical time-series are available for these).

10.2 Work Package 2 – Projecting future impacts of severe weather and climate change

Figure 8 presents excerpts from the WP2 project report.

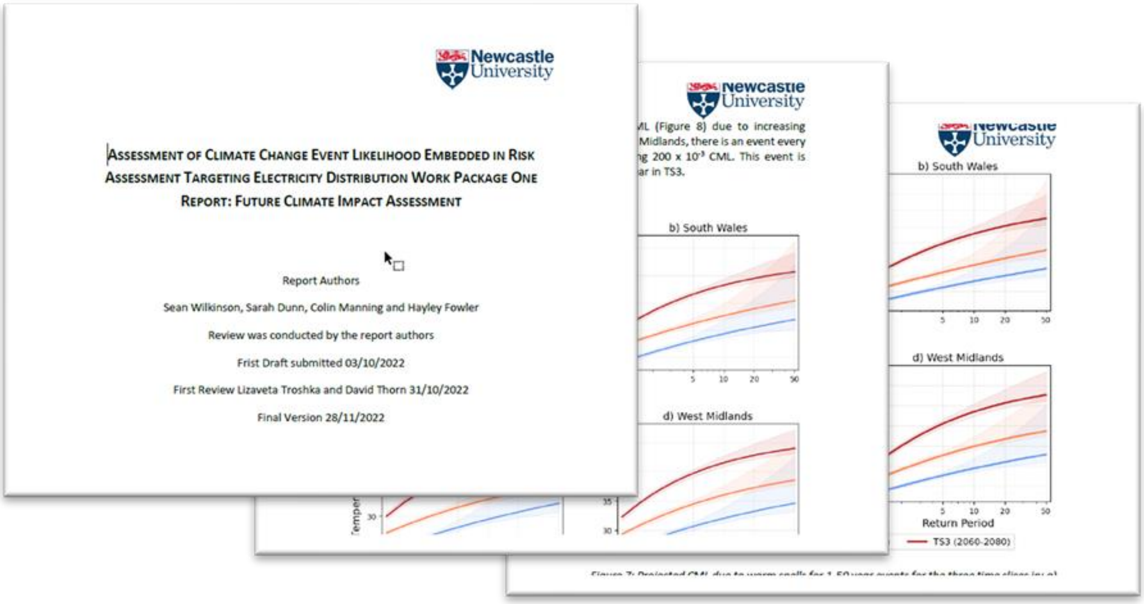

Figure 8 WP2 report excerpts

As discussed in Section 5, this report presents the results of the analysis of the future impact of climate change on the distribution network. This comprised application of the fragility curves from WP1 with the weather intensity variables corresponding to the climate projections, as illustrated for return periods in the above figure.

In addition, a GIS tool was prepared as part of WP2 to provide visualisations of the outputs from WP1 and WP2.

Figure 9 illustrates the screen of the GIS tool showing the severity (CML impact) of the projected faults. Filters are applied such that the CML impact showing corresponds to projected faults attributed to 50 year return period high temperature conditions in the medium-term climate projection (TS2 – 2021-2040).

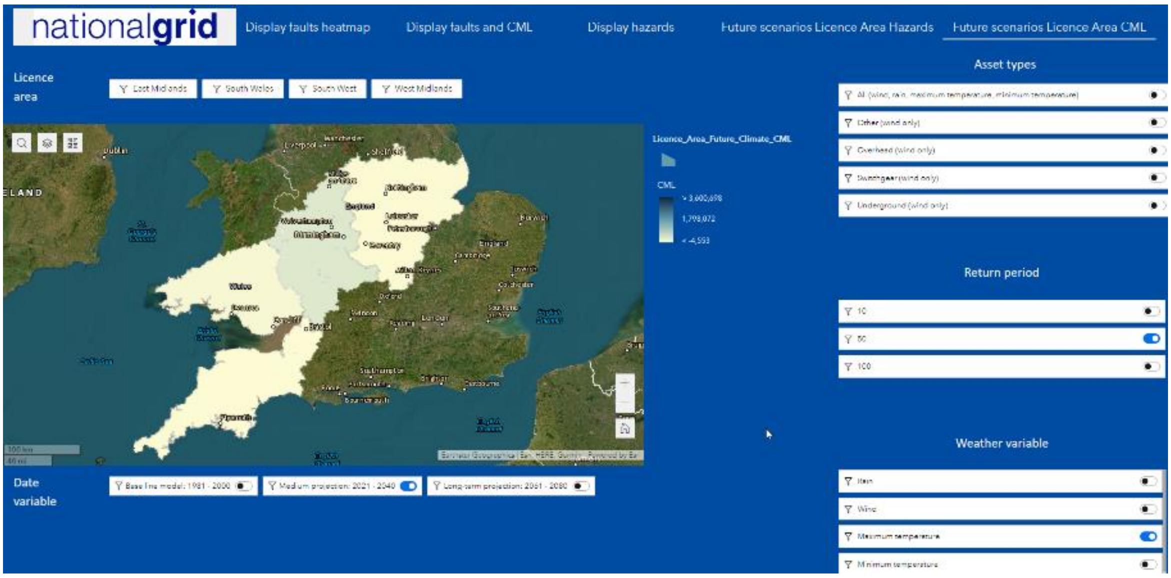

Figure 9 Illustration of GIS tool screen 5 - Future scenarios Licence Area CML

10.3 Work Package 3 – Projecting climate change impacts on embedded generation and consumption patterns

Figure 10 presents excerpts from the WP3 project report.

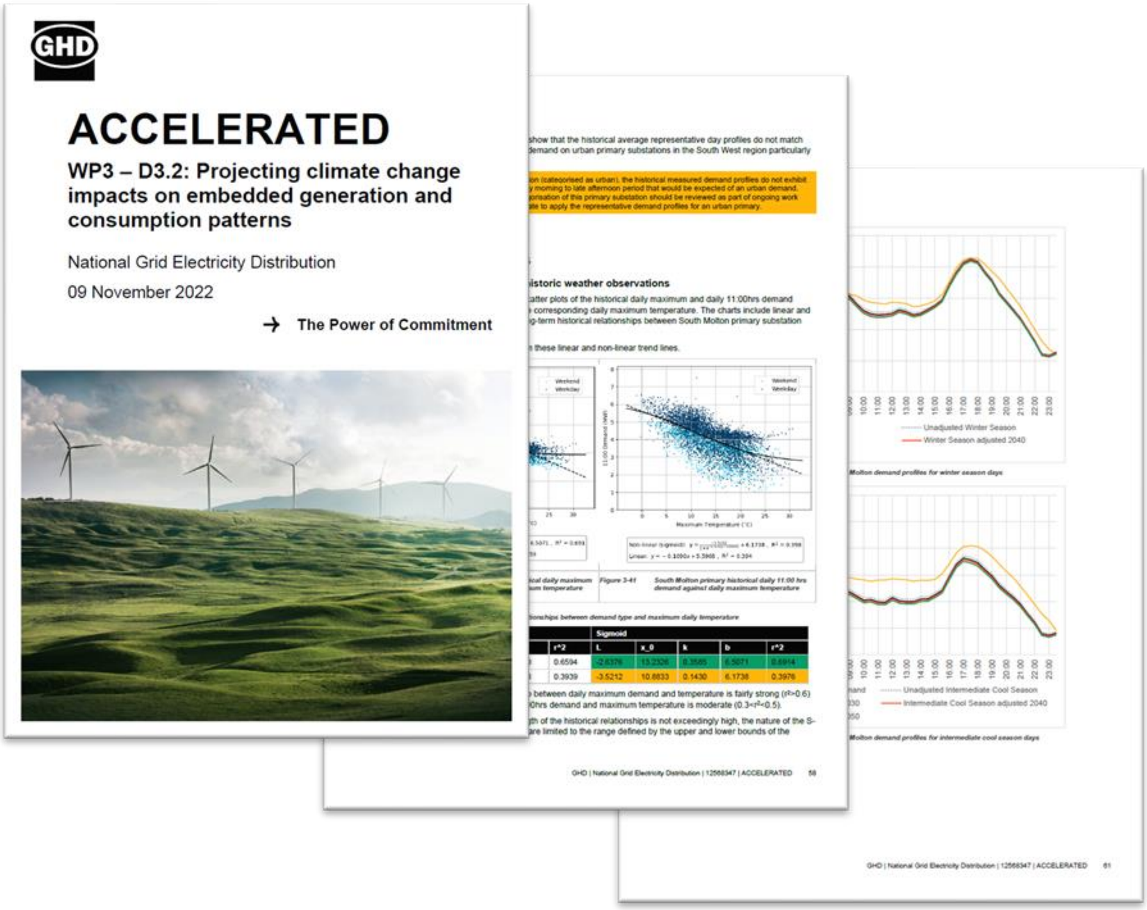

Figure 10 WP3 report excerpts

As discussed in Section 5, this report presents details of the methodology and results of the analysis of the impact of climate change on demand and DG output profiles. It includes details of the long-terms relationships between network demand/DG output measurements and historical weather observations, as illustrated in Figure 11 and Figure 12 for the demand and DG output in the Bodmin primary substation area, respectively.

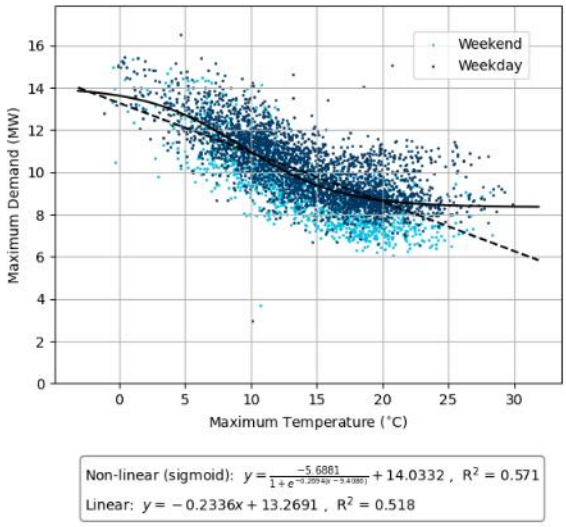

Figure 11 Bodmin primary historical daily maximum demand against daily maximum temperature

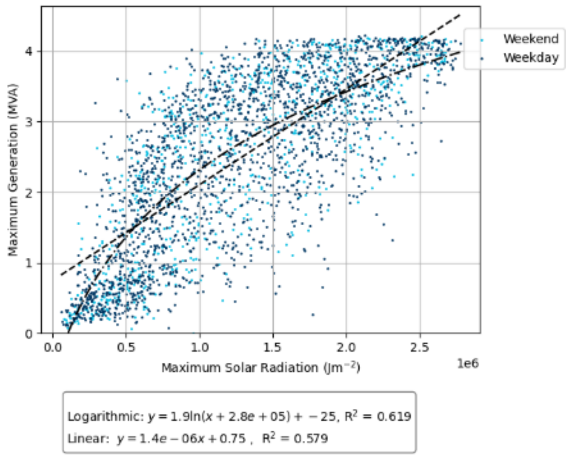

Figure 12 Bodmin primary historical daily maximum DG output against average daily solar radiation

Figure 13 presents the corresponding 2050 adjustment factors applied to the unadjusted profile in each half-hour period, for winter as well as the other seasons.

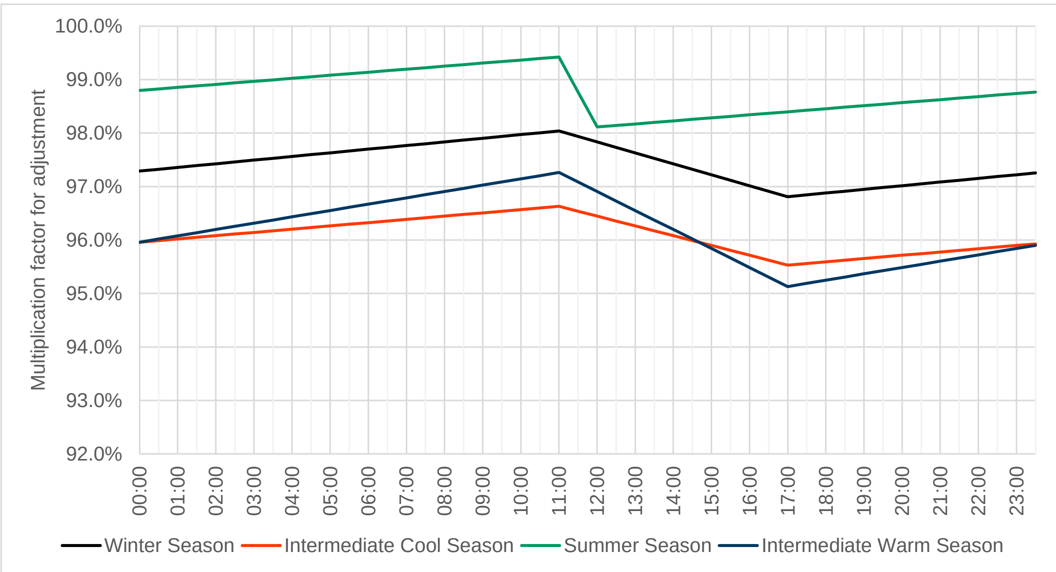

Figure 13 Primary substation 2050 demand half-hourly adjustment factors (example for Bodmin primary)

10.4 Work Package 4 – Climate Change Impact Assessment Procedure

Figure 14 presents excerpts from the WP4 procedure document.

Figure 14 WP4 procedure document excerpts

As discussed in Section 5, this document provides details of the analytical approaches developed in the project, along with applications of these for NGED and examples of the analyses that would be for each of these applications.

11 Data Access Details

Information for ACCELERATED has been published on our innovation website:

National Grid - Assessment of Climate Change Event Likelihood Embedded in Risk Assessment Targeting Electricity Distribution (ACCELERATED)

Specific report and access to the GIS tool can be requested by submitting a request on the website.

12 Background and Foreground IPR

Background IPR (Newcastle University):

• Consequence forecasting methodology developed by Newcastle University and all Newcastle IP contained within the following publications:

- Dunn, S., et al., *Fragility Curves for Assessing the Resilience of Electricity Networks Constructed from an Extensive Fault Database. Natural Hazards Review*, 2018. 19(1): p. 04017019.

- Wilkinson, S., et al., *Consequence Forecasting: A Rational Framework for Predicting the Consequences of Approaching Storms*, draft publication.

New foreground IPR has been created as part of ACCELERATED, this includes the following:

- GIS Tool summarising the results of the climate change impact analysis.
- Methodology for integrating climate change considerations into energy distribution forecasting activities;
- All reports produced during the course of the project.

13 Planned Implementation

The climate change impact assessment procedure developed in WP4 established a procedure for adopting the climate change impact assessment developed in this NIA project as part of NGED's day-to-day activities and strategic planning. It aimed to provide a consistent and robust approach to assess and mitigate the impact of climate change. The procedure provides details of the analytical approaches developed in the project, along with applications of these for NGED and examples of the analyses that would be for each of these applications.

Going forward, the procedure document will be shared with the NGED internal teams. Those teams identified to adopt the analysis will be encouraged to review the example analysis prepared in the project and presented in the procedure document. In addition, the Policy team and Engineering Policy Manager will have responsibility for evaluation of the adequacy of the analysis for meeting mandatory reporting requirements in future, and coordinate identification of areas for development and potentially integration of the ACCELERATED outputs into NGED's Climate Resilience Strategy.

14 Contact

Further details on this project can be made available from the following points of contact:

nged.innovation@nationalgrid.co.uk

Innovation Team

National Grid
Pegasus Business Park,
Herald Way,
Castle Donington,
Derbyshire
DE74 2TU

Glossary

Acronym	Definition
ACCELERATED	Assessment of Climate Change Event Likelihood Embedded in Risk Assessment Targeting Electricity Distribution
ARP	Adaptation Reporting Power
CCC	Climate Change Committee
CI	Customer Interruptions
CML	Customer Minutes Lost
DFES	Distribution Future Energy Scenarios
DG	Distributed Generation
DSO	Distribution System Operator
ENA	Energy Networks Association
GHD	Gutteridge Haskins and Davey Ltd
GIS	Geographic Information System
IPR	Intellectual Property Rights
NGED	National Grid Electricity Distribution
NIA	Network Innovation Allowance
PEA	Project Eligibility Assessment