Adapting the power system to a changing climate:

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Adapting the power system to a changing climate: monitoring progress

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NB: All views contained in this report are attributable solely to the author and do not necessarily reflect those of researchers within the wider Tyndall Centre for Climate Change Research.

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Executive summary

This report presents the final outcomes from the 'Adapting the power system to a changing climate' project awarded by Capabilities in Academic Policy Engagement (CAPE). The remit of this work is to support the Department for Business, Energy & Industrial Strategy (BEIS) and its successor, the Department for Energy Security and Net Zero (DESNZ) in developing climate change adaptation indicators for Great Britain's power distribution network.

The recommendations in this report are based on a literature review, four one-to-one meetings with Distribution Network Operators (DNOs), the Energy Networks Association (ENA), and feedback from DNOs on our draft recommendations. The one-to-one meetings were set up to understand the data DNOs collect for existing reporting purposes, climate data used to inform adaptation actions, standards followed by DNOs for designing adaptation, and how fault data is being recorded and reported. Based on these discussions and literature review on adaptation actions, draft recommendations were made and presented to the Climate Change Resilience Working Group on January 19, 2023, for their feedback. The interviews and discussions concluded that a range of strategies is required for adapting the UK's power network to reduce risks from the harmful effects of climate change. DNOs expressed their willingness to implement adaptation indicators based on their existing reporting systems. Some indicators could be implemented relatively quickly, whereas further review is needed for other indicators. The indicators provide quantifiable evidence of progress in adaptation while learning from the results.

The key recommendations are as follows:

1. **Set the standards for protection and performance for both individual assets and network performance under defined climate projections. Use Annual Exceedance Probability (AEP) or percentiles instead of return periods where appropriate for climate variables.** When setting standards, the following factors should be considered: differentiation between critical and less critical assets; the increasing criticality of the power network as an increasing proportion of energy services are electrified; changes in criticality under different circumstances and interdependencies with other critical infrastructure.

2. **Monitor & report the progress of specific adaptation activities for both critical and less critical assets – particularly to protect from flooding and extreme heat.**
    a. When reporting progress on flood adaptation activities, state the climate change allowance and commensurate AEP applied (following BS 8533:2017 including climate projection and time period) in the design of flood protection measures.
    b. Conduct a detailed review of the risks to assets from extreme heat and heat waves – using the full range of AEP or percentiles available for future climate

projections. The review should consider recent evidence that temperature projections by the UK Climate Projections 2018 may underestimate extreme heat based on observational data (Christidis et al., 2020; Kennedy-Asser et al., 2021). The review should recommend any additional adaptation actions required, such as updates to standards and installation guidelines for new equipment, wider use of dynamic ratings, and retrofitting existing assets with cooling measures. Once completed, an appropriate monitoring system should be designed to check the progress and performance of adaptation activities implemented.

3. **Develop and implement a common validation and verification process to identify and monitor the effect of weather on faults – due to both acute and chronic impacts – in order to expand the best practices in performance monitoring and reporting system for the network.** Use the process to monitor and report the network's performance during adverse weather events and monitor progress in decoupling weather events and faults using the National Fault and Interruption Reporting Scheme (NaFIRS) data. Network performance reporting using interruptions data would require establishing a clear definition of 'extreme weather' and parameters specific to the distribution network. Additional information on the fault record is also needed, including precise fault location and detailed weather information.

4. **Incorporate future climate information (with standards determined by recommendation #1) into specifications and guidelines for equipment and its installation.** Review existing equipment specifications (e.g., IEC, BS), procurement contracts, and installation codes of practice to identify where they require updating to account for climate change.

5. **Incorporate climate information into the Risk Index and investment decisions.** Evaluate the change in Probability of Failure (PoF) of assets associated with climate change over the asset lifetime, and specifications to inform the revision of the Risk Index methodology. Identifying appropriate climate datasets is also essential for the risk index, which can then be used to assess investment options in the cost-benefit analysis.

6. **Assess the impacts of compound events on power networks and design adaptation measures accordingly**. Currently, compound events (e.g., drought followed by heavy rain and strong winds) are not routinely considered as part of climate risk assessments. Combinations and sequences of events can contribute to failure modes that would not be anticipated during a single event. A better understanding of these risks would inform suitable adaptation measures, which could then be monitored and reviewed for both the rollout and performance.

1.0 Introduction

This report presents the project outcomes of the '*Adapting the power system to a changing climate*' in collaboration with the Department for Business, Energy & Industrial Strategy (BEIS) and Ricardo Energy & Environment. The project was awarded by '*Capabilities in Academic Policy Engagement (CAPE)*' to develop indicators to measure the progress of the electricity networks' adaptation to climate change. The remit for this project is limited to electricity Distribution Network Operators (DNOs) in Great Britain based on information already being collected and reported, which could be repurposed to inform reports submitted under the adaptation reporting power (ARPs). The adaptation indicators proposed are in line with Defra's 'Outcome Indicator Framework for the 25-Year Environment Plan' to ensure that adaptation activities are successful through monitoring, reporting, and review.

The objective of this report is to provide recommendations on the potential indicators that can be used to monitor the power distribution network's climate change adaptation activities using existing data collection processes. Most of the data identified for the proposed indicator reporting is already available in the annual regulatory reporting process governed by the Regulatory Instructions and Guidance (RIGs) (Low, 2019). Where this data gives partial insights into adaptation activities, additional recommendations are made to augment this. The assessment also considers some of the existing standards and guidance that are used to inform adaptation assessments to examine whether climate change information could be better incorporated to enhance adaptation. In conducting the review, it became clear there was no common climate resilience standard to which adaptation activities were designed. While an aspiration to be resilient in a high emission scenario – RCP 8.5[1] – was often stated, how this was translated into the design of individual adaptation actions was not always clear. Hence an overarching recommendation on addressing this is also included.

The recommendations in this report are based on a literature review, four one-to-one meetings with Distribution Network Operators (DNOs), the Energy Networks Association (ENA), and feedback from DNOs on our draft recommendations. The one-to-one meetings were set up to understand the data DNOs collect for existing reporting purposes, climate data used to inform adaptation actions, standards followed by DNOs for designing adaptation, and how fault data is being recorded and reported. Based on these discussions and literature review on adaptation actions, draft recommendations were made and presented to the Energy Network Association's Climate Change Resilience Working Group on January 19, 2023, for their feedback. The interviews and discussions concluded that a range of strategies is required for adapting the UK's power network to reduce risks from the harmful effects of climate

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[1] Representative Concentration Pathway (RCP) 8.5 refers to the concentration of greenhouse gas adopted by the IPCC that delivers global warming at an average of 8.5 watts per square meter (worst-case climate change scenarios) across the planet.

change. DNOs expressed their willingness to implement adaptation indicators based on their existing reporting systems. Some indicators could be implemented relatively quickly, whereas further review is needed for other indicators. The indicators provide quantifiable evidence of progress in adaptation while learning from the results.

2.0 Background and context

The Climate Change Act 2008 (The UK Government, 2019) creates a process for energy companies to report the current and future predicted effects of climate change on their organisation and put forward their proposals for adapting to future climate change. Meanwhile, the UK Parliament Joint Committee on the National Security Strategy (2022) recommended the government should develop resilience standards and stress tests that address the effect of climate change in the short, medium, and long term. A stress test aims to understand how the system responds to different types of disruptions and the critical thresholds above which the system cannot operate effectively. Through such understanding, network operators should be able to identify adaptation solutions to extend the life span and/or reduce the degradation process of network assets rather than experience an abrupt failure (Linkov et al., 2022). Woodruff et al. (2022) suggest adaptation strategies should include specific implementation plans, and such plans should be closely monitored with regular reporting and review toward the stated objectives. The recommendations provided here are made to support this reporting and review process to ensure the power network is 'adapting well' in a rapidly changing world (Woodruff et al., 2022).

In response to the climate change adaptation reporting process and to improve the resilience of the UK's energy networks, the Energy Networks Association (ENA) has identified key climate hazards, and their potential impact on the network in collaboration with the UK Met Office as outlined in Table 1 (Energy Networks Association, 2021; Wallace et al., 2020). All of the UK DNOs have published climate resilience strategy documents and adaptation reports for their license areas. Although the adaptation actions identified vary in detail, DNOs have coordinated with other stakeholders (e.g. local authorities) to develop a strategy to adapt to the impacts of climate change on their network over the long term by considering a range of plausible climate projections. Currently, the reports do not contain universal metrics that could be used to monitor the progress of climate change adaptation activities across all DNOs.

Table 1: Key climate hazards, climate analysis and their risks to the power distribution network (Energy Networks Association, 2015; Energy Networks Association, 2021; Wallace et al., 2020)

Climate hazard /thresholds	Future climate analysis; based on RCP8.5	Risks to the power distribution network
Extreme high temperatures (3 consecutive days above 28°C, exceedance of 28°C, 30°C, or 35°C)	Most of the UK currently exceeds 28°C less than 4 times a year. In the future, an exceedance of 28°C >30 times/yr. in Southeast by 2060 from 8-12 times/yr. Increasing hazard frequency.	Failure of switchgear/ transformers; power losses for transformers (-1% loss/ 1°C increase); overloading of transformers & cables; less capacity for overhead (OH) lines (derating of ~1.6%/°C temperature increase) & underground (UG) cables (derating of ~0.6%/°C temperature increase); sagging of OH lines (>50°C);
Heavy rainfall/drought cycles (Average annual minimum 30-day and 60-day rainfall accumulation between May and August)	Little to no change. Increased risk of rainfall deficits associated with quick soil drying. Ground movement due to soil drying leads to potential asset damage in particular assets located in clay soils such as in the East of England and Southeast.	**Drought**: derating of UG cables, drying, ground movement, shrinking, foundation instability for OH structures, increased soil resistivity & ineffective earthing, high dust levels; **Flood & Erosion**: damage to infrastructure, poles, towers & cables
Prolonged rainfall events (1-month rainfall exceeding the 90th or 95th percentile of today's climate)	Thresholds exceeded more frequently in the West of the UK by 2060s (Twice/yr from today's climate). Remain similar in SE. Average summer precipitation is projected to decrease in the future	**Flood & Erosion**: Damage to infrastructure, poles, towers & cables
Intense short-duration rainfall	Hourly extremes are projected to increase in both seasons with increasing atmospheric moisture.	**Flood & Erosion**: Damage to infrastructure, poles, towers & cables
Strong winds (>50mph (amber); >70mph (red). Seasonality of wind(trees) and gust causes damages)	No strong signal within the climate projections for a change to storminess but the potential for increased risk from strong winds in the 21st century particularly west of the UK	Operational failure for above-ground assets (e.g. poles, towers), damaged assets. Gusty conditions cause more damage; seasonality is essential due to the presence of vegetation (overgrowth or wind throw).
Wildfire	Increased risk of wildfire.	Extreme heat to assets (OH lines) in moorland and heathland, smoke affects telecommunication assets

3.0 Metrics and indicators to measure resilience and adaptation

Given the contextual nature of climate adaptation and the diverse range of definitions available for 'adaptation success', there is no universally accepted set of metrics and indicators for adaptation (Price, 2022). A key challenge, as noted by the IPCC (Barros et al., 2014), is that "adaptation has no common reference metrics in the same way that tonnes of greenhouse gases (GHGs) or radiative forcing values are for mitigation". Indicators and metrics are in the early stages of development as to what they can be used for and what capacities are needed to be beneficial for evaluating adaptation success (Arnott et al., 2016). Arnott et al. (2016) define an indicator as a "*quality or trait that suggests ("indicates") effectiveness, progress, or success*", whereas a metric is "*a variable that can be measured (if quantifiable) or tracked (if qualitative) that represents the indicator*". Since no commonly agreed metrics and indicators are available for the power distribution network, the indicators recommended here draw on the existing datasets being gathered or reported by DNOs.

4.0 Existing adaptation processes

The adaptation activities currently being implemented and considered for the distribution network are primarily related to preventing asset failure from flooding and vegetation management. Although vegetation management activities are reported in the RIGs (e.g. 'kilometres of tree cutting per year'), there are attributional challenges related to vegetation and network failures. Other adaptation actions are based on local risks specific to each DNO, such as increasing the pole heights, undergrounding cables, etc.

DNOs have a comprehensive system of recording and reporting faults and their causes to Ofgem (Ambler, 2015). Reports are made annually through the National Fault and Interruption Reporting Scheme (NaFIRS). The reports include the number of faults, location, number of customers affected, time, and duration. Using the fault data available from NaFIRS, it should be possible to assess how weather and climate are impacting the network and identify any trends in the fault types, for example, through statistical analysis. Often exceptional events are associated with extreme weather, which is currently being logged and can be separated from the reports. However, DNOs consider fault records in their current form would be inappropriate to correlate with adaptation monitoring.

There is a lack of agreed standards and guidance for assets to adapt them to climate change. Without agreed standards and guidance, it is difficult to monitor and assess the progress of adaptation. Meanwhile, all new equipment procured by the DNOs comply with international standards such as that of the International Electrotechnical Commission (IEC) and is installed using specific codes of practice and follows the British Standards Institution (BSI). While these standards include climatic information, this data is based on historic climate analysis.

The existing processes for network upgrades are triggered mainly by an increase in demand or the end of the life of an asset. Hence, risks from climate change are not currently considered as a key determinant in the decision-making process for network upgrades.

5.0 Recommendations

We recommend a new Monitoring, Reporting and Evaluation (MRE) system for the adaptation of the power distribution network. To initiate the process, a summary table related to climate change adaptation based on the existing RIGs could be used. The recommendations on monitoring and reporting of specific adaptation activities provided here relate to the four 'R's of resilience (resistance, reliability, redundancy, and response & recovery) to the network components from climate hazards defined by the UK Cabinet Office (Cabinet Office, 2011). The indicators are therefore related to adaptation activities prior to, during, and after the event (Figure 1). Most of the underlying data needed for the proposed indicators are already available from the existing data held by DNOs. Additional recommendations on standards & guidance, as well as incorporating climate information into the investment decisions, are also provided.

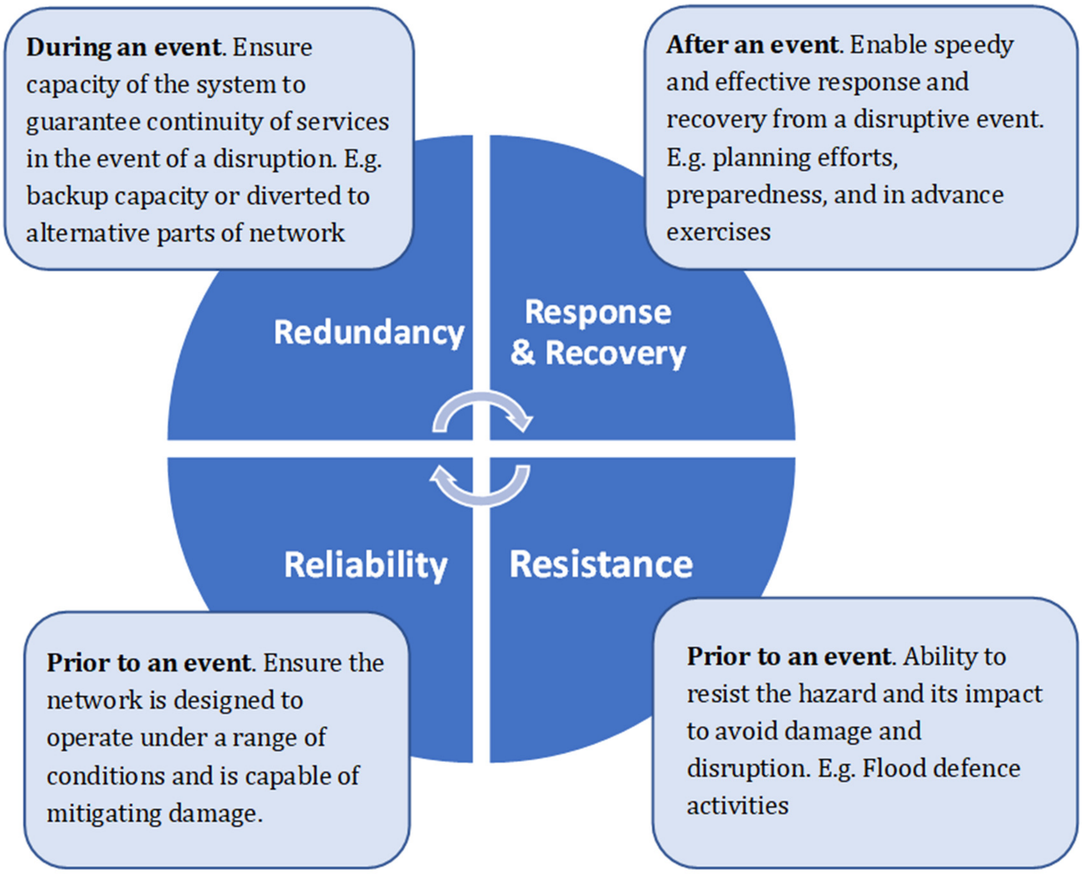

Figure 1: The components and characteristics of infrastructure resilience. Adapted from the UK Cabinet Office (Cabinet Office, 2011).

5.1. Set the standards for protection and performance for both individual assets and network performance to defined climate projections. Use Annual Exceedance Probability (AEP) or percentiles instead of return periods where appropriate for climate variables.

We identify three limitations in the existing standards for protection and performance for both individual assets and network performance. Firstly, the existing guidelines and Code of Practice don't state the climate projections and time period that should be considered. For example, the climate change allowances currently used, such as a 20% or 600mm additional increase in flood defence, do not necessarily protect against a future climate change scenario of RCP 8.5. Secondly, the level of protection (e.g. from flood defences) implemented for critical infrastructures is unclear from the ARPs. Finally, using return periods to specify events in the guidance notes and ARPs is insufficient to highlight the size of extremes. The return period is the reciprocal of the annual exceedance frequency (number of times in a given timeframe) and not a reciprocal of the annual probability of exceedance. The use of return periods fails to capture the performance of defences. Additionally, AEPs are a more robust term to capture the assumption of a non-stationary climate (Sayers et al., 2002). Our recommendations are to:

a) Implement adaptation activities to protect assets, or ensure they operate reliably during a given event or to thresholds derived from the UKCP18 climate projections for a specific time period. The time period selected should be based on the likely lifespan of the asset, and any restrictions on retrofit.
b) Report adaptation actions serving critical infrastructure (as listed under the 'Electricity Supply Emergency Code' (Department for Business Energy & Industrial Strategy, 2019)) to ensure these are captured.
c) Use Annual Exceedance Probability (AEP) or percentiles instead of return periods when setting standards for flood protection as per BS 8533: 2017 (British Standards Institution, 2017) and other climate-related events where appropriate. An example of reporting could be 'the percentage/ total number of critical infrastructures that are protected to a 0.1% annual exceedance probability event with peak river flow climate allowance based on the 70th percentile under RCP 8.5 emission scenario in the 2050s.'

5.2 Monitor & report the progress of specific adaptation activities to both critical and less critical assets – particularly flooding and extreme heat.

We identify flooding and extreme heat as the two key climate hazards that need regular monitoring and reporting that serve both critical and less critical assets, as recommended in 5.1 (b). Data related to flood defences are already being reported, whereas limited data is available for extreme heat and heat waves. Some of the investments related to flood defences which support adaptation are also reported in the RIGs. We recommend a summary table to report the percentage of planned adaptation interventions that have been completed. Datasets from existing RIGs could be used to inform the new MRE system for adaptation of the distribution network assets.

5.2.1 Flood protection

The Engineering Technical Report 138 (ETR 138) is the UK's principal flood protection guidance for Grid and Primary Substations (Energy Networks Association, 2018). According to the ETR138, all primary substations with more than 10,000 'unrecoverable connections'[2] should be protected from a 1-in-1000-year flood (coastal, pluvial and fluvial) event (Energy Networks Association, 2018). Activities related to flood protection are reported annually to Ofgem, such as the number/ % of substations with >10,000 customers protected to a 1-in-1000-year event. DNOs also incorporate some climate allowances as per BS 8533: 2017 or ETR 138 when designing flood defences (British Standards Institution, 2017; Energy Networks Association, 2018), although they are not reported in the ARPs. As explained in section 5.1, the ARPs don't specify climate allowances used or climate projections and the time period considered. We recommend designing flood defences with climate change allowances applied (including timescale & climate projection) and including this information in their annual reports. The forthcoming National Flood Risk Assessment 2 (NaFRA 2) tool (Environment Agency, 2021) is expected to be released by May 2024 and could be used to specify the climate allowances and time periods.

5.2.2 Extreme heat

DNOs follow international standards such as the IEC stipulating performance under different weather conditions when procuring new equipment. While hotter countries use the same international design standards for equipment, they also incorporate additional measures, such as cooling, into equipment housing, as part of the installation.

The UK climate projections 2018 (UKCP18) data for probabilistic projections of climate extremes (25km) over the UK suggests a significant increase in maximum air temperature for the summer months from 1961 to 2100, as illustrated in Figure 2. However, the most extreme events (in terms of intensity and duration) will likely have relatively larger uncertainties due to the relatively small sample size of such events in the historical record. Moreover, observational and reanalysis data have shown that extremes in temperature are projected to increase faster than the annual mean temperature (Kennedy-Asser et al., 2021). The probabilistic projections of ambient air temperatures (25km) over London from the UKCP18 datasets show temperatures above 40°C could be reached by 2040 for a 100-year return period under the 90th percentile for the RCP8.5 emissions scenario. The UK has already recorded 40°C in the Southeast and 38°C in the Northwest in 2022, suggesting extreme heatwaves in the UK are occurring more rapidly than models had suggested (Christidis et al., 2020).

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[2] Connections/customers remaining without supply following the application of HV backup supply.

Observations indicate that heat waves could be further amplified with future warming, and therefore the use of UKCP18 subsets could be inappropriate for analysing the intensity of future extreme events above a certain magnitude (Kennedy-Asser et al., 2021).

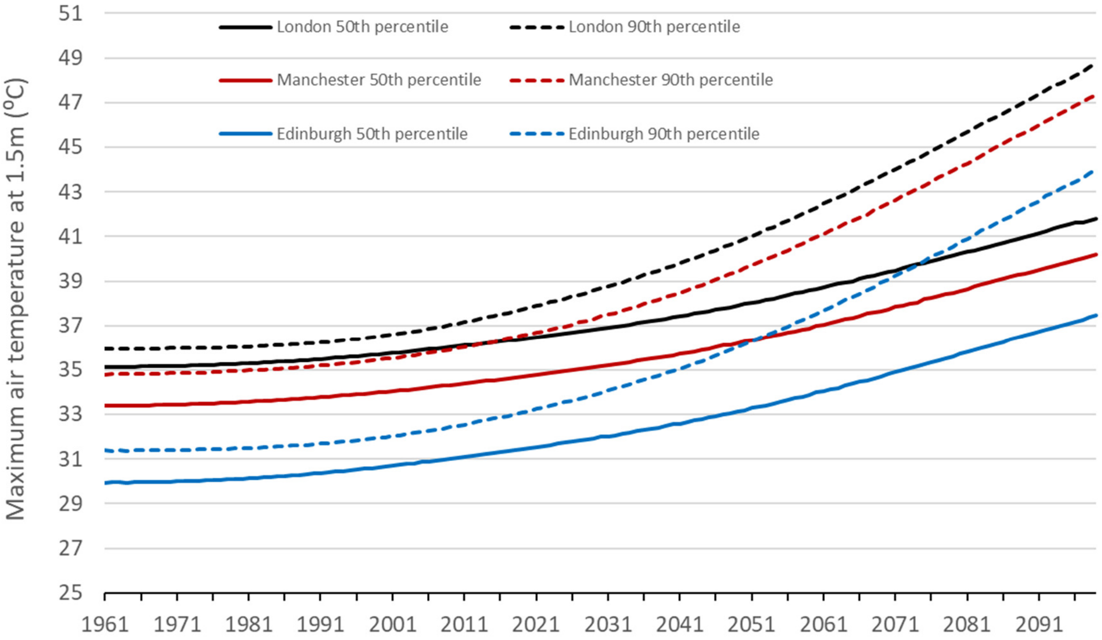

Figure 2: Maximum air temperature at 1.5m for summer months in years out to 2099, for a 100-year return period, for London, Manchester and Edinburgh at 25 sq. km resolution using 1981-2000 baseline and RCP8.5 scenario, showing 50th and 90th percentiles.

Extreme heat can significantly influence the resilience of the power system by increasing the electrical resistance in assets, leading to a reduction in efficiencies (Panteli and Mancarella, 2015). Increased energy losses in assets from extreme temperatures would likely coincide with increased demand for electric cooling (Wood et al., 2015). The electrification of transport amplifies such risks. Currently, all DNOs are adopting local measures based on specific risks to their assets. For example, increasing pole heights to alleviate sagging of the overhead lines (Bertinat et al., 2018) or bespoke dynamic ratings based on the cost-benefit analysis for implementing real-time monitoring kits (SP Energy Networks, 2015). We recommend the following three specific actions as a priority for the network in relation to extreme heat:

a) Review risks for assets from extreme heat and recommend necessary adaptation actions such as updates to standards, installation guidelines for new equipment, wider use of dynamic ratings, and retrofit of existing assets with cooling measures.
b) Based on the review above, implement real-time network condition monitoring systems to expand the capacity of the distribution network under extreme heat (Speakman et al., 2022).

c) Once specific guidance and standards are implemented, DNOs should report on the progress of cooling equipment installed in substations and dynamic ratings for assets as part of adaptation reporting.

5.3 Develop and implement a common validation and verification process to identify the effect of weather on faults in order to build a performance monitoring and reporting system for the network.

Alongside the monitoring and reporting of adaptation activities, monitoring and reporting of the network's performance are also useful to show as a proxy for a measure of success in adapting to climate change. The performance data set includes failure of assets, customer interruptions, and speed of response and recovery after an event. There has been mixed response from DNOs on the effectiveness of interruptions data as an indicator.

The limitation of using the performance data as an indicator is that the impact on the network, such as asset failures from individual climate hazards, may not be instantaneous, or it may be challenging to establish the correlation. For example, customer losses during a flood event could be immediate, whereas the impact from extreme heat may manifest after an event due to the varying deterioration rates of the assets. Additionally, performance data merely show what has happened and do not necessarily measure the impact of any adaptation initiative. In other words, they do not show what would have happened without the intervention. A set of examples of performance monitoring and reporting is shown in Table 2.

Table 2: Examples of performance monitoring and reporting as indicators.

Performance data related to asset's resistance to climate hazard	Performance data related to asset's reliability to climate hazard	Performance data related to asset's reliability to climate hazard	Performance data related to response & recovery after failure
% of primary substations flooded in the last year	Customer interruptions (CI) due to flooding	Customer minutes lost (CML) due to flooding	Supply restoration time in minutes
% of transformers unavailable due to extreme temperatures[3] (e.g. thermal overload) in the last year	Customer interruptions (CI) due to high temperature	Customer minutes lost (CML) due to high temperature	Supply restoration time in minutes
% of overhead lines impacted storms, high winds and windblown debris.	Customer interruptions (CI) due to storms, high winds and windblown debris	Customer minutes lost (CML) due to storms, high winds, and windblown debris	Supply restoration time in minutes

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[3] Extreme high temp defined by Met Office as more than 28ºC for 3 days or more (Wallace et al., 2020)

Our analysis suggests that the metrics in Table 2 could be implemented, provided a common validation and verification of the use of the fault causes, such as flooding, extreme heat, lightning, snow etc., can be ensured. The performance metrics could be established following analysis to understand and identify the ranges that drive faults in various weather conditions using existing data such as weather, faults, network and asset information, maintenance and inspections, flood risk zones and areas etc.

NaFIRS records all supply interruptions, including the location of the fault, equipment, number of customers impacted, time period, and cause of faults (Ambler, 2015). These records also include weather-related causes such as lightning, rain, snow, sleet, blizzard, etc. Although the weather could be an indirect contributor to the fault causes in the network, positive correlations are observed with the number of outages and extreme weather (Noebels and Panteli, 2021). Establishing a statistical relationship between faults and adverse weather could help monitor the ongoing impacts of weather on faults that can be used as a proxy to assess the vulnerability of the network to extreme weather events. Weather actuals before, during, and after the fault, including their duration, need to be analysed for the fault causes and any impacts on recovery and restoration. DNOs obtain weather forecasts and actual (hourly) at 2km resolution from the Met Office, which could be attached/linked to all faults that occurred. Additionally, an agreement on the detail of weather information recorded at the time of a fault is required to determine both whether the fault that occurred is due to extreme weather and support subsequent investigations.

Although NaFIRS doesn't show whether adaptation interventions have prevented faults, a summary report with extreme weather can provide information on the impact of severe weather. We recommend the following in relation to fault reporting and extreme weather:

a) Establish a clear definition of 'extreme weather' and determine parameters more specific to the distribution network. Although there are definitions for extreme weather and thresholds by the Met Office, definitions and parameters more specific to the distribution network are yet to be determined based on the asset specifications. New definitions and parameters could also be embedded into the existing Weather Driven Fault Predictions models to highlight periods of forecasted potential extreme weather and the likelihood of faults. Additionally, this information could also be used in the weather-related fault volume forecast model that correlates to the Customer Interruptions (CI), Customer Minutes Lost (CML) and average time of supply (ATOS) to determine the Cost Benefit Analysis (CBA) of installing network controllable points (NCPs) rather than repairing faults.

b) Obtain additional information to the fault record, including precise fault location and detailed weather information. The fault causes currently being recorded against NaFIRS may not always entirely reflect the actual cause and, at times, be a subjective view of the engineer. Additionally, DNOs do not always capture the exact location of faults that occur on their linear assets. This would be a critical data attribute to collect along with the fault that can drive several additional analyses and allow for a more precise link to extreme weather. This analysis could then be completed against historical faults and weather (up to 5 years) to consult on the definition and parameters of extreme weather, specific conditions and any other aspect such as locations, topology, soil types etc.

Implementing the above would allow for some form of reporting against pre-agreed indicators, or could support a discussion and agreement around what those indicators should be.

5.4 Incorporate future climate information (as determined by recommendation #1) into standards and guidelines for equipment and its installation.

The standards related to products, procedures, systems and services for the distribution network are developed or informed by the IEC and BSI. Additionally, DNOs develop their own codes of practice and follow those produced by the ENA. Most IEC standards cover equipment for use in other countries where the average temperatures are higher and may cover the temperature increase over the lifetime of existing assets. However, considering the potential increase in extreme heat, existing standards and guidance need revision by incorporating climate information, particularly the local installation codes of practice for cooling systems. We recommend a review of all existing standards and guidance on where these changes would be best integrated via IEC/BS etc. standards or procurement contracts and local installation codes of practice (e.g. specifying deeper trenches for underground cables).

5.5 Incorporating climate information into the risk index and investment decisions.

Currently, network upgrades are triggered either by an increase in demand or assets reaching the end of life with a high probability of failure (PoF). Although adaptation actions are seen as one of the inputs to the decision-making process for network upgrades, climate does not seem to be a key determinant for asset replacement.

5.5.1 Incorporating climate into the Risk Index

Climate change can enhance the rate of deterioration of an asset bringing forward the end of life. For example, operating switchgear and transformers at maximum load during periods of extreme heat can reduce their lifespan and increase their susceptibility to failures. The reduction in lifespan (Health Index) of an asset from climate change is not considered in the Common Network Asset Indices Methodology[4] (CNAIM) assessments (Ofgem, 2021). Increased exposure to extreme

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[4] CNAIM is the common framework of definitions, principles and calculation methodologies, for the assessment, forecasting and regulatory reporting of risk for 61 asset register categories. In

heat is likely to cause asset failures (Criticality Index). The existing Risk Index (monetised risk measure) of assets could be revised by incorporating future climate information, such as exposure to extreme heat under the RCP 8.5 scenario. For changes in CNAIM to be considered, each asset type would have to be thoroughly assessed to see if there is an actual reduction in life to the extent that failures are likely to increase. Network assets generally have an expected life of 40 years. We recommend evaluating the change in PoF of assets associated with extreme weather over the asset lifetime to inform the revision of the methodology for the Risk Index.

5.5.2 Climate information into investment decisions

The CBA is a decision support tool and informs how many assets need replacing or reinforcing in the next regulatory period. These network investment decisions are to improve asset health or network performance based on the health & fault indices. Although these analyses consider a range of risks, solutions, whole-life costs and benefits, they do not take into account the risks from future changes in climate in sufficient detail. In principle, the UKCP18 data could be used in CBA for risk reduction in the network following Defra's supplementary guidance to HM Treasury's Green Book (Defra, 2020). While DNOs see the value of incorporating climate change into the CBA, they are unclear on the specific risks to be considered against the equipment specification and its lifetime. Hence climate change data appropriate to the lifetime of assets (e.g. 40 years) is needed for such assessment. We recommend a review of climate risks against equipment lifetime and specifications and identifying appropriate climate datasets to be incorporated into the evaluation of investment options in the CBA.

6.0 Compound and network scale risks

The current reporting system doesn't consider compound events (a combination of hazards leading to a significant impact) (Zscheischler et al., 2018). Simpson et al. (2023) suggest most significant risks from climate change are likely to be from the interactions and interdependencies from cascading and compound climate impacts than individual ones. However, there is a limited understanding of compound events, and further risk assessments are needed for these events to develop adaptation plans.

The resilience measures and adaptation activities are primarily focused on individual assets. Impacts on the distribution system from any failures in local resilience measures also need to be considered alongside failures of the network assets. For example, the failure of local resilience measures (diesel generator) at Gatwick Airport during floods in December 2013 caused severe disruption. The current data collection does not lend itself to identifying ways to monitor the adaptation of the network as a whole to climate change (rather than individual assets). Hence additional consideration is needed to develop suitable processes to assess the adaptation progress of the

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CNAIM several condition parameters are combined into a single value to indicate the overall condition of assets such as switchgear, circuit breakers and transformers.

network as a whole. These processes should include the network's ability to maintain service when multiple assets fail, a weather event that affects a large part of the network, and there is a sequence of weather events or failure of wider infrastructure.

7.0 Challenges for implementing adaptation indicators.

The effectiveness of specific adaptation actions can only be established after an event. Therefore, regular monitoring, reporting and review of specific implementation steps are necessary to ensure the system adapts well in a rapidly changing world (Woodruff et al., 2022). For changes in standards and guidance, an agreement on the climate change projection and annual exceedance probabilities, where appropriate, should be used to develop reliability standards for assets, ensuring they perform under a future climate. The standards would be derived from agreed climate projections and probability to provide an envelope of future weather within which the network would be expected to operate reliably.

Fault-related metrics need careful interpretation. An individual fault may result from compounding factors (e.g. demand, long-term weather patterns, and cumulative heat exposure). Finally, balancing comparability between distribution license areas, rural and urban networks, and aggregation to the national scale needs to be considered alongside the need to retain the context-specific detail necessary for adaptation.

Next steps:

1. Review existing standards and guidelines for network assets to operate reliably under climate futures.

2. Review the existing Risk Index methodology and cost-benefit analysis and determine how climate information can be incorporated into the investment decisions for network assets.

3. Establish a cross-sector agreement on the validation and verification process to identify and monitor extreme weather's effect on network faults.

4. Develop best practices and an agreement in the network's performance monitoring and reporting system.

5. Develop guidance to evaluate the performance and effectiveness of adaptation actions taken.

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