**About the Supergen Energy Networks Hub**

The Supergen Energy Networks Hub (SEN) is a £9M research project funded by the Engineering and Physical Sciences Research Council (EPSRC). The hub – led by Professor Phil Taylor (University of Bristol) – brings together collaborative teams from Industry, Academia, Government and Civil Society to carry out highly impactful, interdisciplinary research, to enable energy networks to become a driving force towards a rapid, safe and just transition to net zero. The project takes a mission-based approach to deliver impactful energy networks research. One core work package of the project is focused on Risk and Resilience, led by Dr. Robin Preece (The University of Manchester). We have focused on responding to questions related to this area. The production of this response has been led by Dr. Laiz Souto de Carvalho (University of Bristol) with contributions from members of this work package – specifically Dr. Robin Preece (The University of Manchester) and Dr. Natalia Zografou-Barredo (Newcastle University). The SEN Hub Risk and Resilience work package team members are happy to answer any questions and to contribute to future working groups as and when necessary.

**Our answers**

**Network asset risk metric**

**OVQ22.** Do you have any views on our proposals for the NARM framework?

**Answer:** The proposed NARM framework has positively contributed for the identification and management of risks associated with deterioration of network assets, but can be improved. The long-term monetised risk measures adopted within RIIO-2 provides an economic indicator about the effectiveness of investment decisions and asset management activities carried out by different energy companies (as defined in the overview document, section 6.144). In addition, it recognises the different nature of network assets and company operation to establish sector-specific NARM methodologies and company-specific elements where appropriate (as defined in the overview document, section 6.147). Conversely, it does not acknowledge that current practices adopted for asset information collection, such as manual inspections and asset management activities, are inadequate for an effective asset condition monitoring. This is evinced by the fact that the majority of power system failures with known causes are attributed to asset deterioration (excluding corrosion). This is exemplified by the authors in [1], as the probability of system failures considerably increases when asset condition is accounted for. In this context, the investment costs in advanced monitoring systems for asset health information collection are justified by the avoided costs associated with power system failures. Incorporating more accurate network asset information into the NARM framework could change investment decisions made by energy companies, as well as incentives and penalties (as defined in the overview document, sections 6.149 and 6.150).

**Climate Resilience**

**OVQ23.** Do you have any views on our proposed long-term approach to embedding climate resilience, including the principles for embedding climate resilience?

**Answer:** The proposed long-term approach to embedding climate resilience needs more reasoning about the definition and quantification of climate resilience and the consideration of different risks associated with a changing climate. The following aspects should be considered and addressed:

* Resilience definition: Definitions of resilience are not currently settled (see slight differences from UK Cabinet Office [2], US Federal Energy Regulatory Commission [3], CIGRE working group C4.47 “Power System “Resilience” [4], UK National Infrastructure Commission [5], IEEE PES Task Force [6]). Ofgem must define resilience for networks in a way that makes it clear and distinct from reliability – an obvious route being through consideration of the impacts on unsecured events (for shock events). But further agreement is needed for definitions associated with indirect effects (interdependencies), or long-term effects (like long term extreme heat). Working groups (as defined in the overview document, section 6.155) will need to establish clear guidance on what can and cannot be considered.
* Resilience quantification: A vast variety of metrics exist for quantifying resilience. To facilitate consistent regulation of this area, it is desirable that these metrics are simple to calculate, allowing for retrospective and forward-looking analyses, while also providing highly informative and consistent results [7]. See reports from SIF Discovery project WELLNESS (Whole Energy System Resilience Vulnerability Assessment) for more details [8]. Defining metrics is the easy part of the problem. Defining the conditions over which the metrics are calculated is the important part of the problem to ensure consistent assessment across networks and across different climate risks. There are no standard methods for this at present. This will be a key problem for the working groups to solve.
* Consideration of risks associated with severe weather in a changing climate: Different risks associated with a changing climate have to be considered in the proposed approach to embedding climate resilience (as mentioned in the overview document, section 6.155). Flooding and sea level rise have been identified as the highest risks associated with climate change in the UK [9]. These risks cover coastal, pluvial, and fluvial flooding as well as storm surges and can affect different parts of the network, such as underground cables, outdoor substations, and foundations. In the past, floodings caused some of the largest and longest power supply interruptions in the UK [10]. These impacts are attributed to the large affected areas and long clearance times, which increase repair and restoration times. That said, the majority of exceptional events which led to the top largest and longest power supply interruptions in the UK was caused by wind and gale. Other extreme weather event categories also caused a small proportion of these largest and longest power supply interruptions in the UK, such as snow, ice, and lightning strikes. The analysis of weather-induced power system failures performed by the authors in [11] and [12] indicates that the majority of occurrences between 2010 and 2019 is attributed to wind and gale in winter, followed by lightning strikes and snow and ice. This analysis indicates the significance of different severe weather event categories across seasons between 2010 and 2019. Recent severe weather events, such as Storm Jocelyn and Storm Isha, also evince that electricity networks are still not prepared against common weather-related failure causes. Climate change is linked to an increase in the risks (i.e., threat, exposure, vulnerability [13]) associated with certain severe weather event categories, such as storms and heatwaves. Current and projected risks associated with different extreme weather events have to be considered for the selection and implementation of appropriate mitigation measures in a timely manner. It is also important to assess the risks associated with extreme weather events in a changing climate at regional level, given that UK DNO license areas cover a considerably wide range of latitudes, topographies, and regional climates. The definition of climate resilience and the principles for embedding it in investment plans and price control mechanisms (as defined in the overview document, section 6.157) should account for these regional differences and represent different climate change risks.
* Consideration of risks associated with ecosystems in a changing climate: Climate change is linked not only to an increase in the risks associated with different severe weather event categories, but also to changes in natural ecosystems [13] (as acknowledged in the overview document, section 6.154). There are 11 direct causes of power system failures attributed to weather phenomena defined by [14]: lightning strikes, rain, snow and ice, ice, freezing fog and frost, wind and gale (excluding wind-borne materials), wind-borne materials, solar heat, flooding, condensation, and corrosion. In turn, there are 7 direct causes of power system failure attributed to fauna and flora: fire not due to faults, falling live trees, falling dead trees, growing trees, birds (including swans and geese), wild animals (including vermin and insects), and farm and domestic animals. This classification includes failures of power system components or groups of components which occur as a direct result of the corresponding impact categories. In [9], climate change risks for energy networks associated with changes in natural ecosystems (induced or accelerated by climate change) were classified as low or negligible. Findings reported by DNOs also indicate that climate change risks for energy networks associated with changes in natural ecosystems are low or negligible. In particular, the implementation of the ETR 132 [15] is reported to have positively contributed to reduce risks associated with vegetation management. Existing processes to mitigate risks associated with wildlife and vegetation growth are considered to be suitable, whereas the potential need for additional resources and investment, given significant changes, is acknowledged. That said, decision making processes concerning wildlife and vegetation management can be improved. By better identifying where and when to trim or remove vegetation in the electricity network surrounding areas, operation and maintenance costs associated with vegetation management – reported to exceed several millions of pounds every year by DNO license area – can be reduced. Likewise, by identifying how projected changes in ecosystems can affect network components and operation, DNOs can reduce investment costs in network upgrades and relocation to mitigate these risks.
* Distinguishing between reliability and resilience problems: It is important to distinguish between reliability and resilience problems which may affect electricity networks so that appropriate risk mitigation measures can be implemented (in line with the overview document, sections 6.157 to 6.162). Power system failures caused by weather include adverse weather conditions (high probability, low impact) and exceptional circumstances (low probability, high impact events). In turn, power supply issues caused by fauna and flora range from transient interruptions (e.g., due to vegetation touching an overhead line) to severe damage (e.g., caused by fallen trees onto the lines). Therefore, it is important to distinguish between high probability, low impact events in the scope of reliability and low probability, high impact events in the scope of resilience. It is important to investigate the conditions in which they may occur and which risks can and cannot be tolerated.
* Methodological approach: The methodology should make use of an appropriate definition and quantification of climate resilience over different timescales and at different locations, considering different risks and regional differences. Consideration of these aspects will improve assessment of climate risks at regional level and facilitate identification and selection of appropriate measures for mitigation of these risks (in line with the overview document, sections 6.157 to 6.162). To this extent, the methodology should suitably incorporate both asset investment and operational flexibility as options for risk mitigation and resilience enhancements. For example, in [16] it is shown that hardening measures at strategic locations can significantly reduce the impacts of extreme weather events and enhance mid- to long-term resilience; in [17] it is shown that operational measures can be used to significantly reduce cascading failure risk. This brings operational costs that need to be weighed against investment costs for network hardening strategies. In this context, a joint evaluation of hardening and operational measures should facilitate identification, selection, and implementation of the best feasible solutions for resilience enhancements. For it to be possible, however, not just the investment and operational costs associated with implementation of different measures should be quantified, but also the resulting financial losses (or avoided losses). To achieve this, well established methods for economic analysis can be utilised. However, results are conditioned by the definition of unacceptable risks (i.e., unacceptable levels of threat, exposure, and impact) at different locations and over different timescales (in line with the overview document, section 6.159).

**OVQ24.** Are there any early learnings we should be aware of/incorporate to make progress on this in RIIO-3 or beyond?

**Answer:** To make progress on climate resilience in this RIIO-3 and beyond, incorporating early learnings from related projects into the proposed approach is critical. Likewise, lessons learned from the handling of past severe weather incidents should not be neglected to improve distribution network preparedness and response to disruptive weather in a changing climate. These learnings should come not just from past severe weather incidents in the UK, but also from international experiences, especially to less known risks in the UK at present time. The following aspects should be considered:

* Preparation plans in the UK: As reported in [18], DNOs currently watch weather fronts and have access to additional weather information from third parties. This information enables them to forecast severe weather events and their spatiotemporal evolution a few days ahead of their occurrence, when emergency plans are initiated. Nevertheless, approaches adopted by different DNOs are different and can be insufficient to prevent long supply interruption durations, as reported in [18]. Using mobile energy resources for quick restoration of parts of the network is impractical if their availability is limited (e.g., given the number of customer interruptions or fuel constraints). In turn, network repair tasks can take several days to be executed when the affected parts of the network are inaccessible (e.g., due to road blockages or extensive damage). Usage of additional pieces of information from weather patterns could help overcome this limitation by increasing forecast times up to several weeks in advance, as shown by [11] and [12]. This approach would enable DNOs to anticipate their emergency plans and mobilise additional resources for repair and restoration tasks.
* Response to weather incidents in the UK: As mentioned in [18], the response of DNOs to fault incidents is evaluated according to the number of customer interruptions and customer minutes lost. Approaches currently adopted by DNOs combine and prioritise repair and restoration strategies in different ways. They also take advantage of mutual assistance with other DNOs to bring in additional resources to help restoration of supply, if needed. Nevertheless, the effectiveness of the response strategies currently adopted by DNOs is strongly influenced by the extent of damage to network components. To overcome this limitation, increasing usage of mobile energy resources should be considered to reduce supply interruption durations, as shown by the authors in [19]. Likewise, effective strategies for pre-positioning of repair and restoration crews and fault clearance prioritisation should be adopted to accelerate repair and restoration tasks. These strategies should be complementary to the Priority Services Register to extend help to vulnerable customers under exceptional circumstances. Improving coordination with government agencies for logistics and community support under exceptional circumstances can also reduce impacts on customers beyond supply interruption.
* Risk assessment: SIF project WELLNESS (Whole Energy System Resilience Vulnerability Assessment) – currently in Alpha phase – is set out to provide core evidence and a coherent approach to resilience standards, assessment, and quantitative metrics that can inform the decision-making process for energy networks [8]. The intent is to fairly and transparently value the resilience contribution from different resources on a level playing field. Significant work is underway covering event modelling, data needs, network impact, metric assessment and selection, integration of flexible devices, and appropriate cost-benefit analysis methods within this project. Strong engagement with the project team is recommended.
* International experiences: International experiences should also be leveraged so that significant progress on climate resilience can be made in RIIO-3 and beyond. This is particularly important to improve preparedness and responsiveness to less known risks in the UK, such as heatwaves. A recent example from the California Independent System Operator showed that demand response and demand reduction schemes can help prevent blackouts under extreme weather conditions linked to high temperature and wildfires [20]. Other examples indicate the importance of resilience planning for energy systems in a changing climate. The Australian Energy Market Operator’s 2020 Integrated System Plan emphasised that enhanced climate and energy system modelling are needed to improve analysis of risks associated with extreme weather events [21]. It also indicated the contribution of planning standards to improve overall system resilience, and the importance of revising these standards to address all current and future risks. The Brazilian National System Operator accounts for adverse climate scenarios which may pose risks for the security of supply to conduct feasibility studies of capacity expansion and generation procurement [22]. It currently adopts the N-2 security criterion for the design and operation of transmission corridors to mitigate the impact of perturbations resulting from adverse weather events on the interconnected system.

**OVQ25.** Do you agree with our suggested approach for embedding climate resilience into RIIO3, namely: introducing resilience strategies; developing forward-looking resilience metrics; and introducing climate resilience working groups?

**Answer:** The proposed approach for embedding climate resilience into RIIO-3 needs more reasoning. The following aspects should be considered for an appropriate introduction of resilience strategies, forward-looking resilience metrics, and climate resilience working groups:

* Introducing resilience strategies: Resilience is inherently about low probability events (as acknowledged in the overview document, section 6.162) which means that traditional probabilistic risk modelling (taking the product of probabilities and impact costs and looking at expected outcomes) are subject to a lot of variability depending on assumptions about the uncertainty and how it is modelled/quantified. Initially, methods based on ‘threshold’ performance (i.e., thresholds based on ‘acceptable’ levels of performance degradation) may be more pragmatic. Such methods still require significant work to establish robust quantification and assessment methodologies, suitable for different shock events across different networks. First, because resilience enhancements may combine different planning and operational strategies implementable over different spatiotemporal resolutions to maximise resilience benefits. Second, because the selection of resilience enhancements based on ‘threshold’ performance will require significant investments – likely to exceed several billions of pounds over the implementation period for each DNO license area – to ensure compliance with minimum requirements.
* Developing forward-looking resilience metrics: Resilience quantification is not currently standardised sufficiently to enable off-the-shelf methods or products to be used. Methods for impact assessment are currently more developed than methods for restoration assessment. Both aspects are needed to make complete assessments. Moreover, exceptional circumstances, such as extreme weather events, are currently excluded from the performance figures of DNOs. Although performance indicators can be computed for different interruption categories, it remains a question as how to define ‘acceptable’ levels of performance degradation for each of these categories. For example, the Brazilian Electricity Regulatory Agency requires SAIDI and SAIFI (i.e., DEC and FEC) values computed for different interruption categories (namely, external/internal causes, planned/unplanned, critical/non-critical) [23], but also excludes exceptional circumstances from performance figures of energy companies. In principle, the usage of forward-looking approaches for risk mitigation could improve the identification and management of risks associated with a changing climate for energy networks (as mentioned in the overview document, section 6.167) – in a similar way to the NARM framework for asset management. To achieve this, however, existing limitations in climate and energy models must be addressed so that risks associated with a changing climate can be sufficiently understood. Regional differences must also be considered, as in the NARM framework, so that sector-specific approaches can be coherently developed. That said, the development of forward-looking resilience metrics is more complicated than it sounds, for the complexity of this concept (see our answer to OVQ26 for more details).
* Introducing climate resilience working groups: Working groups are critical – and should link with academia to leverage extensive learning from CIGRE and IEEE that has already taken place in this area. Working groups should be comprised by different stakeholders in the energy sector and beyond, having strong cross-disciplinary and intersectoral contributions. This approach will ensure that different planning and operational aspects of the energy supply chain are taken into account for the selection of appropriate climate resilience enhancement measures (in line with the objectives described in the overview document, section 6.160).

**Resilience metric**

**OVQ26.** Do you agree with the proposals that we have set out around the resilience metric?

**Answer:** In terms. As is, the proposals around the resilience metric have potential to lead to a distorted resilience assessment process – and to a future energy system which is neither resilient nor reliable or secure. To prevent this from happening, the following aspects need to be fully addressed:

* Defining metrics and conditions of validity for a wide range of complex factors: Significant care should be taken if collapsing a wide variety of complex factors to a small number of metrics (perhaps even to a single metric). This will make the metric less meaningful. It also opens up opportunities to game the metrics in order to justify the investment decisions being proposed or to inflate (or deflate) the apparent resilience of a network operator. As stated in OVA23, “Defining metrics is the easy part of the problem. Defining the conditions over which the metrics are calculated is the important part of the problem to ensure consistent assessment across networks and across different climate risks. There are no standard methods for this at present.”
* Resilience attributes in a complex system: Robustness, resourcefulness, and recovery are the key attributes of a resilient system [24]. These attributes cover a wide range of design and operational aspects of power networks (i.e., hardening and operational measures), as well as different parts of the electricity supply chain (e.g., supply, demand, component reinforcement and repair, repair and restoration crews). This inner complexity of power systems requires the consideration of a wide range of options for resilience assessment and enhancement decisions. It is strongly recommended to keep separate aspects of resilience (for example, climate, workforce, cybersecurity etc.) separate when quantifying metrics.
* Resilience assessment in a complex climate change scenario: In terms of climate resilience, the high number of risks associated with a changing climate for energy networks requires a comprehensive assessment for the identification of appropriate mitigation measures. In this context, using a small number of metrics for resilience assessment and enhancement decisions to may lead to simplistic conclusions that will not contribute for climate-resilient energy networks. This shortcoming will be worsened even further if climate change risk mitigation priorities are defined at national level rather than at regional level.
* Resilience as a multidimensional concept: The inner complexity of power systems, the attributes of a resilient system, and the different risks for electricity networks at regional level clearly indicate that resilience is a multidimensional concept. Even if there is one common resilience objective amongst energy companies (including GD, GT, ET, and ED companies, as explained in point the overview document, section 6.173), there are several different aspects to be considered to fully represent a multidimensional concept such as resilience.
* Resilience assessment and coherence across regions: It is also important to consider that different locations are subject to different categories and levels of risk (including climate, workforce, cybersecurity etc.). To ensure a fair assessment of resilience across all companies, performance indicators should be based on mutual risks and/or on the extent of mitigation of different high and medium risks. In addition, defining a list of basic risks that must be addressed by all companies would improve identification, assessment, and mitigation of these risks across regions.

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