SIF Scenarios for Extreme Events - Alpha Phase

Stress Event Scenarios

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Project No.:	021700	**Compiled By:**	Daniel O'Brien
Document No.:	56732R	**Verified By:**	Megan Pearce
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Originating Office: FRAZER-NASH CONSULTANCY LIMITED
Hill Park South, KBR Campus, Springfield Drive, Leatherhead, Surrey, KT22 7LH
Tel: +44 (0)1306 885050

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1 Background

1.1 Project context

High-impact, low-probability "extreme events" pose significant threats to the Great British (GB) whole energy system. Whilst UK government and the regulator Ofgem currently carry out qualitative scenario planning assessments to understand the energy system resilience to extreme event shocks there does not currently exist a quantitative approach to understand the strengths, weaknesses, opportunities and threats for the whole GB energy system.

From July 2024, National Grid ESO will transition to National Energy System Operator (NESO), becoming wholly government-owned and independent from National Grid. A NESO licence condition will be to produce an Energy Resilience Assessment Report on regular intervals, that will be enhanced by data-driven, evidence based, and support the case for resilience investment [1]. The resilience modelling tool, developed by this Strategic Innovation Fund (SIF) project, aims to model risks associated with stress event scenarios and their effects on end consumers.

The system operator envisions using the resilience model to understand GB's whole system vulnerabilities to various events which may disrupt electricity and gas supply, assessing the effect on customers including critical services and vulnerable consumers, and considering dependencies with essential services beyond the energy system. A longer-term objective is to be able to integrate the role of hydrogen, as well other interdependent networks, in order to appraise future energy systems and their benefit to consumers and wider society.

Following a successful Discovery phase, this project, named Scenarios for Extreme Events (SfEE), is now within an Alpha phase, comprising five work packages:

- Work Package 1 involves designing the risk assessment framework.
- Work Package 2 determines the scenarios to be modelled. It will investigate a high wind speed weather scenario and gas supply loss non-weather scenario.
- Work Package 3 focuses on developing resilience metrics to gauge the severity of impacts, allowing scenarios to be compared.
- Work Package 4 focuses on the design and development of a resilience model capable of simulating the impacts of extreme events. This model aims to demonstrate the functionality of the selected modelling approach by calculating the impacts of example events. This will help to inform future resilience model design and planning decisions.
- Work Package 5 entails the cost-benefit analysis of the resilience model.

1.2 Project vision

The overall purpose of the Scenarios for Extreme Events SIF project is to model risks, associated with low probability events, and impacts this has for the end consumer. Critically, this project looks to translate impacts on the GB whole energy system, caused by extreme events, into societal disruption narratives that look at consumer-focused resilience i.e. disconnections to critical services and vulnerable consumers. This is an evolution of the traditional energy-focused metrics such as MW/hr losses or supply/demand ratios which the sector have previously used. Using relatable metrics is an important step to improve engagement with stakeholders, particularly when managing expectations of event resilience/response or discussing future investment with Ofgem and Government. Taking this approach across the GB system is a novel element to this project, setting it apart from other innovation projects we have engaged with.

1.3 Document map

This document sits within a set of deliverables from Alpha Phase which are mapped in the Resilience Metrics and Risk Framework [2] and summarised in Figure 1 below.

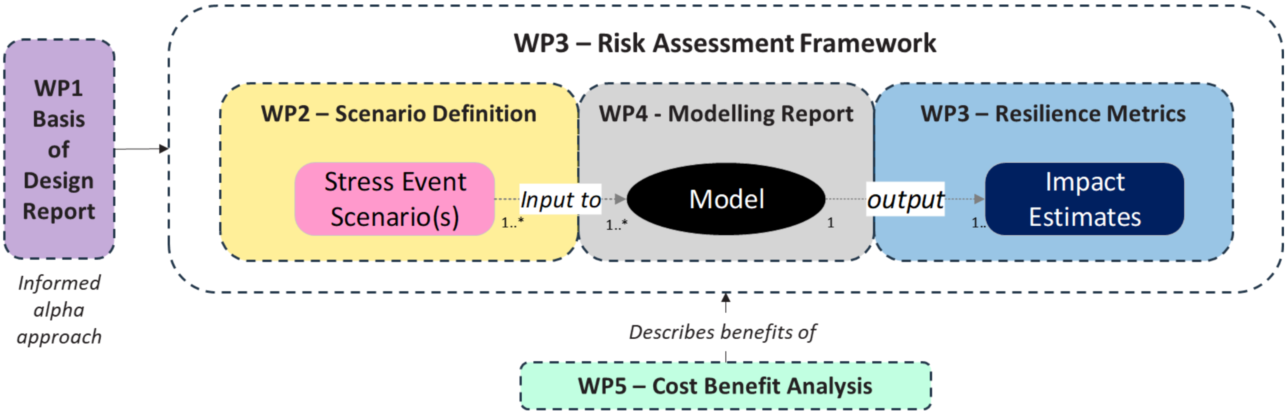

Figure 1 – Alpha Phase Document Map

Documented outputs from each of these work packages are referenced below:

- **WP1 - Basis of design report** – Provided within Ref [3].
- **WP2 – Scenario definition** – Provided within sections 3 & 4 of this report.
- **WP3 – Risk assessment framework** – Framework provided with section 2 of this report and with resilience metrics described within section 5.
- **WP4 – Modelling Report** - Provided within Ref [4].
- **WP5 – Cost benefit analysis** – Provided within Ref [5].

2 Risk assessment framework

To improve the resilience of GB whole energy system we need to quantify the risk to it. This section builds upon the Risk Assessment Framework described in Discovery Phase [6] by updating the development process, expanding the framework, and outlining a periodic risk assessment cycle for the GB energy network.

2.1 Development process

The five stages in the risk assessment development process are described in Table 1.

Table 1: Risk Assessment Development Process Overview

Number	Stage Name	Further Information
1	Define Risk	Refined in section 2.2.
2	Categorise Events and Identify Data Sources	Weather event categorisation is included in: • **Error! Reference source not found.** Weather Hazards to the GB whole energy system • **Error! Reference source not found.** Windstorm Archetypes for Scenarios • **Error! Reference source not found.** Scenarios Event Categorisation (hazards other than wind) Non-weather events: • Provided within section 3
3	Create Scenarios	The scenario development methodology is described in section 3. The stress events that were developed and used in the resilience model in Alpha Phase are described in section 4.
4	Create Resilience Model	A prototype resilience model has been developed in Alpha Phase. The modelling report [4] describes the: design process; model inputs, functionality, and outputs; network interdependencies; scenario analysis, and next steps beyond Alpha.
5	Quantify Impacts using Resilience Measures	The risk framework is outlined in this section, which describes how event likelihoods and impacts are calculated. This is followed by resilience metrics and their relation to impact quantification in section 5.

2.2 Risk definition

Risk assessment is typically defined as the product of the likelihood of an event and the impact it has. The impact to infrastructure also depends on the location (x) and time horizon (T), e.g. the next week, month, or year. This describes the potential for exposure to loss [7].

$$Risk = \sum_{x,T}^{n} Likelihood * Impact\ (x, T)$$

2.3 Framework overview

The Risk Assessment Framework enables the future system operator (FSO)to evaluate risks to the GB energy network. It consists of three main components:

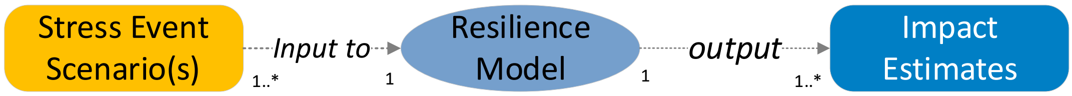

Figure 2: Simplified Risk Assessment Framework

As shown in Figure 2, one or more (1..*) stress event scenarios are defined and input into the resilience model, which estimates impacts to consumers and the network in terms of resilience metrics.

Each stress event scenario will have a likelihood of occurring, and the model will predict its impact. Likelihoods and impacts will be given scores from 1 to 5 for and tracked over time to inform annual risk assessments (see section 2.4).

2.3.1 Quantifying likelihoods

Future stress event scenario definitions will include quantification of their likelihood of occurrence. This will be inferred from the frequency of previous events and supported with rationale from scientific literature and expert engagement, following which a “Likelihood Score”, from 1 to 5, can be assigned.

2.3.2 Quantifying impacts

The resilience model can be used to represent configurations of the GB whole energy system. This includes the existing network configuration (such as HV cables, substations and above ground installations) as well as modified configurations to simulate increased resiliency. The resilience model takes inputs from the stress event scenario definitions, such as asset failures, energy generation and demand, and uses this to model energy flows around transmission and distribution networks for gas and electricity. The resilience model uses this to output estimates of impacts to consumers and the network.

The impacts to consumers and the network are quantified as “Resilience Metrics”, such as:

- Number and duration of consumer disconnections.
- Number and duration of vulnerable consumer disconnections.
- Number and duration of critical service disconnections.
- Energy Not Supplied (MWh)
- Value of Lost Load (£)
- Generation Margin (MW)

The output values of these resilience metrics can be grouped within set numerical thresholds that relate to a given “Impact Score”. For example, if the Generation Margin is greater than 0 MW, then the impact score is “Low”. Impact scores are on a 1 to 5 scale from lowest to highest. Further description and examples are provided in section 5.

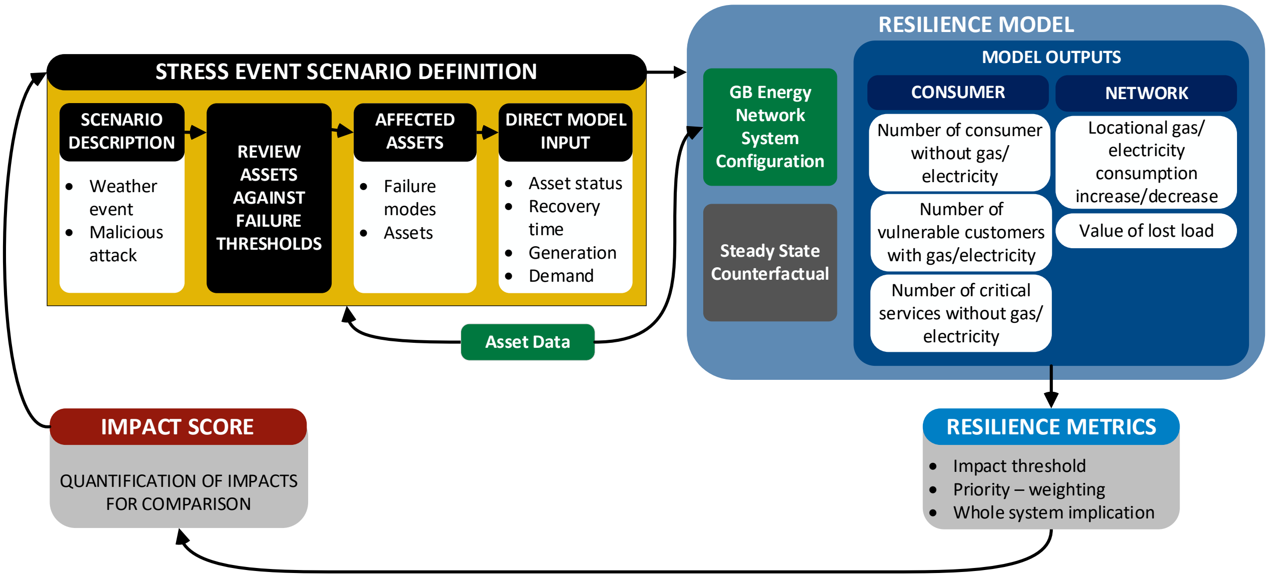

Figure 3: Risk Assessment Framework

2.4 Risk assessment cycle

As part of its new licence conditions, the end user will annually assess the risk to the GB whole energy system, to:

- Vulnerabilities of the GB whole energy system;
- Assess the likelihood and potential impact of risks; and
- Provide advice on mitigations that would limit and address the impact of risks.

The framework described in this section can be used to produce quantitative risk assessments. This is a key part of the annual Risk Assessment Cycle shown in Figure 4 and described in subsequent sections.

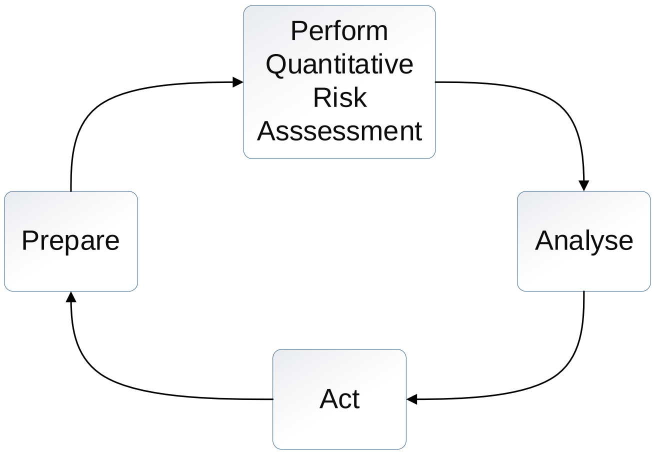

Figure 4: Risk Assessment Cycle

2.4.1 Prepare

Before performing each quantitative risk assessment, the following should be decided:

- Which configuration(s) of the GB energy network should be modelled?

- Which stress event scenarios are going to be used as inputs to the resilience model?

To inform this, a core resilience team will:

- Review latest risk & resilience literature (such as the UK National Risk Register [8])
- Consult with experts from across industry, such as network operators and academia.
- Assess the effectiveness of possible mitigations.

Scenarios, the resilience model, and resilience metrics should be refined as required and validated by subject matter experts to reflect best practice.

2.4.2 Perform quantitative risk assessment

The GB whole energy system resilience model will be run using agreed stress event scenarios and system configurations. Customer impacts will be estimated in terms of resilience metrics for each scenario, then compared against agreed thresholds to give an impact score. The likelihood of each stress event scenario can be combined with the impact score to give a baseline to enable comparisons.

The UK National Risk Register [8] presents the spectrum of risks to the UK on a 5x5 grid, with impact on the y-axis and likelihood on the x-axis (see Figure 5). Each individual risk has a description and a risk range plotted individually with its error bars (Figure 6). It is proposed that this format is used to present the likelihood of scenarios and the impact they are predicted to have to the GB energy network over the year.

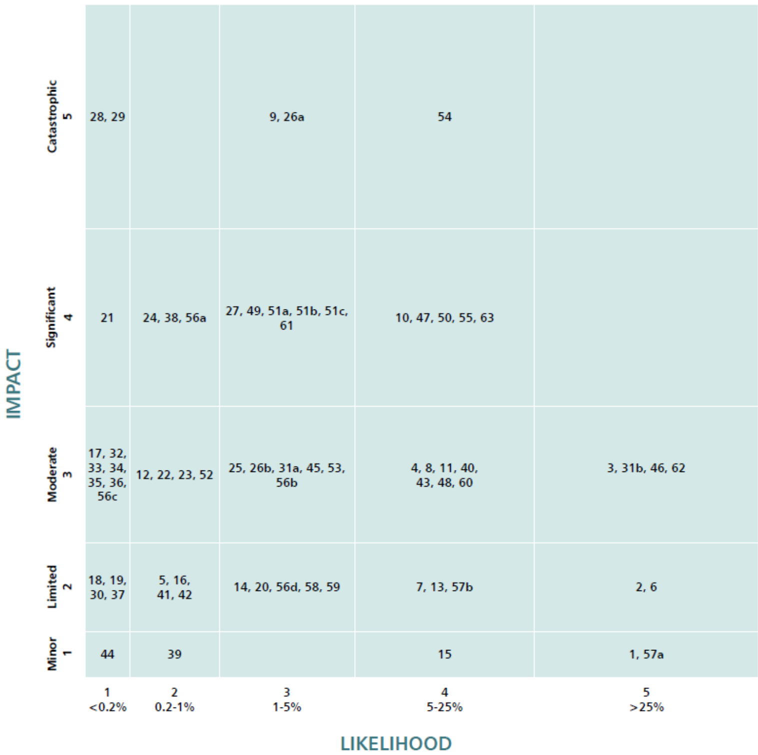

Figure 5: Suggested format for plotting all risks

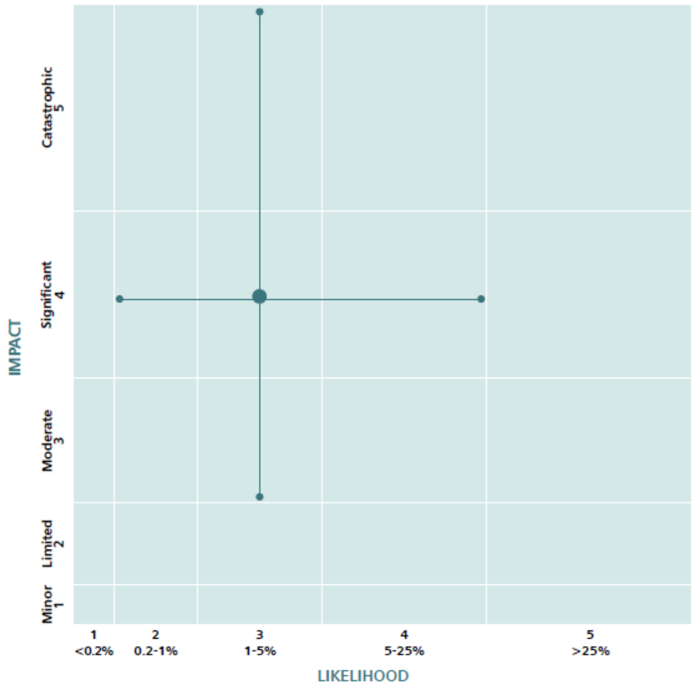

Figure 6: Suggested format for presenting individual risks.

The individual risk plot shown in Figure 6 could be for any stress event scenario, such as a heat wave. Error bars can be used to represent the range of potential likelihood of a given stress event scenario. Variations in the severity of a given scenario, e.g. an event occurring over a larger area or for a longer period, can be captured within the model input data and used to understand the range of impacts. Likelihood and impact ranges should be validated by subject matter experts.

For each risk assessment cycle, changes can be made to test different GB whole energy system configurations and stress event scenarios. Each scenario may have different likelihoods of occurrence, and changes to model inputs may result in different impact estimates that can be plotted and compared using a common format.

2.4.3 Analyse

The quantitative risk assessment will be assessed and used to enhance and prioritise the advice and resilience recommendations that will be provided to government within the produced energy resilience assessment report. This assessment will consider:

- Understanding GB whole energy system vulnerabilities.
- Identify key interdependencies between electricity, gas and other networks.
- Investigate the efficacy of existing and theoretical resilience interventions.
- Provide recommendations for risks to be considered within national risk register.
- Validation of outputs to ensure that all components of the risk framework are accurate and reliable.

Risk estimates should be validated to refine stress event scenario definitions, GB whole energy system configurations and the underlying resilience model. Impact estimations should be compared against past events, published journal papers and validated by subject matter experts.

2.4.4 Act

Between risk assessment cycles, the energy resilience assessment report will be collated. It will be reviewed by SME's before submitted to government along with prioritised recommendations for mitigations. Risks will be prioritised and the next set of risks for deep dive will be identified.

3 Scenario development methodology

3.1 Purpose of stress event scenarios

In the context of Alpha Phase, stress event scenarios have two purposes:

1. **To provide inputs to the Alpha phase model** that enable effective demonstration of its capabilities, including modelling of demand and capacity on electricity and gas networks within the area of interest, across both transmission and distribution. The ability of the model to capture cross-network effects is a key aspect of this, as it represents a proof-of-concept for a novel resilience modelling capability.

2. **To demonstrate the process of developing stress event scenarios**, as outlined in this document. In Beta Phase and beyond the scenarios required to capture a range of foreseeable events will be considerably more complex, so it is important that the process for scoping and defining those scenarios is both robust and produces outputs that are suitable to inform modelling.

To this end, while the stress event scenarios presented in this document are intended to convey some degree of realism and relationship to historical examples and possible future events, they are not considered predictions of actual likely occurrences. Rather, they have been chosen to demonstrate the Alpha Phase model's novel capability – while network operators can model the resilience of their own assets in detail, the focus of this project was to demonstrate the potential value of capturing cross-network effects.

3.2 Component events

As the primary 'building blocks' of stress event scenarios, it was recognised that creating a consistent set of component events would support scenario development by providing defined options that could be incorporated into scenarios, either alone or in combination with others. As in Discovery Phase, the UK National Risk Register was the primary reference for event definitions. An updated version of the national risk register [8], published in August 2023, identifies sixty-three risk categories, and has been used as the primary reference in Alpha.

To determine whether risks in the National Risk Register were relevant to this project, a down-selection process was undertaken to filter out events with no reasonably foreseeable impacts on the GB energy system. For a risk to be considered as relevant, it's resultant impact would need to cause:

- **Physical damage** (mechanical, thermal, chemical or radiological impacts on a system or component that compromise its ability to perform its intended function), *e.g. fire damage, flood damage.*
- **Incompatible environmental conditions** (local atmospheric conditions which negatively affect or completely preclude the operation of a system or component without necessarily damaging it), *e.g. heatwave, cold snap, storm (high winds).*
- **Disruption to access or control** (impacts which prevent physical and/or remote access to a system or component by people or systems required for its operation), *e.g. terrorist attack on transport, cyber-attack.*
- **Disruption to key inputs** (impacts which prevent or inhibit required inputs from reaching the system or component), *e.g. failure of electricity or gas supply.*
- **Disruption to Suitably Qualified and Experienced Personnel (SQEP) availability** (impacts which limit the availability of people required to operate the system or component)*, e.g. industrial action, pandemic.*

Risks were then grouped into thirteen event types as illustrated in Figure 7. A given event type can be caused by multiple risks and these risks have been mapped from the UK National Risk Register (risk identifier displayed in brackets). These risks were then grouped into three event categories that share similar characteristics to assist in the framing and definition of scenarios.

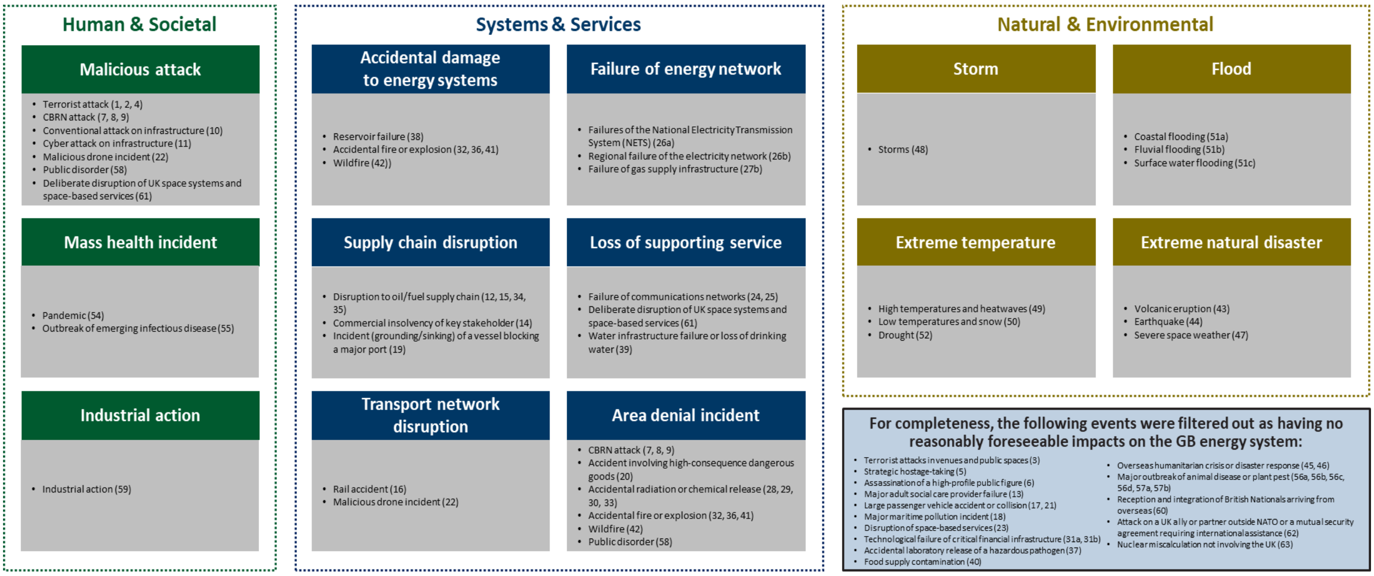

Figure 7: Consolidated component event types within three event categories.

For natural & environmental events such as storms, research from Met Office was incorporated into scenario definitions to augment the basic definition provided by the UK National Risk Register and enable linking to a range of historical event data (see Annex C).

3.3 Scenario blueprint

To ensure scenarios were defined consistently and captured all required parameters for modelling, a generic format for building stress event scenarios was developed. This blueprint (Figure 8) comprised four main components, intended to be defined from top-to-bottom covering increasing levels of detail from a high-level concept down to specific model inputs.

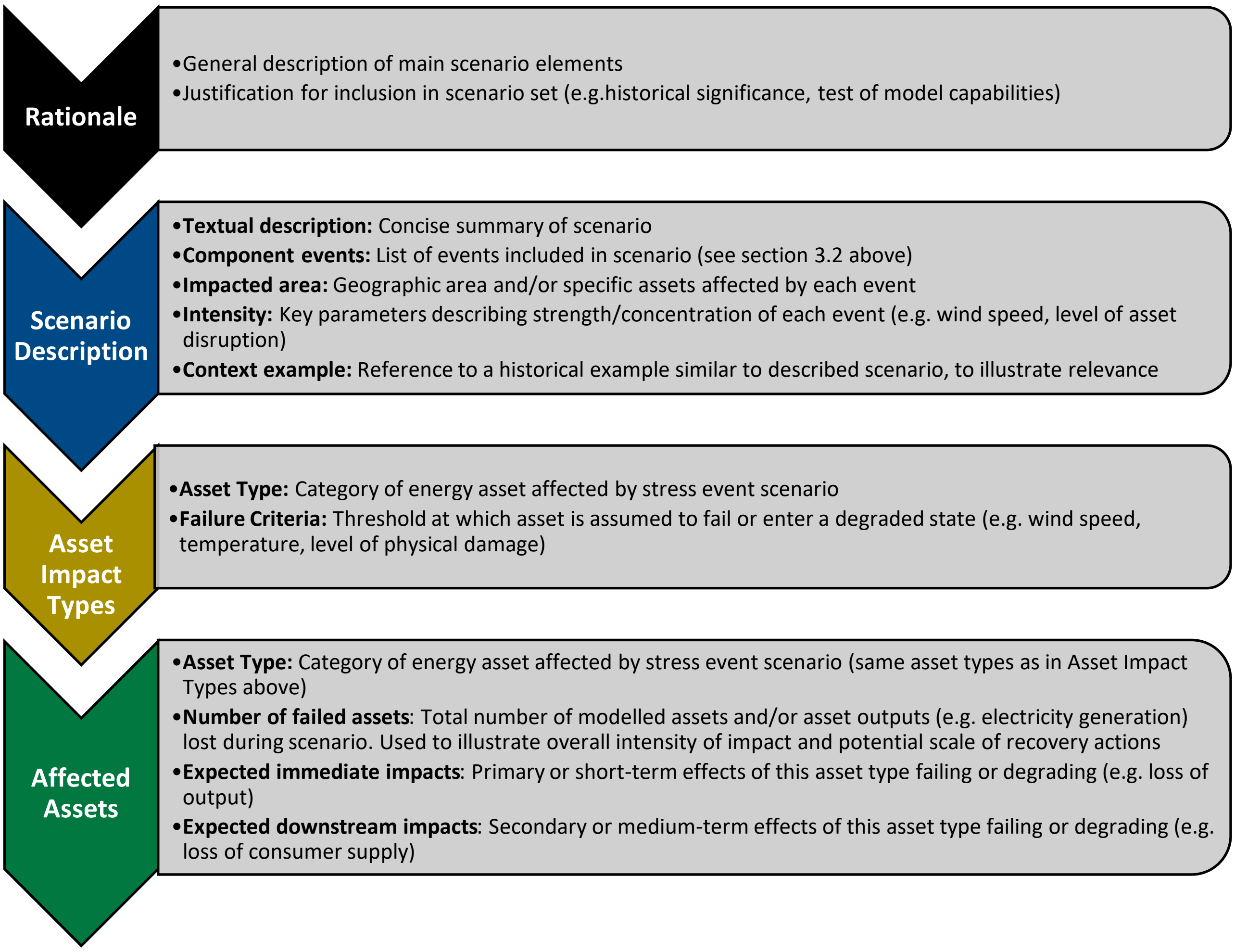

Figure 8: Scenario blueprint.

Three scenarios were prepared for Alpha Phase and used to demonstrate the prototype model:

- **Weather scenario** – high wind speeds (See section 4.1)
- **Non-weather scenario 1** – Northern transmission line outage (See section 4.2)
- **Non-weather scenario 2** – St. Fergus gas terminal supply loss (See section 4.3)

3.4 Aspirations for Beta phase

Using the experience gained and lessons learned from Alpha Phase, the project team plan to significantly advance our extreme events modelling capability in a Beta Phase project. This will include expansion of the scenario development process outlined here, such that the stress event scenarios used by the Beta Phase model capture a wider range of possible events, cover effects on Inter-dependent networks beyond electricity and gas, such as water and telecoms, and provide greater flexibility in how scenarios are built, tested, and validated. The key objectives of this work will be:

1. **The ability to model more complex scenarios**, including those that interact with other networks (e.g. water, telecommunications, transportation), and the ability to model a scenario against different baseline network states (e.g. higher energy demand in winter).
2. **Improved visualisation of scenario impacts**, such as graphical representations of how resilience metrics (e.g. number of customers disconnected) evolve over a range of time projections.

3. **A more advanced scenario-building process**, including the ability to adjust scenario inputs by changing location, intensity and timescales, or to define from scratch by manually selecting key parameters and leveraging more data on historical events (e.g. storms, floods, terrorist attacks) to inform and establish archetypical events (e.g. a generic “100-year storm”).

4 Stress event scenarios

This section describes the set of scenarios, defined during Alpha Phase as inputs to the model. Details of the implementation of these scenarios in a modelling context, as well as the outputs and conclusions arising from them, are discussed in the Alpha Phase Modelling Report [4].

4.1 Weather scenario – high wind speeds

4.1.1 Rationale

A scenario involving high winds was selected to demonstrate direct impacts of extreme weather events on the electricity network, such as mechanical damage to a range of asset types, primarily overhead electricity transmission and distribution lines. Annex A provides an overview of consider weather hazards that pose the greatest risk to the GB energy network. An evaluation of windstorm archetypes is provided within Annex B.

The effect high wind has on electricity generation is also recognised within this scenario, due to the limits of wind speed in which wind turbines can safely operate. A number of high-quality datasets were available to build an understanding of wind speeds across the entire area of interest.

For this scenario the wind speeds were based on the maximum gust speeds of Storm Arwen, which was the most severe in the datasets available in terms of the overall average maximum gust speed across Scotland. These data match with the Northerly windstorm archetype discussed in **Error! Reference source not found.**B

4.1.2 Scenario description

Title	Textual Description	Component Event	Impacted Area	Intensity	Context Example
High wind speeds	A major storm with exceptionally high wind speeds concentrated on north-east Scotland	Storms	Entire area of interest, with highest speeds in north-east region – particularly Aberdeenshire, Angus and Moray.	Maximum gust speeds ranging from 23.9 – 37.6 m/s (53.5 – 84.1 mph) • Strichen, Aberdeenshire: 37.6 m/s (84.1 mph) • Banchory, Aberdeenshire: 37.3 m/s (83.5 mph) • Bridge of Dun, Angus: 35.9 m/s (80.4 mph)	Storm Arwen, Nov 2021

4.1.3 Asset impact types

Asset type	Failure Criteria (for model sensitivity testing only – not indicative of real asset thresholds)
Overhead electricity transmission line	Max. gust speed >= 35 m/s (78.3 mph)
Electricity distribution line	Max. gust speed >= 35 m/s (78.3 mph)
Electricity generation (wind)	Max. gust speed >= 25 m/s (55.9 mph)

4.1.4 Affected assets

Asset Type	Number of Failed Assets	Failure Mode	Expected Immediate Impacts	Expected Downstream Impacts
Overhead electricity transmission line	~10+	Mechanical damage (e.g. via tree impact)	Reduction in transmission network redundancy/ resilience	Increased vulnerability to further failures
Electricity generation (wind)	2.8 GW equivalent	Deliberate shutdown (to prevent damage)	Reduction in available electricity generation capacity	Increased electricity prices, increased reliance on gas for energy

+ Note, number of failed assets based on wind speed exceeding a failure threshold. Within the modelling report [3], details are provided of both a moderately severe scenario, where wind speeds above 40 m/s result in asset failure, and an extremely severe scenario, where wind speeds above 35 m/s result in asset failure.

4.2 Non-weather scenario 1 – Northern transmission line outage

4.2.1 Rationale

A scenario involving failure of gas supply to consumers was chosen to investigate the cross-network effects of unmet demand, particularly on the electricity distribution network where a rapid demand shift from gas to electricity is a known risk that has been realised in this past. For example, in Falkirk in 2019 a governor failure resulted in loss of gas supply to a large number of domestic consumers. This resulted in increased demand on the electricity distribution network as those consumers switched from gas to electric appliances for their heating and cooking needs.

SGN operate a high-pressure pipeline, the Northern Transmission line, which transports natural gas from the National Transmission System (NTS) compressor station in Aberdeen to locations beyond the city of Inverness, some of the most remote regions at the extremities of the gas system. Scenario 1 models an unplanned outage at the Aberdeen compressor station, due to component failure or damage to the Local Transmission System (LTS) pipeline itself, preventing transmission along the LTS Northern Transmission line.

4.2.2 Scenario description

Title	Textual Description	Component Event	Impacted Area	Intensity	Context Example
Northern transmission line outage	Failure of gas supply from Aberdeen compressor station, caused by spontaneous equipment failure.	Failure of gas supply infrastructure	Aberdeen compressor station only	Total loss of supply	Falkirk gas outage, 2019

4.2.3 Asset impact types

Asset type	Failure Criteria

Gas compressor station	Spontaneous equipment failure

4.2.4 Affected assets

Asset Type	Number of Failed Assets	Failure Mode	Expected Immediate Impacts	Expected Downstream Impacts
Gas Compressor Station	1	Spontaneous equipment failure	Loss of flow and pressure through Northern Transmission Line	Loss of supply to customers, increased demand on electricity for energy

4.3 Non-weather scenario 2 – St Fergus gas terminal supply loss

4.3.1 Rationale

A second gas-related scenario was devised to test more extreme impacts on the gas network and enable demonstration of cross-network impacts. In this scenario the assets chosen were the two main input pipelines (Line 1 and Line 2) to the St. Fergus gas terminal near Peterhead, which would result in a loss of gas supply from that terminal to NTS. St Fergus gas terminal is one of the largest entry points on the NTS, with natural gas conventionally being transported south. This scenario assumes an extremely unlikely event of a complete gas supply outage from St Fergus during peak winter demand, and consequent compressor configuration preventing gas from reaching offtakes between St Fergus and the Aberdeen compressor station.

4.3.2 Scenario description

Title	Textual Description	Component Event	Impacted Area	Intensity	Context Example
Gas supply failure	Failure of gas supply from North Sea platforms to the St. Fergus gas terminal.	Failure of gas supply infrastructure	St. Fergus gas input supply only	Total loss of supply on Line 1 and Line 2	Vesterled pipeline outage, Aug 2013 – loss of power at Heimdal Riser resulted in platform being shut down, and flow through Vesterled to St. Fergus dropping to zero.

4.3.3 Asset impact types

Asset type	Failure Criteria
Gas Terminal	Loss of input supply

4.3.4 Affected assets

Asset Type	Number of Failed Assets	Failure Mode	Expected Immediate Impacts	Expected Downstream Impacts

Gas Terminal	1	Loss of supply	Loss of flow and pressure through NTS	Potential loss of supply to customers, increased demand on electricity for energy

5 Resilience metrics

5.1 Resilience metrics definition

Resilience metrics are a set of potential impacts to consumers of the GB whole energy system, such as the number of consumers without gas supply for a given duration. These are the result of the network being subject to one or more stress event scenarios, leading to assets failing and issues that propagate through the transmission and distribution networks including cross sector propagation.

5.2 Relating resilience metrics to impacts

There are numerous resilience metrics that describe impacts to consumers or the GB whole energy system. Each individual resilience metric will have five numerical thresholds which represent its impact on a scale from 1 to 5 – insignificant to high. We are interested in the impact score for each metric and across all metrics.

5.2.1 Single resilience metric - Impact score

Error! Reference source not found. presents an example of corresponding impact scores (shown in brackets) for the "generation margin" resilience metric. Generation margin is the difference between the available electricity generation capacity and the maximum expected level of demand on the grid. This example shows that if the generation margin is more than 0 MW and less than 1000 MW it defined as having an insignificant impact, and an associated impact score of one. Other impact scores are shown with associated ranges of generation margins.

Note: further thresholds will be decided for impact scores of 2 and 4 in future stages.

5.2.2 All resilience metrics - Impact score

For each impact score there are numerous resilience metric thresholds that map to it. For example, if either of the following are true, this is defined as a high impact to the GB energy network:

- Generation Margin is less than -500 MW.
- Energy Not Supplied (ENS) is greater than 578 MWh per annum.

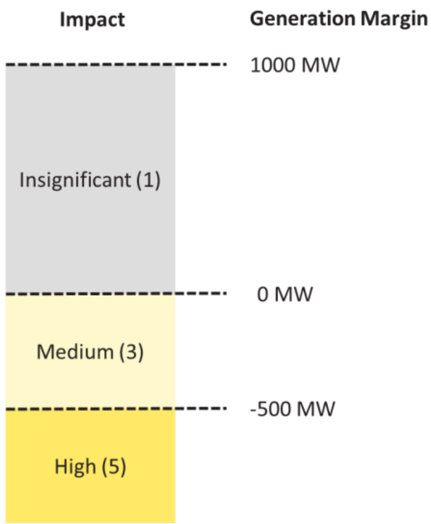

Figure 9: Generation margin resilience metric with associated impact scores.

There is a matrix of resilience metrics that correspond to a given impact score. The highest impact score for any given scenario is taken as the impact score.

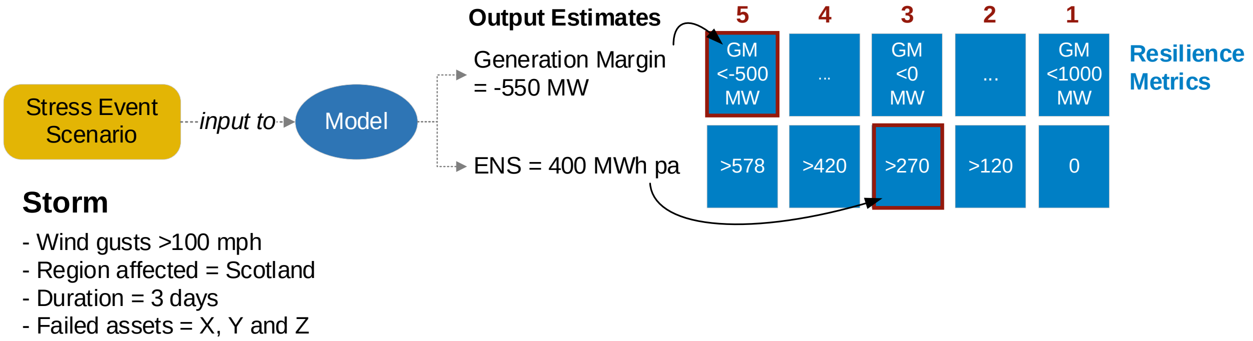

Figure 10: Simplified example of resilience metric scoring and how these translate to impact scores..

A simplified example is presented in Figure 10, which illustrates an extreme storm stress event scenario being input into the resilience model. For this scenario, the model outputs the following estimates:

- a generation margin of -550 MW, and
- an Energy Not Supplied (ENS) of 400 MW per annum (pa).

In this example, a generation margin of -550 MW would score “5”, and an ENS of 400MWh would score “3”. Since the worst-case impact score is “5”, for the generation margin, this would be taken as the impact score.

5.3 Agreed resilience metrics

A set of resilience metrics has been agreed and prioritised with the end user for both electricity and gas as shown in Table 2 and Table 3.

Table 2: Electricity resilience metrics

Resilience Metric	Priority	Stage to Implement
Number and length of consumer disconnections	1	Alpha
Total Energy Not Supplied (MWh pa)	1	Alpha
Number and length of vulnerable consumer disconnections	2	Alpha
Value of lost load	2	Alpha
Generation margin (MW)	2	Beta
Number and length of critical service disconnections	2	Beta

Table 3: Gas Resilience Metrics

Resilience Metric	Priority	Stage to Implement
Number and length of consumer disconnections	1	Alpha
Total Energy Not Supplied (MWh pa)	1	Alpha
Number and length of vulnerable consumer disconnections	2	Alpha

We have agreed the impact score thresholds for the length and duration of electricity disconnections, energy not supplied and Generation Margin. These metrics will be reviewed and revised as appropriated within Beta phase. Some of these details are not public knowledge, therefore access to this presentation may be provided on request. Further details on specific resilience metrics and engagements with the TNOs and DNOs are included in the Resilience Metrics and Risk Framework presentation [9].

5.4 Future work

We have inferred resilience metrics for the GB energy network listed below from stakeholder workshops with SSEN and Cadent Gas, however, these are preliminary and need to be confirmed in future phases:

- Energy Not Supplied
- Number of Gas Consumers Off Supply

Specific impact score thresholds need to be agreed for the remaining resilience metrics that are not elucidated in the Resilience metrics and Risk framework presentation [9].

6 References and glossary

6.1 References

[1] Ofgem, "Independent System Operator and Planner Electricity System Operator Licence Conditions," 2023.

[2] Frazer-Nash Consultancy , "021700-142266V Scenarios for Extreme Events - Alpha phase Resilience Metrics and Risk Framework".

[3] Frazer-Nash, "021700-140634V Scenarios of Extreme Events - Basis of Design Report".

[4] Frazer-Nash Consultancy, "021700-56848R - Scenarios for Extreme Events - Alpha phase modelling report".

[5] Frazer-Nash Consultancy , "021700-56866R - Scenarios for Extreme Events - WP Benefits analysis report".

[6] Frazer-Nash Consultancy , "Sceanrios for Extreme Events, Discovery Phase, Risk Assessment Framework and Literature Review Summary".

[7] Business Continuity Institute, "Disaster Recovery Journal".

[8] HM Government, "UK National Risk Register 2023".

[9] 021700-142266V, *Scenario for Extreme Events - Alpha Phase - Resilience Metrics and Risk Framework presentation.*

6.2 Glossary

6.2.1 Key terms

Term	Meaning
Critical services	Critical services have been defined for this project as [essential services] which could experience high levels of disruption during a short-term power disruption and which other [essential services] have a 'high' dependency on. α model will limit critical service consideration to hospitals only as these are one of the essential services that meet this category and have easily accessible geographic data.
Electricity distribution	Electricity distribution is the process of delivering electricity from the transmission system to individual consumers. It involves reducing the high voltage from the transmission grids to a lower voltage suitable for use by organizations and individuals. This is achieved through a network of substations, transformers, and distribution lines. The voltage is further reduced near the customer's premises for safe use in lighting, industrial equipment, and household appliances. Distribution Network Operators (DNOs) in Great Britain are: - Electricity North West - Northern Powergrid - Scottish & Southern Energy Networks - SP Energy Networks - UK Power Networks - Western Power Distribution
Electricity transmission	A high-voltage electric power transmission network that serves the majority of Great Britain and some of the surrounding islands. It ensures that electricity generated anywhere on the grid can be used to satisfy demand elsewhere. It is owned and operated by National Grid plc in England and Wales. In Scotland, the grid is owned by ScottishPower Transmission in the south, and by SSEN in the north. Infrastructure connecting offshore wind farms to the grid is owned by offshore transmission owners. The transmission network consists of 400 kV, 275 kV, and a few 220 kV power lines, and their associated substations. It is a wide area synchronous grid operating at 50 hertz. There are undersea interconnectors to the Isle of Man, Northern Ireland, the Republic of Ireland, France, Belgium, the Netherlands, and Norway.
Essential services	Essential services are those that the public rely on a daily, or near daily, basis.
Event category	High-level grouping of event types within the following three categories with common attributes: • Human & Societal • Systems & Services • Natural & Environmental

Term	Meaning
Event type	A defined list of thirteen distinct events with mapped risks from the national risk register which have been identified as potential causes.
Gas distribution	In Great Britain, gas is distributed to consumers from [gas transmission] through Gas Distribution Networks (GDNs). There are 8 GDNs, which are managed by 4 companies. The GDNs in the UK are: East of England, North London, North West, West Midlands, Northern Scotland, Southern, Wales and West. These GDNs are managed by: Cadent Gas Ltd, Northern Gas Networks Ltd, SGN, Wales and West Utilities Limited.
Gas transmission	In Great Britain, the gas transmission system is owned and operated by National Gas Transmission. They are responsible for the National Transmission System (NTS), which comprises approximately 7,630 kilometers (4,760 miles) of high-pressure pipe and more than 500 Above-Ground Installations (AGIs).
GB whole energy system	The Great Britain (GB) energy system is a system that includes the electricity and gas networks, ensuring the generation, transmission, and distribution of energy across the country. Both networks are regulated by Ofgem, the government regulator for gas and electricity markets in Great Britain. The electricity network, or National Grid, is a high-voltage electric power transmission network serving the majority of Great Britain, connecting power stations and major substations. The gas network includes the National Transmission System for high-pressure gas transmission and regional Gas Distribution Networks that deliver gas to end users.
Impact estimates	[Model] outputs that represent impacts to electricity or gas customers, critical services or vulnerable consumers due to a [stress event scenario]. These can be compared to [resilience metrics] thresholds to give impact scores in the [risk framework].
Resilience model	The extreme events model which generates [impact estimates] to consumers based on defined [stress event scenarios].
Network operators	All of the network operators in Great Britain for [Electricity Transmission], [Electricity Distribution], [Gas Transmission] and [Gas Distribution].
Resilience metrics	Descriptions of impacts to end-users of the [GB Energy Network] with associated numerical thresholds for [impact estimates] on a scale of 1 to 5 (insignificant to high).

Term	Meaning
Risk	Product of the likelihood of an event and the impact it has: Risk = Likelihood x Impact. This describes the potential for exposure to loss, where: • Likelihood is the probability of an event happening and • Impact considers both the duration (timeframe) of an impact and location (geographical area) that is affected.
Risk estimate	Product of the likelihood of the [stress event scenario] and the impact score the [model] estimates: Estimated Risk = Likelihood x Impact Score
Risk framework	The methodology to quantify risk to the GB energy network, using [stress event scenarios] input to the [model] to generate [impact estimates].
Stress event scenario	Definition of an event (linked to the UK National Risk Register) that could strain the GB energy network and lead to negative operational impacts.
Total risk	Total Risk is defined as the sum of risks to Infrastructure, in a specific location (x), over a defined time period (T).
α Modelled Area	A region in northern Scotland used as a test bed for prototype model development in alpha phase. This includes [electricity transmission], [electricity distribution], [gas transmission] and [gas distribution], and excludes substations: Inverarnan, Cruachan, Dalmally.

6.2.2 Acronyms and Abbreviations

Abbreviation	Meaning
CI	Critical Infrastructure
DNO	Distribution Network Operator
ENS	Energy Not Supplied
ESO	Electricity System Operator
GB	Great Britain
NESO	National Energy System Operator
MWh	Megawatt-hour

Abbreviation	Meaning
pa	Per annum
SSEN	Scottish and Southern Electricity Networks
TNO	Transmission Network Operator

FRAZER-NASH CONSULTANCY
A KBR COMPANY

180 West George Street
Glasgow
G2 2NR

Tel: +44 (0)141 3415400

fnc.co.uk

Offices at:
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