Project NIMBUS

Network Innovation and Meteorology to Build for Sustainability

Discovery phase

Technical report and recommendations

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Executive Summary

NIMBUS, a partnership with SSEN Transmission, SSEN Distribution and Icebreaker One is an ambitious project with the potential to accelerate the transition to net zero by prolonging the life of assets, improving their reliability and management through the introduction of new, granular data sources and improvements to network asset design, investment and operations.

Thorough analysis of sector needs for improved network asset methodologies for the design, maintenance and decision-making of electricity assets, NIMBUS has developed a business-driven use case to be demonstrated in Alpha, delivered the objectives of our Discovery proposal and met the SIF Innovation challenge aims.

Icebreaker One has undertaken an analysis of sector and user needs for improved asset risk methodologies for the design, maintenance and decision-making of electricity network assets to develop a business-driven use case to be demonstrated in the Alpha, next phase of NIMBUS.

Weather conditions are known to accelerate the wear-and-tear on assets but little research has been done to understand how this can be quantified. The primary use case seeks to explore and quantify this by using data about the weather experienced by the asset with the asset's service history to identify key weather factors that should be considered in Probability of Failure calculations within the industry-adopted methodologies.

Key benefits include:

- **Economic**: The business-driven use case developed in NIMBUS discovery will reduce the costs of penalty due to network downtime, improve grid connectivity and avoid high-risk/urgent repair operations for the Transmission Network Operators and Distribution Network Operators subject to regulatory requirements of keeping the network running and delivering power to the end customer. The ability to forecast asset degradation more accurately enables a risk-based approach to condition assessment that has the potential to reduce assessment frequency (and therefore cost of assessment) for low-risk assets.

- **Resilience**: The use case will enable better asset resilience by improving the accuracy of grid-wide risk scoring within the asset risk models and methodologies used within the UK energy systems.
- **Environmental**: NIMBUS is designed to be an ambitious project with the potential to accelerate the transition to net zero by prolonging the life of assets by understanding their degradation better, improving their reliability and management through the introduction of new, granular data sources and consequently improving network asset design, investment and operations.

NIMBUS has far-reaching impacts and applicability across the sector with its intentionally narrow scope to ensure achievability. The principles, methodologies, and tools developed and tested will produce guidelines for how the sector can reuse this analysis and enable these processes and analyses to be retooled for different assets.

Introduction

The Discovery phase was split into four work packages (WPs):

1. **WP1: Project Management (SSE)**
2. **WP2: Critical use cases (Icebreaker One):** An innovative, problem-solving methodology was applied to shortlist from 38 problem statements, to 3, to reach a single business-driven use case that was directly testable within SSE, and had applicability across the energy sector.
3. **WP3: Understanding Data Requirements, Interoperability and Policy (Icebreaker One):** Research to identify data sources and dataset as well as determine the availability, accessibility and other systems barriers involved in integrating meteorological data into current network risk and management models and activities.
4. **WP4: Clear cost-benefit analysis (SSE):** A cost-benefit analysis to ensure that the priority use case addressed business needs and had appropriate consumer benefits

This report focuses on the two work packages led by Icebreaker One. WP2: Critical Use Cases which focused on uncovering user needs and challenges, and WP3: Understanding Data Requirements, Interoperability and Policy which involved identifying data, methodologies, technology, policy and systems to enable the use case.

WP2: Critical Use Cases: Through stakeholder engagement, we identified material challenges faced by energy sector stakeholders in understanding the climate-related risks and considerations on assets. We considered user, market and societal needs, policy and regulatory issues, and operational and technical capabilities through desk research and extensive stakeholder interviews as well as use case and data discovery workshops.

Focused on the user needs from a Transmission and Distribution Network Operator's perspective, we undertook a series of discovery interview calls and desk research to identify the focus of the priority use case, paying particular attention to the specific challenges and potential benefits for using meteorological data in asset risk and asset management for the Transmission and Distribution Network Operators.

Starting from a long list of potential use case ideas, Icebreaker One led a series of prioritisation exercises to arrive at a final use case to take forward in the Alpha phase. This use case involves modelling the effect of weather-related degradation to the

Probability of Failure (PoF) for transmission line infrastructure assets such as towers, fittings and power lines.

WP3: Understanding Data Requirements, Interoperability and Policy: Using common industry asset risk modelling frameworks, historic data and asset level data as a starting point, Icebreaker One analysed relevant data and research landscapes, standard industry practices, user functions, systems and procedures to gain a thorough understanding of the challenges and opportunities for meteorological data to be integrated into the asset management and risk modelling of the UK's energy infrastructure assets.

We then undertook research to identify data sources and datasets as well as determined the availability, accessibility and other systems barriers involved in integrating meteorological data into current network risk models and management.

This report lays out the stakeholders engaged, the methodologies used, the research conducted and the analysis performed in the discovery phase of NIMBUS. It also presents our recommendations and further development required for the alpha phase to perform the use case, directions of further development, project transferability and conclusions reached throughout NIMBUS to date. Finally, we have summarised the lessons learned and constraints faced during the 9-week discovery phase.

Work Package 2: Critical Use Cases

Approach and Innovation

This section outlines the research and innovation framing the delivery of Work Package 2 (WP2). The work package includes the research methodology for the initial identification of a long-list of use cases; outlining the methodology for collaboratively identifying a priority use case; and presenting the granular details of the context, problem statement, user needs and primary stakeholders involved in the use case. This process prioritised user needs throughout the delivery of the work package through extensive consultation mechanisms.

Critical Use Cases Summary

Through desk research, workshops and stakeholder interviews, Icebreaker One led the identification of a collaboratively agreed priority use case. The purpose of identifying a primary use case was to ensure NIMBUS is based on specific, well understood problems faced by the energy sector,which if solved, could lead to achieving net-zero. A prioritised use case allowed Icebreaker One to research to then identify what data and other solutions were needed to solve those challenges. The primary use case taken forward involves modelling the effect of weather-related degradation to the Probability of Failure (PoF) for transmission line infrastructure assets such as towers, fittings and power lines.

The methodology taken was to:

1. Identify a long list of potential use cases through desk research, literature review, direct stakeholder contributions (written), and interviews with SSEN, Met Office and other relevant stakeholders from the wider industry.
2. Identify and explore the resulting key problem statements and how meteorological data could be used to solve these, with potential benefits and challenges also identified. Taking this approach ensured user needs were explored from a number of perspectives and roles, leading to a robust and diverse long list.
3. Choose a final priority use case through stakeholder engagement to complete WP3 (detailed later).

We received feedback from key stakeholders that the breadth and detail of this document adds value to the project both for participating stakeholders and the wider industry.

Centering research around Open Engagement and user needs

The lead project partner for Project NIMBUS is SSEN Transmission, the Transmission Network Operator arm of the SSE plc business, one of the three main Transmission Network Operators licensed by Ofgem within Great Britain covering northern Scotland.

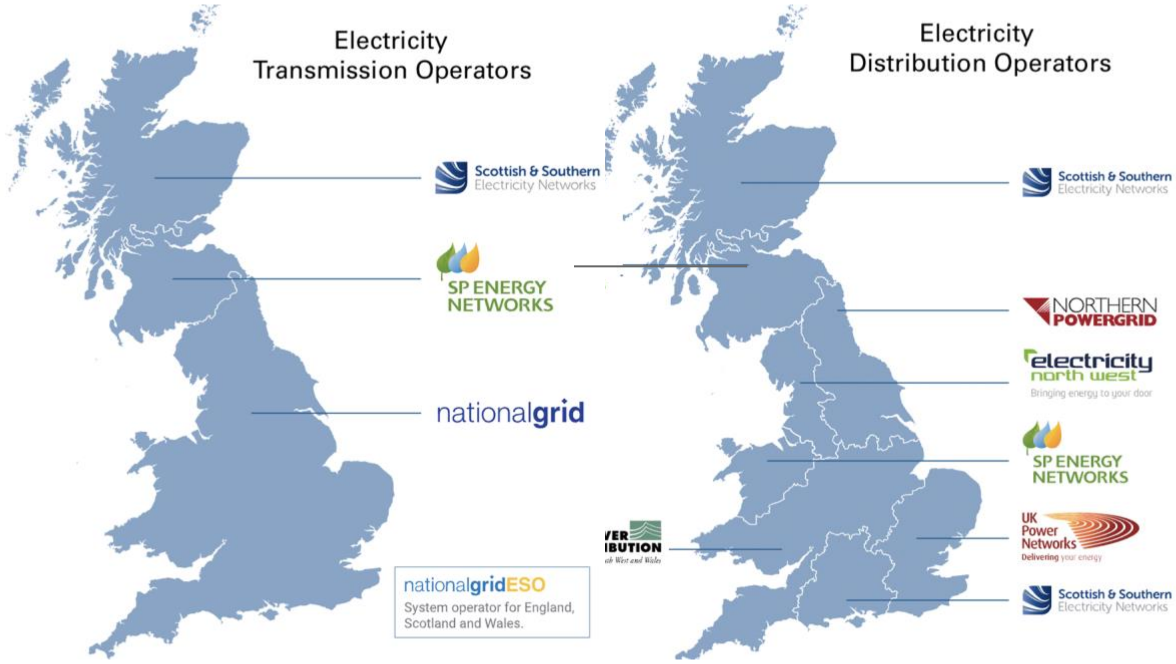


Figure 1: Transmission and Distribution Network Operators across Great Britain and their respective geographies, adapted from the visualisation tool available from the ENA's information portal.

NIMBUS has also drawn knowledge from and interviewed the asset management team from SSEN Distribution (the Distribution Network Operator business of SSE Plc), to understand the potential applicability of the programme to distribution network assets, both operationally and from a risk management point-of-view. While the focus of the use case is on high-voltage transmission lines connecting energy generation to substations and distribution lines, a goal of NIMBUS is to explore its relevance to other transmission and distribution operators to help meet their asset resilience objectives.

Icebreaker One had discovery calls with Distribution Network Operators such as UK Power Networks (UKPN) and Scottish Power Energy Networks (SPEN Distribution) to explore how DNOs are currently considering climate and meteorological effects on their assets' resilience.

The Met Office was also involved in NIMBUS as the United Kingdom's national weather service and executive agency of the Department for Business, Energy and Industrial Strategy. With an established business relationship with SSEN, the Met Office provided knowledge and industry expertise from its experiences providing weather and climate-related services to the Armed Forces, government departments, the public, civil aviation, shipping, industry, agriculture and other commercial sectors. As part of the NIMBUS programme, the Met Office provided meteorological and weather service expertise and weather data recommendations for the research and development of NIMBUS.

Icebreaker One further consulted with EA Technologies, whose software runs the standard risk models used in all risk reporting by UK energy transmission and distribution companies, and with DTN (formerly MeteoGroup), a leading weather data provider already engaged by several UK utilities companies.

Finally, Icebreaker One interviewed academic partners and technology providers to learn more about how weather data is used in a variety of contexts related to physical infrastructure.

Research methodology for identifying the primary use case

The first stage of work produced a long-list of thirty-eight potential use cases addressing challenges faced by energy transmission and distribution networks. These were accompanied by a first-pass analysis of the weather factors that may affect the assets.

Desk research, a deliberative workshop with key stakeholders (SSEN Transmission, SSEN Distribution, and the Met Office), and application of Icebreaker One's criteria for use case prioritisation were used to inform the identification of a priority use case during WP2. These methods continue a focus on user needs by inviting participation from a diverse and balanced range of stakeholders.

During a workshop held on 17 March 2022, SSE participants voted on a long list of thirty-eight potential use cases in order to narrow these down to a top ten "shortlist". Subsequently, Icebreaker One held a vote, through five rounds of elimination, to calculate the top three use cases to take forward.

The three finalist use case ideas that came out of the workshop were:

1. Historical accident data to identify "high risk/high incident" parts of the system that need investment.
2. Model weather-related degradation to Probability of Failure for assets connecting large volumes of generation to the grid.
3. Predictive hazard identification for extreme weather events using remote monitoring.

Through internal assessment using the Icebreaker One detailed use case prioritisation criteria, Use Case 2 was prioritised from the above list. Prioritisation criteria included the use case's criticality for other Transmission Operators and Distribution Network Operators and appropriate fit with project timeframes. It was decided that Use Case 1, although high-priority, could be incorporated into the primary use case as a building block to achieving the objectives of the primary use case. Discussion of Use Case 3 further recognised challenges which did not align with the NIMBUS timelines such as: scope, lack of detailed information and internal sponsorship for the use case, timelines for deliverables (data and technology), and potential overlap with other Strategic Innovation Fund (SIF) projects, such as SPEN's Predict4Resilience project.

Following the identification of one priority use case, research focused on specifying the scope of the primary use case and initial exploration of factors such as existing models, methodologies, data requirements, data availability, and other critical success factors. This primarily involved consolidating the first and second finalist use cases, identifying commonalities and agreeing on the starting point of the primary use case – historic data analysis to feed into Probability of Failure models within the Network Asset Risk Metrics (NARM) methodology.

Once internally decided on the primary use case starting point, plan and scope, Icebreaker One then:

- Conducted second round interviews with SSEN Asset risk teams as "sponsors" of the primary use case to identify existing work and research already carried out;
- Held further discovery calls with SSEN Distribution asset management, engineering and maintenance teams to collaborate, explore applicability and align with their objectives;
- Interviewed other Transmission Operators and Distribution Network Operators to understand the current methodologies, data and initiatives addressing climate-related asset risk.

Engagement with SSEN stakeholders supported Icebreaker One internal assessments of use case prioritisation criteria, adding weight to the decision.

Priority use case selection context and rationale

Weather data and other meteorological considerations are not currently accounted for in Transmissions and Distribution Energy Systems asset risk models. Currently, assets are modelled to depreciate at a constant linear rate based on the age of the asset and certain material location and other parameters throughout their lifecycle. However, the impact of weather influences in the degradation and failures of asset systems can be incorporated into current models to increase the life of the asset, and better understand the risk profile/return-on-investment of the expenditure on energy systems.

In recent years, UK networks have suffered severe weather events such as storm Eunice which resulted in extended periods of network downtime, as well as heavy rainfall leading to flooding and landslides in Northern Scotland that took out a large transmission tower. In light of net zero objectives and decarbonisation commitments across the energy system, the industry needs to address the effects of the changing climate on its network infrastructure by understanding the risks posed by weather and meteorological factors.

To address the climate-related challenges, Transmission System Operators (TSOs) and Distribution Network Operators (DNOs) can integrate historical weather and event data within their asset risk and scoring methodologies to identify assets in the network particularly vulnerable to meteorological influenced degradation which leads to fault and failure. Analysing historical accident, fault or outage data with data of weather events to find correlations can yield insight into meteorological effects on the network systems when planning the build, site location and maintenance for the systems' assets. Insights through historical data analysis will also have an impact on how the assets life cycles are modelled and associated risks. By managing these risks more effectively, TSOs and DNOs can dynamically and promptly manage their assets and network systems thereby improving and extending its assets' useful life, while also improving the risk/return profiles of these assets.

Benefits for solving the use case for Transmission and Distribution Networks

TSOs and DNOs, as regulated licence holders for the operations of transmitting and distributing electricity to the whole of the UK, must report on and calculate asset risks using a series of industry-agreed models and methodologies. These methodologies, such as the Network Asset Risk Metric (NARM) risk model, used by all DNOs and TSOs to report network risk annually, was not found to include a significant consideration of asset-specific meteorological history.

Weather conditions are known to accelerate the wear-and-tear on assets but little research (see section titled Existing research and scientific literature p.26) has been done to understand how this can be quantified. The primary use case seeks to explore and quantify this by using data about weather experienced by the asset combined with asset service history to identify key weather factors that should be considered in Probability of Failure calculations within the industry-adopted methodologies.

The purpose of the use case is to improve risk modelling for individual assets so that TSOs and DNOs can understand the weather and climate consequences on their assets health, functionality and resilience to changing climate.

It is also expected to reduce the costs of penalty due to network downtime, improve grid connectivity and avoid high-risk/urgent repair operations for the TSOs and DNOs which are subject to regulatory requirements of keeping the network running and delivering power to the end customer. The use case will also enable better asset resilience by improving the accuracy of grid-wide risk scoring within the asset risk models and methodologies used within the UK energy systems.

The ability to forecast asset degradation more accurately enables a risk-based approach to condition assessment that has the potential to reduce assessment frequency (and therefore cost of assessment) for low-risk assets. Currently assessment is on a fixed schedule based on the worst-case rate of degradation. Applying the same principle to refurbishment, which is also currently on a fixed schedule, could reduce the amount of refit, and extend the timeframe for repair costs for lower-risk assets.

Stakeholders consulted during use case development and prioritisation

Summary table of the Open Engagement research and discovery activities for the NIMBUS discovery phase.

Item	#
Unique organisations *researched for discovery phase*	**27**
Total stakeholder ***participants*** *by* ***organisation type****:*	**38**
Distribution Network Operators	10
Meteorological Data Providers	9
Transmissions Service Operators	8
Technology / data services Providers	7
Academics	3
Stakeholder ***participants*** *breakdown by* ***professional role***	
Meteorologist / academics scientists	8
Asset management & asset risk professionals	8
Services / solutions engineers	8
Data / analytics professionals	7
Networks specialists	5
Weather / meteorological data specialists	2
Stakeholders interviewed ***not*** *from SSE or the Met Office*	13
Number of two-hour ***stakeholder workshops*** *held*	**2**
(17 March 2022) Use case workshop participants	20
(6 April 2022) Data discovery workshop participants	12

Further development

In order to add value to Project NIMBUS, the transferability of learnings has been built into the research approach informing all stages of the project. Further detail can be found here.

Although falling beyond the scope of the current project, the priority use case also holds the potential for further development. Considering these factors may be of value to energy networks across the UK, as well as to primary stakeholders in the current project. These include items such as:

- Further engagement for the development and transfer of the use case to other transmission assets (substations, insulators/connectors, underground cables) switchgear, transformers) as well as distribution assets.
- Cost and price analysis for commercial meteorological data service provision (weighing the benefits of developing in-house capacity vs third–party consultant).
- Short and long-term predictive and real-time technology solutions for on-going maintenance and new infrastructure development for the different teams or business functions within transmission and distribution networks.

Work Package 3: Understanding data requirements, interoperability, and policy

Approach and Innovation

This section outlines the research and innovation framing for the delivery of Work Package 3 (WP3). The work package includes a summary of research and engagement methods followed by a review of existing models, methodologies and systems for energy network asset management. Datasets and data sources are then discussed and the section concludes with an overview of challenges and recommendations for further development.

Research Methodology

For the priority use case, Icebreaker One investigated and created a list of data requirements and potential data sources. This research included examining data source availability as well as how readily it could be used. Sources examined included open, public, and paid-for data by primary, commercial and global data providers. This research was conducted through desk research and interviews with key stakeholders in SSEN Transmission and Distribution, weather data and weather data service providers, and other relevant industry software providers.

Links to referenced documentation and glossary of terms used in this section

Source documents

- Ofgem published Network Asset Risk Metrics (NARM) information and handbooks documentation
- Common Network Assets Indices Methodology (CNAIM) framework documentation
- Ofgem-published official decision to keep Network Output Measures (NOMs) Methodology and supporting documentation
- NOMs Methodology documentation
- Network Asset Risk Annex (NARA) documentation for SSEN and Scottish Power (SPEN)

Glossary

Term	***Description***

TO / TSO	*Shorthand to describe the Transmission Operator and/or Transmission System Operators*
DNO	*Shorthand for Distribution Network Operators*
CBRM	*Condition-Based Risk Management, a system used to quantify, monetize and report on network risk*
CNAIM	*Common Network Asset Indices Methodology developed and adopted by all DNOs*
NARM	*Refers to Network Asset Risk Metrics, a framework used to calculate asset risks which are imputed into CNAIM*
RIIO	*Refers to Ofgem network price controls and reporting regulation.* *It stands for Revenue = (Incentives + Innovation + Outputs) for transmission and distribution license holders which is used by the regulator to ensure reliable service, value for money, maximum performance, operation efficiency, innovation and resilience is delivered from the networks for current and future customers. The hyphenated numbers refer to the timeframes for which the RIIO regulatory framework applies, and the letters, such as ED, refers to the relevant network function, i.e. ED for Electricity Distribution, T for Transmission and GD for Gas Dristribution.* *Timeframes for active RIIO regulations are:* *RIIO-1: 2013-2023* *RIIO-2: 2021-2028*
NOMs	*Network Output Measures, primarily used by TOs*
NARA	*Network Asset Risk Annex, used by TOs*
LSA	*Licensee Specific Appendices*
PoF	*Probability of Failure, used in NARM, NARA and other asset risk modelling methodologies*
CoF	*Consequences of Failure, NARM, NARA and other asset risk modelling methodologies*
EoL	*End of Life, estimates used in the above mentioned methodologies and other asset life cycle assessment and risk models*

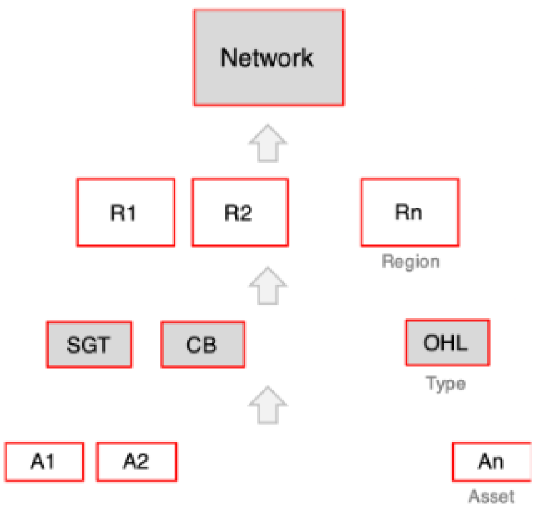
Existing asset risk models and methodologies

Condition-Based Risk Management for National Electricity Infrastructure Assets

Distribution Network Operators in the UK use Conditional Based Risk Management (CBRM) models to assess and report on their asset risks – the consequences of failure and fault as a monetized value for asset risk management. This is a licensing requirement for all licence holders operating in Great Britain under RIIO (Revenue = Incentives + Innovation + Outputs) regulation. Both Transmission Operators (TOs) and Distribution Network Operators (DNOs) use Conditional Based Risk Management models to systematically link detailed engineering knowledge of network assets to critical corporate decision making processes, report on network performance and justify investment decisions.

RISK IS MODELLED AT AN ASSET LEVEL

We calculate Risk at an Asset level, assuming asset failures are independent, this allows aggregation and comparison of risk across geography and asset type.



- Asset failures are independent of other Assets.
- Failure modes for a particular asset are independent
- Events given a failure mode are not independent – the same event can arise through different failure modes
- The model does not include circuit and network information
- Asset specific system consequences act as a proxy for this information

Figure 2: An extract from SSEN Transmission's Network Asset Risk methodology internal handbook (for network risk calculations) - diagramatic representation of risks modelled at an asset level describing asset, asset type and regional inputs feeding into the network risk modelling methodology.

Distribution Network Operator methodologies – Common Network Asset Indices Methodology (CNAIM)

The Common Network Asset Indices Methodology (CNAIM) framework was co-developed by the six DNOs in Great Britain to align their assessment and calculation methodologies for asset health and criticality through Condition-Based Risk Management assessment for electricity distribution assets as well as for forecasting and regulatory reporting of risk as part of their electricity distribution licencing requirements. The CNAIM is subject to approval by Ofgem for the period of which it applies, and is used across the 61 DNO Asset Categories (as described by Ofgem).

The RIIO-ED2 Regulatory Instructions and Guidance requires DNOs to align all current processes and practices with this standard while reporting annually on their asset risk. The CNAIM framework, although primarily used by DNOs, is also relevant to the DNOs with transmission operator licence requirements such as SSEN Transmission and Scottish Power Transmission.

Why is CNAIM used?

DNOs use the Common Network Asset Indices Methodology (CNAIM) framework to satisfy regulatory requirements for reporting outputs on Network Asset Risk Metrics (NARM) for RIIO-ED2 as an extension of the Standard Licence Condition 51 for RIIO-ED1, its predecessor.

The NARM framework applies to both Transmission Network Operators as well as Distribution Network Operators and is reported to Ofgem annually to measure the effectiveness of the asset intervention programmes as directed in its RIIO-ED2 price control determination. It is primarily used to input asset management information into planning, pricing and budgeting for distribution network and asset risk management.

How is NARM used?

Common Network Asset Indices Methodology (CNAIM) prescribes fixed inputs, calculations and calibration parameters for asset health and criticality in a consistent way to enable comparative analysis year-on-year. Asset health and critically is thus communicated via risk matrices (NARM) delivered through the numerical calculation of the condition-based Probability of Failure (PoF) per km per annum and the Consequence of Failure (CoF) as a monetized value.

Understanding model inputs: Asset Health, Criticality and Asset Categorisation

Probability of Failure is calculated based on present conditions (degradation) of the asset and likelihood of future deterioration using age-based elements and health scores. Consequently, the Probability of Failure is used to determine the impacts on the network through the Consequence of Failure measure, represented by the monetized value at risk. Criticality, therefore, is a relative measure of the Consequences of Failure compared with Reference Cost of Failures for the asset. NARM outputs comprise the Health index, Criticality Index and finally the Risk index, which combines the Health and Criticality indices and provides a value for the long-term risk of the asset.

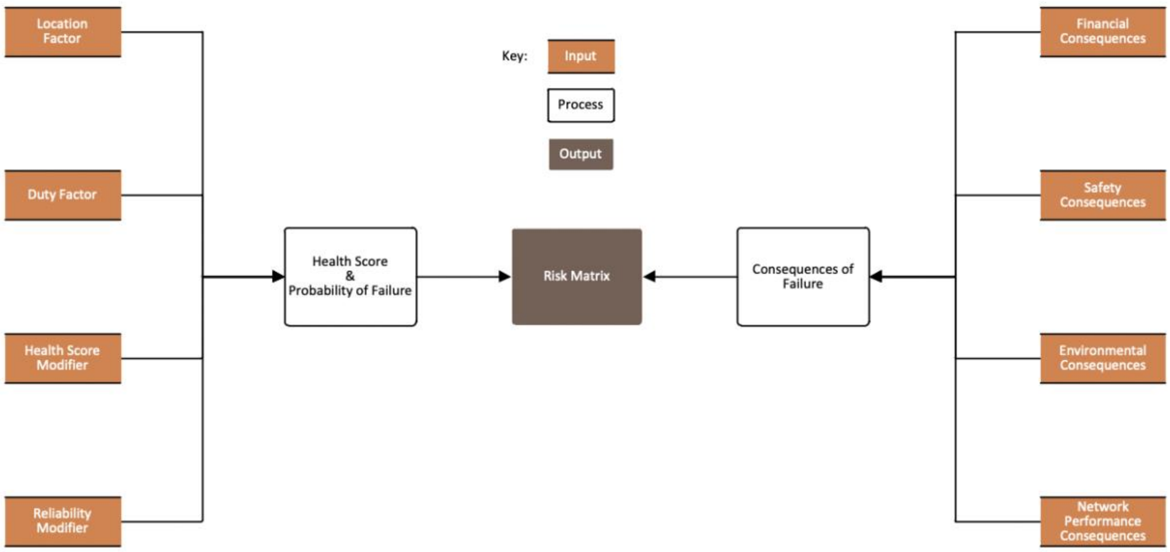


Figure 3: Process diagram for calculating Network Asset Risk Matrix (NARM) for assets.

NARM details the parameters, values and conditions to be used and the outputs are inputted into the Network Asset Indices, thereby relating to how asset risks change through refurbishment, replacement and other intervention activities.

As different types of asset health, criticality and functional failure vary between each asset, the framework provides detailed methodologies according to asset groupings (Asset Category) including: Asset Register Category and Health Index Asset Category as defined by CNAIM.

NARM is periodically updated (subject to change approval process) providing scope to consider climate and meteorological considerations in future iterations of the framework.

For the NIMBUS use case the focus of the assets at the initial and Alpha phase would belong to the high voltage transmission assets, namely the High Voltage tower, poles and overhead line assets.

Health Index Asset Category	**Asset Register Category**
EHV OHL Conductor (Tower Lines)	33kV OHL (Tower Line) Conductor 66kV OHL (Tower Line) Conductor
EHV OHL Support - Towers	33KV Tower 66kV Tower
132 kV OHL Fittings	132kV Fittings
132 OHL Conductor (Tower Lines)	132kV OHL (Tower Line) Conductor
132 OHL Support - Tower	132kV Tower

Table 1: Extract from CNAIM Health Index and Asset register Categories for higher voltage distribution line and tower assets.

Other assets such as underground cables, switchgear, and transformers were deemed outside the scope of the current phase and would be further explored, along with the Low Voltage (distribution assets) tower, pole, fittings and conductor assets, at later stages in the project.

Transmission Assets Methodologies – Network Output Measures (NOMs) and Network Asset Risk Annexes (NARA)

As the primary use case focus relates to transmission assets for Discovery and Alpha phases of Project NIMBUS, Electricity Transmission Operators report to the RIIO price control framework instead using the Network Output Measures (NOMs) methodology. For transmission network owners and operators, on-shore licence holders in Great Britain have to report via this NOMs Methodology, which was developed and accepted by the TOs in 2018. NOMs Methodology fulfils the same requirements and follows similar principles to those of NARM for DNOs and relates to transmission assets operating at 400, 275 and 132KV. NOMs are binding secondary outputs for the Transmission Operators to evidence long-term resilience and value for money by using early warning measures or lead indicators through assessing the underlying performance of the transmission system.

In addition to this common methodology framework, the Transmission Operators have developed Network Asset Risk Annexes (NARA) as well as Licensee Specific Appendices (LSAs) which describe in more detail how they use NOMs outputs for their businesses.

The Licensee Specific Appendices are not publicly available as each TO's assets and operations are confidential, however are shared with Ofgem for review and approval.

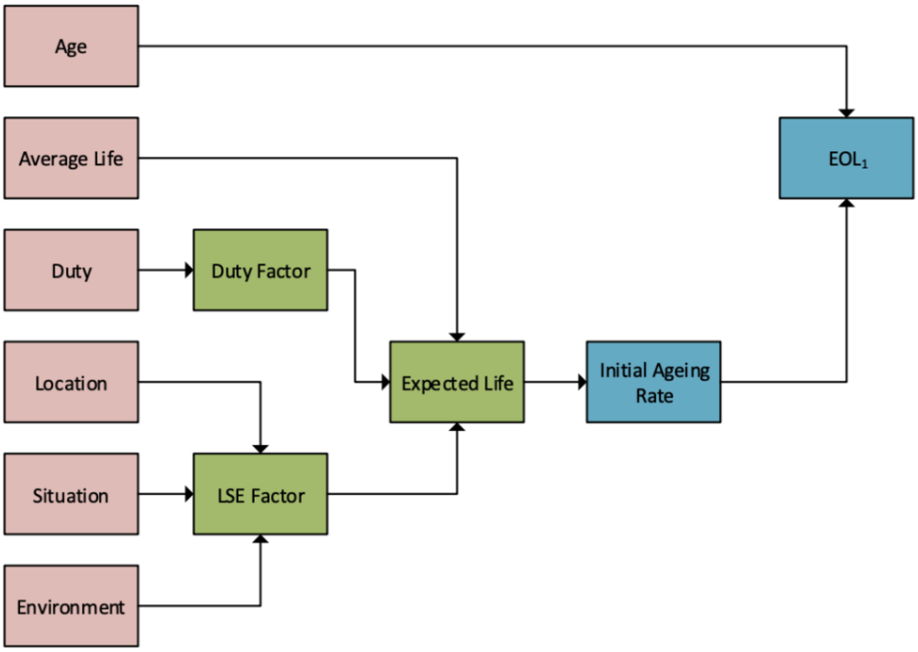
Much like CNAIM sets out the Network Asset Risk Metrics (NARM) methodologies for Distribution Network Operators, Transmission Operators have a prescriptive methodology of asset risk parameters, calculations and conditions for their transmission assets that has been co-developed by the operators and set out in the Network Asset Risk Annex (NARA) documents. Separate NARA workbooks exist for the three Transmission Operators in Great Britain.

Gaps in methodology and scope for improvement

Both NARM and NOMs (including NARA) methodologies are prescriptive and currently do not take into account weather and climate related inputs beyond initial static values (linear-depreciation and/or End of Life Modifiers or EoL, for transmission assets) and simple binary factors for indoor or outdoor environmental conditions.

Figure 4: General NARA process for network lines inputs for the derivation calculations for initial End of Life calculation input into Probability of Failure calculations for Transmission Operators.

The Probability of Failure (PoF) here derives information relating to the location's environment (Location Factors), with adjustments made depending on use (duty factor),



condition (observed and measured) and asset make/model (reliability factor). Location factors gain input from proximity to the coast, altitude, corrosion and whether the asset is indoor or outdoor.

Consequences of Failure (CoF) and therefore network performance calculations can also be dependent on environmental sensitivities of the asset with regards to weather conditions, ground stability and flooding, lightning and storms as well as temperature extremes or changes.

An example of environmental inputs or locational factors in the above asset risk models would involve location ratings based on air pollution and atmospheric salt water concentration, an example below that has a three level rating, A, B and C.

- Rating A: Within 10 km proximity to the coast or chemical plant
- Rating B: Within 60km proximity to the coast or an industrial factory
- Rating C: Beyond the above

As discussed, this level of input for environmental or weather based considerations is insufficient, lacking any climate, temperature, wind, rainfall, and other meteorological factors or weather hazards which impact the asset and subsequent network risks estimated using these standardised models.

Data required for the use case

Identification of the assets to be analysed for the use case

The priority use case will initially focus on assets incorporated in the SSE Transmission line from Beauly (Inverness) to Shin (Dunrae). It was chosen as a case study for the following reasons:

- The line runs from North to South, covering approximately 200 towers and related assets over multiple climatic zones and geographic terrains.
- The line has been in service for a long time period thus giving a rich documented history of faults and maintenance.

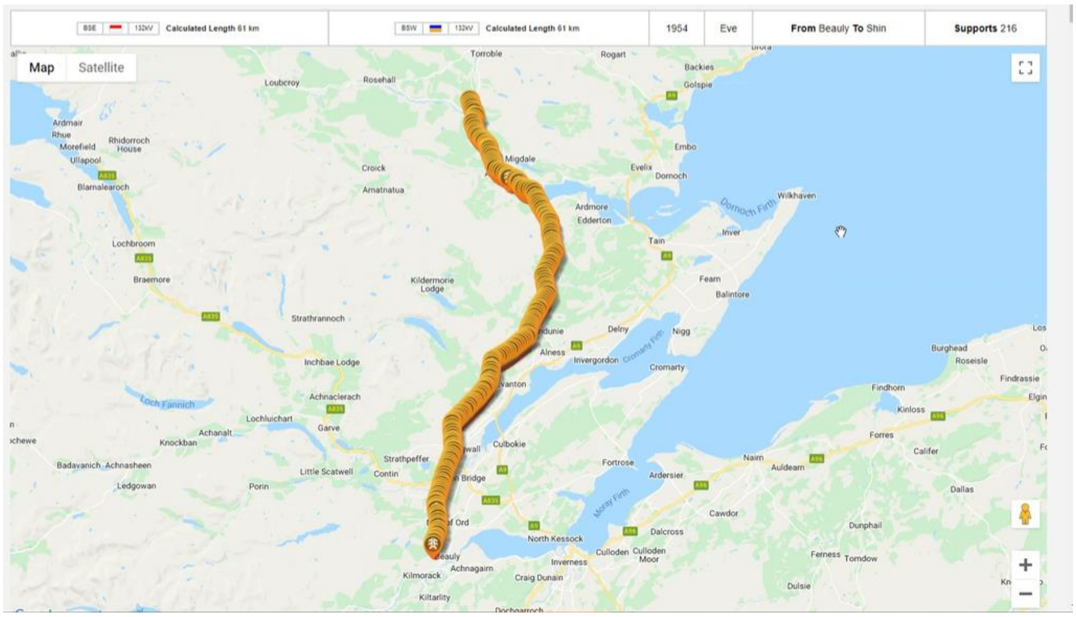


Figure 5: Screenshot of the network map tracing the use case selected transmission line asset running from North to South Scotland visualised by SSEN Transmission's network mapping system.

The use case will focus on asset degradation. This is because it meets two research gaps and associated user needs:

1. Energy networks need to address degradation rather than just asset failure, incorporating general weather impacts as well as extreme weather events.
2. Energy networks need to assess degradation of assets as a whole, rather than focusing only on specific components.

Furthermore, assessing asset degradation will incorporate a variety of data sources including numerical data, free text and images (involved in measuring asset faults, failure modes, interventions, inspections and replacements). This will provide a robust challenge to the use case and related data analysis methodologies.

Data sources

In exploring which data is required to satisfy the use case, Icebreaker One has identified the following broad data categories needed with additional analysis on the data types:

1. SSEN Network geographical map and asset location information

Analysis: This information is held internally and not publicly available information due to the security aspects of critical national infrastructure locations. There have been a number of initiatives looking to provide access and represent the network asset maps and systems models through government and partner collaboration (such as Digital Twins) in the early stages of development to address this challenge.

2. Maintenance and operational reports and logs of asset conditions, defects, interventions, refurbishments, critical events, fault and failure logs as well as replacement information held internally by SSEN

Analysis: SSEN has described its 5 to 10 year maintenance surveying and condition reporting cycles, which are similar to those of Scottish Power, recorded on dedicated systems using drone, helicopter and visual inspection. Through our research we've found that additional defect surveys (and not conditions) are separate activities and happen at 1 year intervals. There is consideration as to whether these operational cycles need to be informed by weather and climate considerations rather than standardised reporting cycle frequencies.

3. Factors and inputs from Conditional Based Risk Management (CBRM), CNAIM and other methodologies from NARM, NOMs and NARA frameworks that are used to calculate the Probability of Failure, End of Life and other relevant asset risk metrics and outputs.

Analysis: While the CBRM systems for asset risk models have served an essential purpose in creating a common framework for asset risk management, there remains the opportunity to increase its accuracy and detail as it has been noted by asset professionals that the CBRM outputs are not always an accurate representations of what realistically happens. Inputs to the CBRM have been described as “basic” and it was noted during calls that environmental and weather aspects impact the degradation and therefore the asset risks, thereby confirming the need for the use case in using meteorological data to inform CBRM's outputs and its subsequent impact on reporting, investment and maintenance decision put forward by the Network Operators to the regulator.

4. Historical weather experienced locally to the assets to a sufficient degree of accuracy, frequency, and reliability

Analysis: For the purpose of this analysis, accessing and easily using asset-level weather and climate logs of matching frequency and accuracy from a sufficiently long historic period will be a challenging task. It is unclear as to whether this data is available as real data compared with extrapolated or modelled data, time period gaps and differences in formats, collection and management methodologies as well as operational types is still opaque. In the future, integrating datasets between different maintenance, operational and externally held weather station data first with SSEN then with other Transmission Operators (SPEN & National Grid) to explore regional asset differences will form the necessary basis for further development for project NIMBUS.

The findings of our weather and other meteorological data discovery and dataset identification exercise is summarised in Table 2. Top meteorological datasets identified relevant to the use case can be found in the following sections.

Meteorological data providers

Icebreaker One conducted desk research on the types of meteorological datasets available initially, and then identified leading potentially useful datasets through this research. The number of data source organisations researched for the Discovery phase was 31 including commercial data services providers.

Data providers researched included

- Leading commercial weather data service providers
- Public / Open weather data via research, academia and/or gov. institutions
- Other commercial weather and analytics providers

Data sources from the following organisations were explored and summarised below (full analysis including data set availability, data access and links here):

Source organisation	Org type	Access / comments / API
Met Office	Public / commercial	Open to registered users / paid-for specialist datasets / API access available
European Centre for Medium-Range Weather Forecasts (ECMWF)	Public / commercial	Open to registered users / Migration to Climate Data Store paid-for / API access available
Economic Interest Grouping of the National Meteorological Services of the European Economic Area (ECOMET)	Public	Open to registered users / Migration to Climate Data Store paid-for / limited API access (in development)
NASA's Global Modelling and Assimilation Office	Public	Open / GES-DISC data download / API not available
European Space Agency (Copernicus Data Hub, Sentinel Satellite Data)	Public	Open to registered users / some data available on demand through request proposal / API not available
The Centre for Environmental Data Analysis (CEDA Archives)	Public	Open to registered users / migration to MARS catalogue paid-for access at higher resolutions / NetCDF
DTN (formerly MeteoGroup)	Private	Paid for / consultative process to access data / API access available
Meteomatics	Private	Paid for / consultative process to access data / API access available
Others (MetDesk, Climate X, LineVision, Visio and others)	Private	Paid for / needs based / API access available

Table 2: Meteorological data source research summary.

Data requirements

To inform the weather and asset data discovery for the analysis, the team formulated the following general question:

> *Does [organisation] have historical weather data going back [N] years, at [M] spatial resolution and [T] temporal resolution for location [XY]?*
>
> *Where:*
>
> *N = length of a maintenance check or longer*

> *M = max and min spatial resolution*
>
> *T = max and min temporal resolution*

Through detailed interview calls with the asset risk and asset management teams, Icebreaker One uncovered the following:

> *A tower is expected to stand usually for 80-100 years, but the component parts on it will require replacing, for which we've identified a 35-45 year period. Transmission line assets are visually checked for degradation by drone, helicopter, or from the ground, approximately every 5 years.*
>
> *Towers are spaced approximately 300m apart.*
>
> *The XY location we've identified for testing the data is a 216-tower, 61 km line from Beauly to Shin, built in 1954. The line crosses a variety of geography and has a long maintenance history.*

Hence, the above problem statement was further refined:

- N can be a maximum of 45 years and a minimum of 10 years, considering robust and easily accessible maintenance records and the lifetime of the asset chosen.
- M will need to be a maximum of 1km resolution, and a minimum of 10km, to provide some differentiation along the 60km route.
- T should be determined as part of the analysis, with a working assumption that it falls somewhere between 1 hour and 1 week.

SSE Distribution have weather data to 2km resolution for their regions, but only going back 5 years. Historic weather information with sufficient geographical spatial resolution was discovered to be partially provided by the Met Office as a service provider to SSE, however further research was conducted to understand if the specific data points included (for example, wind speeds, directions and height coverage) would satisfy the use case's objectives.

Dataset identification

Icebreaker One convened a weather data workshop [slides, working document] with participants from SSE Transmission and Distribution, and the Met Office. The first half of the workshop used the domain expertise of the SSE participants to build a picture of the weather factors likely to cause degradation and failure of transmission line assets. Following this, the Met Office team shared their thoughts about data they might bring to bear on the analysis, both from existing datasets and custom-generated ones that combine or interpolate datasets.

Using information from the Met Office alongside desk research and interviews with academic and private-sector meteorological data analysts, Icebreaker One assessed the datasets from the organisations identified earlier against the data requirements to arrive at a shortlist of three datasets:

- HadUK-Grid
- ERA5
- EURRA

Each of these in isolation does not fully meet the requirements. HadUK-Grid has only monthly wind information, and it is likely wind is an important factor for asset degradation. ERA5 has hourly temporal resolution for a wide range of measures but is only at 30km spatial resolution. EURRA is at 5.5km resolution with wind speed and direction but lacks data points such as maximum wind gusts that are available in the others.

It is likely that a custom dataset will need to be developed by a meteorological data provider that combines factors from more than one of the source datasets.

Open Questions to be explored during Alpha

While exploring these data sets and availability, we came to the following conclusions and open questions to be addressed during NIMBUS's Alpha phase:

- While we identified a number of historical datasets relevant to the use case, more analysis is needed in applying the datasets in actual risk models to determine "usefulness", accuracy and appropriate resolution needed.
- Public meteorological data sets vary in granularity, but there are gaps in certain weather hazards and meteorological aspects and other parameters between different datasets and data models, for example temperature variation, wind differences in directions and across heights, prolonged extreme heat or cold and other considerations which will need to be determined.
- There is only a small amount of real weather / meteorological data compiled from satellite, local weather stations and other logs, however much of the increased accuracy, frequency, spatial and temporal resolutions and coverage are actually the result of combining, transformation and modelling data science. This means that public access data feeds and datasets may still prove challenging

to utilise for the purpose of the use case in the short term and within the timeframe of the NIMBUS project.

- "One size does not fit all" – from our analysis of the common Asset Risk Metrics and methods to calculate asset risks used by TOs and DNOs, different calculation methods, inputs and parameters are appropriate for the different assets (6 lead assets or 12 overall components for Transmission Operators, 61 asset types for Distribution Network Operators). This would also imply that different assets', and asset component's risk assessments may require separate and distinct weather information, for example the difference between asset risk estimation of a transformer compared to an overhead cable.

Existing research and scientific literature

Limited academic research has been conducted on the effects of weather on transmission lines and towers in the UK. That which does exist tends to either be broken down into very specific elements (e.g. targeting specific asset components such as bolts, or isolated extreme weather phenomena or hazards), or conducted with a wide lens (e.g. incorporating energy infrastructure into research on the effects of climate on the wider built environment). Previous research has been conducted on weather forecasting for Dynamic Line Ratings, but our reviews have found lacking evidence of directly transferable research to the objectives of the NIMBUS priority use case.

Academic research:

The full literature review and analysis can be found here.

The majority of academic papers found focus on the effects of specific weather phenomena (e.g. wind downbursts, icing etc.) on transmission towers and lines. Likewise extreme weather phenomena were addressed, with a tendency to focus on wind storms (e.g. hurricanes and tornadoes) and thunderstorms. Searches did not reveal any comprehensive and linked analysis of the effects of more general weather and climate on the above assets from the search terms used. It is possible that this is addressed in other publication forms, such as textbooks and white papers, which are not stored on journal databases.

Finally, a significant amount of research to date has focussed on asset failure. There remain large research gaps with regards to the effects of weather - particularly multiple aspects of weather and/or weather events - on asset degradation over time. Some literature is available regarding corrosion, however this often relates to specific components made of specific materials (e.g. steel bolts) rather than assemblage structures with multiple components.

Wider sectoral research

Research has been performed on the effects of weather on the built environment in the UK more generally, but not at a granular level and on asset types specifically for the energy sector's lead assets (as defined by the Network Asset Risk Annex, NARA published by Ofgem). The research has mainly been focused on forward looking scenarios and using climate change forecasts to predict possible effects depending on hazards (increased landslides, or storms in Northern parts of Scotland).

In US- energy systems focused research published by the Department of Energy in the United States of America, three extreme climate trends have been explored in causing major issues to the energy sector across the country over the past ten years:

- Increasing air and water temperatures;
- Decreasing water availability across regions and seasons; and
- Increasing intensity and frequency of storm events, flooding and sea level rise

However the research is not asset-specific and therefore lacks the sufficient detail required by NIMBUS, and mainly looks at the consequences of extreme weather events rather than the cumulative effects on the asset's degradation and therefore useful life itself.

Systems currently used

Icebreaker One research identified a range of information and operational technology management systems currently used by energy networks. Although TO's asset locations, maintenance and operational information is proprietary and kept confidential (and only shared for approval by Ofgem), Icebreaker One discovered certain tools and third-party systems in use to perform operational, data handling and technical reporting functions. These are outlined below and identified for the purposes of integration with or within the use case, where required.

- Cyberhawk for condition surveying, including high-resolution photos from drones/helicopters and asset degradation ratings (1=pristine to 4=severely degraded) on a variety of elements of the transmission line available on their iHawk platform. This platform is used by SSE and at least one other distribution company

- SAP is widely used in the industry as the asset registry, and also data platform for inspection, fault and maintenance logs
- ArcGIS, ESRI map overlays on asset and network maps
- EA Technologies for Conditional Based Risk Management and asset risk indices methodology (CNAIM) is used by all companies interviewed
- PowerOn is in use for network operations management at SSE and at least one other distribution company

In the Alpha phase, the compatibility of these data systems and data silos are expected to be explored in order to streamline the asset risk and asset management capabilities across SSEN's transmission and distribution functions and objectives.

Interoperability

Platforms and data

While developing the use case for NIMBUS, Icebreaker One was keen to explore its relevance, scope and transferability not just for other Transmission and Distribution network operators, but also beyond the use case and into other sectors. The following aspects have been considered as part of the discovery phase of NIMBUS, summarised below:

- Risk reporting using NARM and CNAIM is a standardised process, and there is a high likelihood that the data and processes for weather-related probability-of-failure assessments developed for SSE transmission assets will readily apply to all similar assets at other providers.
- All TSOs and DNOs use EA Technologies Condition Based Risk Management platform to build their risk reports to Ofgem, providing the possibility for a future software-supported application of the analysis.
- There is an opportunity to develop a common approach for using weather-based asset degradation forecasts to enable risk-based maintenance and inspection cycles and investment decisions. The operational application of this (scheduling visits, work logging, supply chain management and so on) is likely to be organisation-dependent.
- Raw weather datasets are generally hard to find, understand and access. Processing them further for specific uses requires skilled meteorological data analysts. There is an opportunity to build, document and make available a weather dataset that is widely applicable to assess historic weather effects on physical assets.

- While the asset degradation models will differ, it is likely that weather datasets and processes created in NIMBUS Alpha will be useful for asset risk modelling in a variety of sectors, including rail, gas, road and water.

Data sharing governance framework

There are opportunities to streamline data availability, accessibility and shareability for the meteorological and asset datasets created and mobilised by NIMBUS. Bringing them into Icebreaker One's Open Energy data sharing framework would provide a structured mechanism for publishing API access, metadata cataloguing, naming conventions and data licensing conditions (including Energy Data Taskforce Presumed Open principles).

In Alpha, we recommend testing the implementation of the Open Energy data sensitivity classes (developed under the Modernising Energy Data Access programme) to help the energy industry understand what NIMBUS data can be shared, and how, and producing guidance to help organisations apply these lessons

Having identified the data governance requirements, relevant datasets can be added to the Energy Search so that they are readily available (with appropriate access controls) to other organisations to use in their own operations, planning or analyses.

Recommendations for further development

Based on the prioritised use case, **WP3** has produced the recommendations on data interoperability below:

- Assess ability to access, consolidate and integrate various internal data sources as described above in section titled data required for the use case, including SSEN Transmission operational and maintenance data logs, reports and other information.

- Identify accuracy and completeness of datasets for the purpose of the use case considering internal and external capabilities to transform, supplement, backcast or forecast for gaps, inconsistencies, incompatibility and other data use and integration issues.

- Identify a minimum set of weather hazards and subsequent parameters for asset degradation analysis, at an adequate spatial and temporal resolution. This will enable meteorological data providers to publish well-understood datasets for asset risk specialists to use in their own assessments.

- Assess data availability and indexing possibilities of existing weather and climate datasets for easier discovery and access for the purpose of asset risk estimation for the wider energy industry and the Open Energy governance framework to improve.
- Explore the relevance of the use case data analysis and developed methods to other lead transmission assets while also exploring scalability and relevant to distribution network operation functions.
- Conduct working sessions and exploratory workshops between the co-developers and stakeholders of the Common Network Asset Indices Methodology (CNAIM), the Network Asset Risk Metrics (NARM) for distribution operators as well as the Network Asset Risk Annex (NARA) methodologies for transmission operators.
- Assess how to meaningfully integrate weather and climate data metrics as a part of RIIO requirements and asset risk estimation methodologies for the appropriate level of consideration of climate change scenarios and the future of the energy sector's mitigation and adaptation efforts in transitioning to a digitalised low carbon energy system.
- Using the selected use case as a base, climate change models and methodologies from other industries such as insurance, risk management and climate finance should be considered for their applicability in forecasting asset degradation in a variety of climate change scenarios.

Lessons Learned

WP2: Work conducted in WP2 demonstrated the value of a use case-based approach to researching new areas of data use. The benefits of this approach included:

- Presenting an opportunity for collaborative, multi-perspective thinking in creating the use case long-list; creating value for all stakeholders and the wider industry by highlighting the sheer breadth of potential uses for weather data.
- Conducting a robust prioritisation exercise, guiding optimum investment of resources and time, both for key project stakeholders and the wider industry.
- Producing an appropriate level of specificity with regards to the priority use case, supporting future project planning and the parallel cost-benefit analysis.

Icebreaker One did not experience any technical or regulatory constraints in the process of developing WP2. However, two commercial constraints were encountered in the process of developing and narrowing down the use case long-list. Firstly, certain stakeholders expressed concerns regarding commercial interest surrounding the input of ideas into a collective resource. This was mitigated by explaining the collective value of the long-list resource to all energy networks, as well as relevant data providers, across the UK.

Secondly, some data providing organisations expressed challenges with open development of project resources in a manner that could potentially introduce or draw attention to competitors, which may not have been identified in closed discussions. This constraint was addressed by highlighting project requirements to demonstrate value for money and by highlighting the potential market size for data provision (e.g. geographic or use case transferability) for organisations able to provide competitive products and services.

WP3: Work conducted in WP3 successfully explored a range of data types, from a variety of sources, that are potentially implicated in delivery of the priority use case. In conducting this exercise, Icebreaker One also demonstrated the value of Open Engagement methods, which served to highlight a far greater range of potentially useful data sets and sources than would have otherwise been known.

Icebreaker One did not identify any regulatory constraints in this work package, however commercial and technical constraints were experienced. Commercial constraints and mitigations mirror those outlined in relation to WP2. Several technical constraints were identified and are outlined below.

The first technical constraint relates to gaps in weather data provision at a sufficient temporal and geographic granularity. This was particularly found in relation to wind data which is vital for project success. This constraint was addressed through extensive exploration of different weather data sources and services that could be employed - including on a paid basis - to address these gaps. This research highlighted that it is technically possible to produce adequate data, however there may be financial (e.g. paid services), upskilling (e.g. training to perform appropriate data transformations), or time costs (e.g. negotiation of data sharing agreements) associated with performing these activities.

The second technical constraint relates to the consistency and historical records held within energy networks (or across different teams within a single network), which could possibly affect transferability of the use case. For example, it was not possible to universally determine how far back asset inspection, fault and maintenance records reach for all energy networks across the UK, or what format(s) these are recorded in.

These issues were explored thoroughly in interviews with SSE professionals, providing mitigations within the NIMBUS project and for the proposed case study transmission line. Going forwards, it would be beneficial to establish whether, or to what extent, there is variation between energy networks.

The final technical constraint encountered both in relation to network and weather data concerns data openness and licensing. In some cases, this may also be considered a commercial constraint. For example, asset inspection and maintenance data required from energy networks may not previously have been widely shared beyond the data-collecting organisation. Using this data may either implicate time or financial costs in the form of bespoke licence negotiation, or may have an impact on the openness of downstream datasets produced via use case analysis (e.g. if they affect commercial sensitivity on the part of the energy network). Furthermore, weather data sets produced specifically for the project may require negotiation or payment in order to make open. While it was not possible to mitigate all possible constraints in this area, research conducted in WP3 focussed on data that is Open or Public wherever possible. This aimed to ensure that project NIMBUS remains as open as possible, thus maximising value to the wider industry.

Conclusion

NIMBUS is an ambitious project with the potential to accelerate the transition to net zero by prolonging the life of assets by understanding their degradation better, improving their reliability and management through the introduction of new, granular data sources and consequently improving network asset design, investment and operations.

To address asset risk estimation and management challenges in light of changing climate leading to increasing weather-related effects on electricity networks, Icebreaker One along with SSEN Transmission have explored the network operator needs and challenges, scoped the data provisions and existing frameworks, identified data sources and datasets and finally put forward recommendations and next steps for the Alpha phase of NIMBUS.

Through exploring use cases from a range of problem statements, scoping the technological and data sharing capabilities needed to enable the use case and ensuring transferability and relevance to the wider industry, NIMBUS aims to deliver a clear and useful way for weather, climate and other meteorological effects to be integrated into standard common asset risk estimation methodologies and asset management capabilities for Transmission and Distribution Network Operators. This work contributes to securing a resilient electricity network for the future of the energy industry in the UK.