Scottish & Southern Electricity Networks

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A Risk-Based Approach to Asset Management

A Network for Net Zero

October 2019

Scottish Hydro Electric Transmission plc

Contents

1 Introduction

Scottish Hydro Electric Transmission (SHET) is the owner and operator of a safe and secure electricity transmission network in the North of Scotland. We strive to meet the expectations of our stakeholders and deliver on our legislative requirements.

Our risk-based approach to Asset Management is underpinned by our commitment to maintain the highest industry standards through our certification to the BS ISO 55001 standard.

In order to deliver these key requirements, we continually monitor and assess the condition of our assets to maintain the reliable and resilient network that is expected by our stakeholders.

Where asset condition deteriorates, we undertake a programme of cost-effective, risk-based interventions to maintain the longevity and performance of the transmission network. During the RIIO-T2 period, SHET is proposing to invest circa £690 million to deliver 29 Asset-Related interventions to meet this goal.

The purpose of this paper is to provide insight into the key strategies and decision-making processes that underpin our risk-based approach to Asset Management and how we identify and select the 29 asset interventions we believe are essential to meet the ongoing requirement to deliver a safe and secure network throughout the RIIO-T2 period and beyond and achieve our ambitious goal of a *Network for Net Zero*.

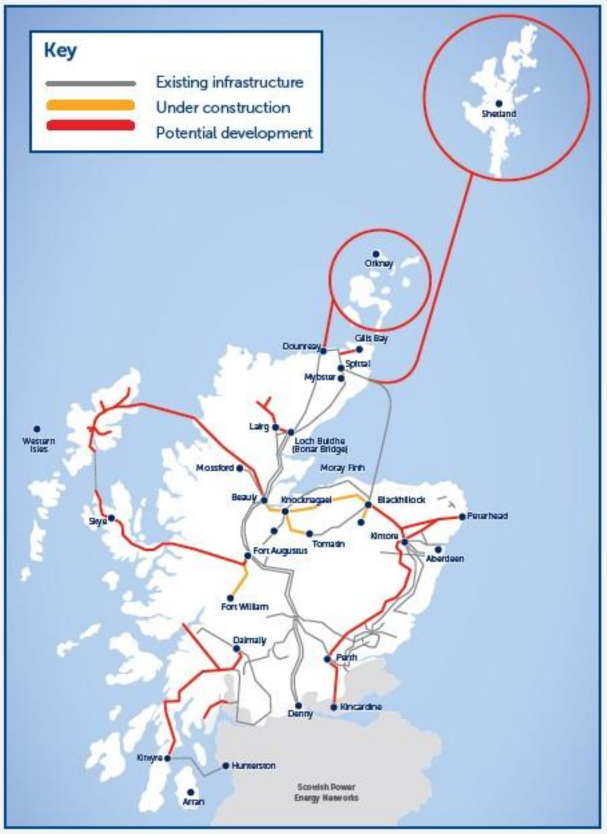

Figure 1 – SHET Network

Each of the sections in this paper addresses a different phase of our risk-based approach to asset management.

In Section 2, we explore the guiding principles that underpin the SHET approach to managing our assets. Section 3 outlines the strategies we employ for each of our lead asset classes and Section 4 details how we apply these principles & strategies to develop the non-load intervention proposals within our RIIO-T2 Draft Business Plan.

2 SHET Guiding Principles for developing our RIIO-T2 Non-Load Business Plan

The SHET RIIO-T2 Draft Business Plan, published in June 2019, identifies five clear goals (Figure 2) to be achieved during the five-year period of the T2 Business Plan.

The Draft Business Plan also sets out our proposed strategy, ambitions, targets, activities and costs for the period. It is the result of 2 years of extensive consultation with our Customers, Consumers, Stakeholders and Future Customers.

The Non-Load "core" element of the draft T2 Business Plan was created within this consultation process and has been developed with the clear guiding principles of:

- Cost effective interventions, made at the right time, to deliver best value to Consumers
- Ensuring the safe and secure operation of the SHET Network by improving resilience and continuing to deliver the reliability levels expected by consumers and customers

Figure 2 – SHET 5 Clear Goals for RIIO-T2

2.1 Shaping Investment Decisions through Stakeholder Engagement

Stakeholder Engagement has been a core component of all aspects of the SHET RIIO-T2 Draft Business Plan and has been instrumental in defining how we approach our proposed asset/non-load related investments.

During our Asset Management and Operations stakeholder workshop, held in March 2019, SHET engineers and asset managers outlined various alternative investment proposals for discussion, review and feedback.

For asset replacement, stakeholders were informed of the guiding principles and strategies that underpin SHET's risk and condition-based approach to asset interventions and were asked to provide their preferences on how SHET should develop our intervention options.

SHET explained that our first option – Do Nothing – was not a long-term viable approach to take, as the resulting outputs of this approach would be increased risk of asset failures, leading to disruption of supplies to the homes and business connected to the electricity network. Stakeholder feedback was very clear on this issue – reliability and continuity of supply was a key base requirement.

The other two options proposed were presented as the 'Minimum Standard' and 'Responsible Operator' options (see Figure 3).

Minimum Standard	Responsible Operator
Replace or refurbish assets forecast to fail during T2, bringing them up to current specifications	Bring T3 enabling works forward when carrying out T2 works

Figure 3 – Definition of SHET RIIO-T2 Approach to Non-Load Investments

Stakeholders made it clear to SHET that the minimum standard for all asset interventions should be that replaced or refurbished assets should meet current industry technical specifications. As a responsible operator, SHET should also consider bringing forward enabling works for T3 asset interventions at the same locations, where it can be demonstrated that this is a cost-effective solution that brings value to stakeholders and consumers.

This approach has been adopted for all asset interventions included within the SHET RIIO-T2 Draft Business Plan.

2.2 Network Reliability Ambition

Since privatisation, SHET, as a responsible network operator, has demonstrated a strong history of delivering sustained improvements in network reliability which will continue throughout the RIIO-T2 period. Our reliability goal, as defined in the SHET RIIO-T2 Draft Business Plan, is to provide *100% network reliability for homes & businesses* by making cost-effective investment in new technologies to manage our growing and complex asset base smartly and efficiently. Whilst our non-load investment is not directly driven by this goal, we believe it will contribute towards it.

This long-term network reliability ambition is driven by the output of consumer surveys & customer feedback that have provided SHET with clear guidance on the high value placed on uninterrupted supply and unconstrained access to electricity network.

The 29 asset interventions, proposed within our RIIO-T2 Draft Business Plan, are the output of a rigorous development process, using detailed asset condition information as the driver to undertake work. SHET's approach to invest in new technologies and ways of working will ensure that our condition-based interventions also deliver improved asset performance, that will help us to meet our goal of *100% network reliability for homes & businesses* by 2026.

An example of this stakeholder led approach is that all transformers installed during the T2 period will be built to current industry specifications, ensuring that they are equipped with the latest sensor technology, capable of providing real-time asset condition information, as standard.

Use of this technology will provide asset managers with the earliest possible indication of any plant or equipment performance deterioration, allowing interventions to be efficiently & cost effectively planned & delivered at the right time, minimising any disruption to customers.

3 The SHET Approach to Risk-Based Asset Management

3.1 Understanding our Assets and Their Condition

The SHET network comprises a large number of electricity substations, connected by overhead lines and underground cables. The continuing reliable performance of these assets is essential to the delivery of a safe and secure network for the homes and businesses we supply.

Within our regulatory framework, these assets are grouped into 2 classes – Lead & Non-lead Assets.

<u>Lead Assets</u>

The lead asset classes on the SHET network are:

- Transformers & Reactors
- Circuit Breakers
- Underground Cables
- Overhead Lines
    - Conductors
    - Fittings
    - Towers

<u>Non-Lead Assets</u>

The non-lead asset classes on the SHET network include:

- Circuit Switchers
- Disconnectors
- Earth Switches
- Busbars, Post insulators & Fittings
- Instrument Transformers
- Ancillary Systems e.g. batteries
- Protection, Control, Telecommunications & Smart Monitoring systems
- Civils & Buildings

All SHET lead & non-lead assets are built with an anticipated design life. Over time, asset condition can deteriorate and unchecked, this can lead to an increased risk of asset failure, as shown in figure 4.

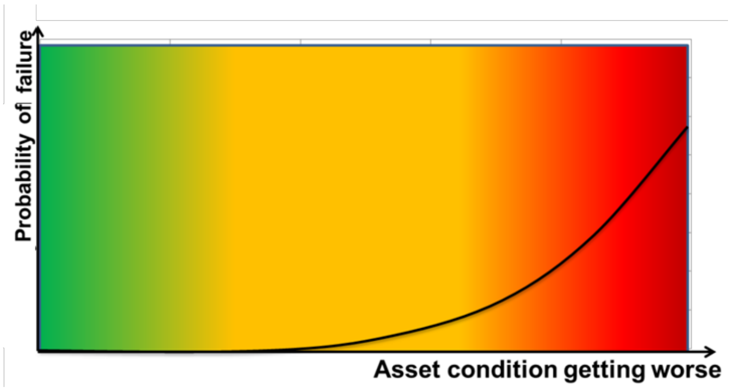

Figure 4 – Typical asset condition deterioration over time

Deterioration of asset condition is normal and expected by SHET. This occurs due to the operational conditions and stresses that the assets are subjected to during their working life and include:

- Electrical stress – experienced by assets like circuit breakers during the clearance of fault currents
- Thermal stress – experienced by Transformers, Reactors & Cables, due to the heating effect of carrying loads close to their design limits for short or sustained periods to meet network demands
- Mechanical stress – experienced by all assets during fault conditions, but most often seen on overhead line assets as wind-induced vibration
- Environmental factors – these can include landslides, wildfires, salt & industrial pollution, as well as excessive wind, snow & ice

If unchecked, the deterioration associated with our asset base can have a significant detrimental effect on the Transmission Network and the customers connected to it.

To ensure our understanding of current asset condition is accurate, SHET undertakes periodic inspections and testing of our assets to assess and measure their condition.

All SHET asset condition information, current and historical, is held within our Maximo asset database and a number of other data-management platforms. This data is a key component in the decision-making processes used to manage our asset base and to identify and select the appropriate interventions to meet our asset management objectives.

3.2 Network Asset Risk Metric

SHET, in collaboration with the other UK Transmission Owners and Ofgem, has developed and implemented a Network Asset Risk Metric or NARM, within the broader Network Output Measures (NOMs) methodology, to provide a broadly consistent approach to the calculation of lead asset risk across the UK Transmission System.

In simple terms, Asset Risk/NARM is a combination of how probable an asset is to fail (Probability of Failure), and the consequences of that failure (Consequence of Failure).

Probability of Failure

Asset condition is monitored using visual inspections and testing regimes, outlined in section 5 of this paper. The outputs of these monitoring activities provide useful early indications of the deterioration of an asset and allows assessment of when the asset may fail. This information is used to calculate a Probability of Failure (PoF) value for each asset.

<u>Consequence of Failure</u>

Asset and site-specific information is studied to determine the Consequence of Failure, or CoF. This CoF contains assessments of the societal consequences of the asset failing on the environment, safety and the wider transmission network. It also considers the cost of replacing that asset.

This complex risk modelling process is undertaken within the SHET Condition Based Risk Management (CBRM) tool. CBRM takes up to date asset condition information from a number of data sources, including the SHET asset database – Maximo and the SHET Geographical Information System.

CBRM undertakes a series of complex calculations to determine the PoF & CoF of each lead asset on the SHET network and combines these values to deliver a NARM score for each lead asset.

The output of this risk-based analysis process is a series of data tables (extract from the SHET Transformer NARM calculation in Table 2) that identify the highest risk assets of each type (Transformers, Circuit Breakers, Underground Cables & Overhead Lines), prioritised by their monetised risk or NARM value.

SHET Asset	NARM - Monetised Risk Score Risk£(million)	Asset Condition Information
100373342 – 132kV Transformer - Dyce	£2.891	Main tank deterioration
100373434 – 132kV Transformer - Dyce	£2.891	Main tank deterioration
100373592 – 132kV Transformer - Redmoss	£2.200	Main tank deterioration
100373502 – 132kV Transformer - Peterhead	£1.979	Internal winding insulation is at end of Life

Table 2 – Extract of NARM scores for Transformers

The NARM tables are not used in isolation by SHET to select specific assets for intervention. They are one of the tools, used to inform the risk-based, asset intervention decision-making process, outlined in Section 4 of this paper.

Although NARM considers only lead assets, our planning process considers the condition of all associated non-lead assets at the same site as part of our rigorous approach to delivering cost-effective, risk-based interventions that deliver the best value to consumers.

During the T2 period, we expect that the risk-based NARM approach may be extended to some of our non-lead asset classes.

More detail on how SHET calculates our NARM can be found in Issue 18 of the Common Network Output Measures Methodology[1], published on the Ofgem website.

[1] https://www.ofgem.gov.uk/system/files/docs/2018/08/noms_common_methodology_issue_18.pdf

Total Network Risk

As an effective asset manager, it is incumbent upon SHET to ensure that the level of network asset risk is monitored and managed to ensure the continued safe and secure operation of the network.

We have previously stated that the NARM is a function of the condition of the asset. As an asset ages, the expected and normal deterioration of asset condition will result in a steady increase of the risk of failure and NARM of the asset.

The total current Network Risk is therefore a summation of current NARM scores for all lead assets on the SHET network. The NOMs methodology allows us to calculate and model our NARM across a range of different scenarios. To do this we need to update the CBRM risk models to reflect the network changes that will take place between now and the end of RIIO-T1. We can then use CBRM to forecast an indicative NARM for the start of T2 and use the same model rolled forwards to 2026 to generate a T2 'non-intervention' NARM i.e. the forecast Network Risk if we took no action to refurbish or replace high risk assets during the T2 period.

By applying our proposed T2 business plan interventions to the model, we can also estimate the impact of the proposed intervention plan.

The SHET RIIO-T2 Draft Business plan shows an indicative NARM score for the SHET network at the start of the T2 period, as well as the modelled end point without any asset intervention (Figure 5).

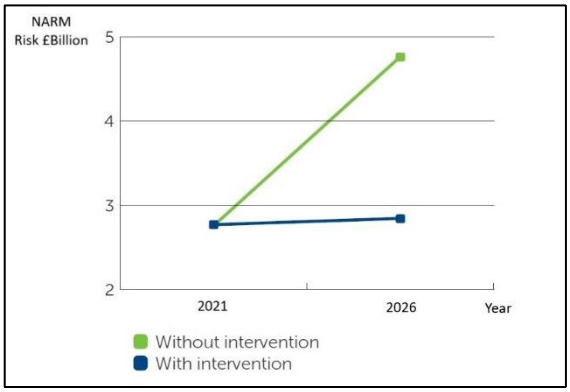

Figure 5 – SHET Indicative Network Asset Risk Metric Scenarios

These indicative NARM values were calculated in April 2019, during the final phase of the NOMs methodology development process that concluded at the end of July 2019.

The final modifications to the CBRM risk model calibration factors, undertaken during this period, will have an impact on the overall SHET predicted NARM score for the start of T2.

As SHET continue the development of our RIIO-T2 business plan, the risk model calculations will be reviewed and updated for the final T2 Business Plan submission in December 2019, when a T2 Network Risk target will be proposed.

3.3 SHET Condition-Based Asset Intervention Strategy

As a responsible Network Operator and Asset Manager, SHET continually monitors the condition and performance of our assets to ensure we operate the safe and secure network expected by our customers and stakeholders.

In previous sections of this paper we explain how the condition of the asset is linked to the risk of that particular asset failing and how we quantify this risk, by applying a consequence of the asset failing using our NARM process.

When we calculate the risk for each lead asset, we can obtain a high NARM score for an asset in good condition, where the impact on the network is high if that asset failed. Similarly, an asset in relatively poor condition will output a low NARM score if the impact on the network is low. This means that when deciding which assets should be considered for intervention during any time period, we look at their condition as the primary driver. Within our asset management system, we categorise the condition of our assets into 4 broad groups (Table 3).

1	Good Condition - No visible or quantifiable signs of deterioration
2	Good Condition – Minor visible deterioration only
3	Significant visible & quantifiable signs of deterioration – increased risk of failure within the medium term
4	Poor Condition – asset is approaching end of life

Table 3 – Asset Condition Scoring Methodology

Assets in groups 1 & 2 above do not require an intervention, even if the impact of their failure is significant to the network. The condition of these assets will be monitored through our normal condition monitoring, inspection & maintenance processes.

Assets in groups 3 & 4 are examined in more detail. This analysis & decisions made in this process are explained in section 4 of this paper, but there is an increased risk that some form of intervention will be required to return the condition & performance of assets in these groups to an acceptable level.

3.3 SHET Lead Asset Strategies

In the previous section, we identified Asset Condition as the primary driver for identifying if an intervention should be considered. In this section we describe the strategies we have developed to manage the deterioration of assets within each of our lead asset classes.

Transformers & Reactors

Transformers & Reactors are of similar construction but have very different functions on the SHET network.

Transformers connect parts of the network together that operate at different voltage levels. They are often the interface between the SHET network and the assets of our distribution system and generation customers.

Reactors are used to control voltage on the network or to change power flows. They have a key role to play at critical nodes on the network to ensure SHET operates a safe and secure network.

Figure 6 – 275, 120MVA Parsons Peebles SGT manufactured in 1970

The SHET strategy for Transformers & Reactors is to intervene before the asset fails. The potential consequences of an in-service failure are significant, due to the large volume of flammable insulating oil contained within each asset; the impact of a disruptive failure on the condition of nearby assets; and the impact to customers during the time taken to replace a failed asset.

The SHET RIIO-T2 Draft Business Plan proposes cost-effective, condition driven, risk-based interventions on 11 transformers from our asset base, operating at 275kV and 24 transformers operating at 132kV. SHET also proposes to deliver an intervention on 1 Reactor during the T2 period.

Circuit Breakers

Circuit Breakers are lead assets that act as switches on the transmission network and break the short circuit currents caused by faults.

There are two main types of circuit breaker on the network:

- GIS - gas insulated switchgear, where the equipment is fully contained within a metal chamber filled with Sulphur Hexafluoride (SF_6) insulating gas.
- AIS – air insulated switchgear (see picture), where the equipment connections are exposed to the air. These circuit breakers also typically contain smaller quantities of SF_6 gas within them.

Figure 7 – 132kV AIS Circuit Breaker

The SHET asset strategy for condition driven intervention on our circuit breaker population is very closely linked with our Environmental Strategy.

Leakage of SF_6 insulating gas from our GIS & AIS switchgear assets is a significant factor in our assessment of asset condition. Controlling the leakage of this harmful greenhouse gas is very important to SHET in our role as a responsible network operator and we closely monitor the performance of all SF_6 insulated assets. Where leakage is detected, immediate reactive interventions are taken to reduce or prevent any further occurrences.

This is a key strategy in our RIIO-T2 Draft Business Plan and forms part of our ambitious target to move towards a network for net zero.

To help deliver this ambitious target, SHET will reduce SF_6 leakage, relative to our network holding and asset growth during the RIIO-T2 period. To achieve this, our RIIO-T2 Draft Business Plan proposes that we will intervene on 3 of our population of 275kV circuit breakers and 62 of our 132kV breakers.

SHET has been trialling the use of alternative insulating gasses at both 132kV & 275kV during the T1 regulatory period. Where a cost-effective solution can be demonstrated, the intervention strategy for our 132kV circuit breakers will consider the use of these alternative insulating gas switchgear solutions.

<u>Underground Cables</u>

Underground cables comprise a relatively small, but important part of the SHET network. Like our overhead line network, cable systems are used to connect between our electricity substations, enabling the flow of energy around our network, predominantly within our larger population centres, like Dundee and Aberdeen, but increasingly to connect our HVDC assets using a combination of underground and submarine cable systems.

There are 3 main types of underground cable installed on the SHET network:

XLPE – the majority of our SHET cable assets are of XLPE (cross-linked polyethylene) construction. These assets are relatively new, in good condition and are not being considered for intervention during the T2 period.

Fluid-filled – SHET has a small amount of our cable network constructed from fluid-filled cables that use oil as their insulating medium. The remaining fluid-filled cables on the network are in a good condition for their age and are not being considered for intervention during T2.

Gas-Filled – SHET has a small amount of gas compression cables still installed on our network in the Aberdeen area. These two cables (approx. 12km total length) are at the end of their asset life and it is proposed to replace them with XLPE cable, during the T2 period.

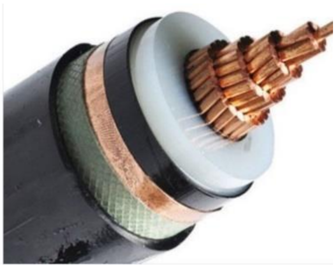

Figure 8 – 132kV XLPE Cable

Figure 9 – 132kV XLPE Cable Installation

Overhead Lines

The most visible of SHETs asset base is our overhead line network, connecting our electricity substations at 132kV, 275kV and 400kV voltage levels. The SHET network connects substations across the entire North of Scotland and SHETs overhead lines are regularly exposed to the harshest environmental conditions experienced by any transmission assets in the UK.

We identified in section 3.1 that overhead line systems are comprised of 3 lead asset classes. Each of these 3 components plays an important part in the construction of our overhead line network, but due to the different operational stresses they are subjected to, they have very different design lives.

Towers & Poles	Towers OHL towers (or pylons) are typically of steel lattice construction, with concrete foundations. They come in different sizes for different voltage levels and conductor configurations and provide the basic function of holding the conductor system at a safe distance from the ground. They typically 2 electrical circuits, one on each side of the tower, but also come in single circuit configurations.  Figure 10 – 132kV Steel Lattice Tower & Wood Pole Lines The anticipated life of a steel tower is 60-80 years, depending upon the environment it is in. Poles A significant part of the SHET OHL network is constructed using wood or composite poles. Pole lines are predominantly single circuit lines, providing a radial feed to substations and our generation customers and have an anticipated asset life of 40 years.

Conductors	Conductors are the current carrying component of our OHL assets and they are attached to our towers and poles by fittings. There are different configurations of conductor on the SHET network, depending upon the voltage of the power line and it's required current-carrying capacity. The vast majority of the conductor installed on the SHET 132kV network is of ACSR (Aluminium Conductor, Steel Reinforced) construction. This type of conductor can suffer from corrosion of the steel core, resulting in reduced strength & increased risk of failure.  **Figure 11 – Example of ACSR Conductor** The typical life of conductor, depending upon location & environment, is 40-60 years.
Fittings	Fittings are the mechanical components that connect the towers and poles to the conductor and also control the inherent vibration of the conductor. The anticipated asset life of fittings depends very much on the environmental conditions they experience, and it is not unknown for assets subjected to sustained periods of strong & extreme wind to reach an end of life condition in less than the 30-40 year anticipated asset life.

The SHET asset strategy for our OHL networks is to replace the earth wire and conductors where we have evidence that their condition has reached the point where further deterioration would increase the risk of failure to unacceptable levels, affecting the safe and secure operation of our network.

Similar detailed condition assessments are undertaken on our tower, wood pole and fittings assets to estimate their remaining asset life and determine the appropriate cost-effective interventions as a 'responsible operator' to minimise the impact of system outages on our customers and stakeholders.

The SHET RIIO-T2 Draft Business Plan identifies 291km of 132kV OHL routes for intervention during the T2 period.

4 Developing the Non-Load/Asset Intervention Plan

The previous sections of this paper have outlined the stakeholder-led principles and asset strategies that underpin the SHET asset intervention decision-making process.

In this section, SHET maps (see Figure 12) the rigorous, risk-based approach taken to apply these principles and strategies to identify, evaluate & select the cost-effective asset interventions that deliver the optimum value to consumers and ensure the safe and secure operation of the transmission network.

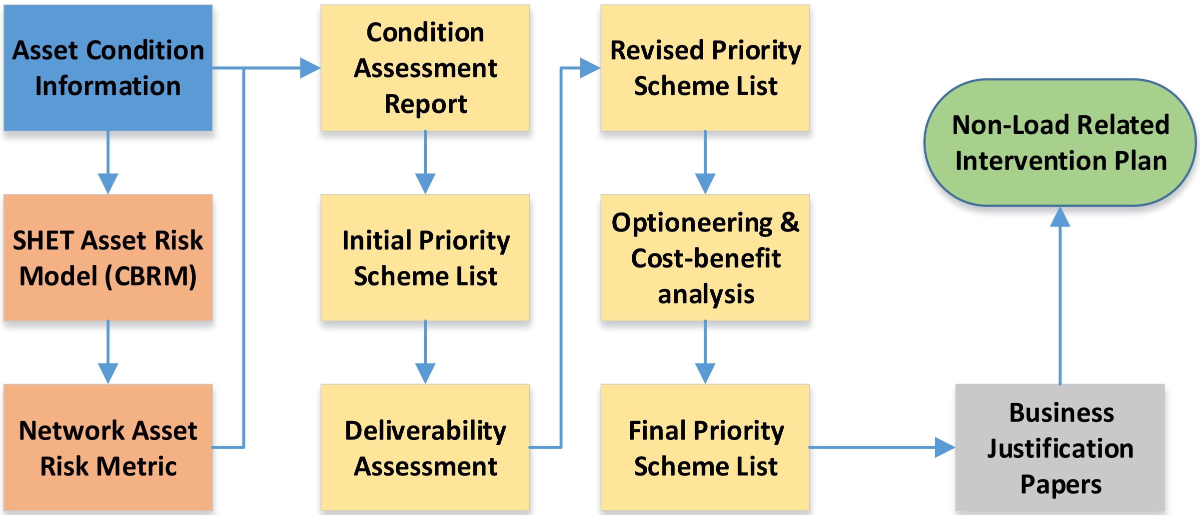

Figure 12 - Determining the SHET Non-Load Intervention Plan

SHETs asset intervention decision-making process is undertaken in 4 distinct & comprehensive phases, reflected in the colour-coded steps in Figure 12 above.

Phase 1 – Data Gathering, underpins SHET's approach to cost-effective, intervention decision-making by ensuring that accurate, up to date, asset condition information is the starting point for all projects.

Phase 2 – Risk-based Analysis demonstrates SHET's commitment to risk-based intervention decision-making by using our accurate asset condition information, within the complex CBRM risk modelling tool to calculate a monetised risk NARM score for all SHET lead assets.

Phase 3 – Optioneering is the lengthiest & most complex phase in the SHET asset intervention decision-making process. It involves the exercise of engineering & commercial judgement to develop the outputs of our Data Gathering & Risk-based Analysis phases into a portfolio of asset intervention options and associated lifetime benefits for consideration in our Draft T2 Business Plan.

Phase 4 – Non-Load Plan involves the development of the 29 Business Justification Papers that comprise the Draft T2 Non-load Intervention Plan. These papers summarise the outputs of the complex and rigorous assessments undertaken in Phases 1, 2 & 3 and propose the intervention that provides the most cost effective, safe & deliverable solution that delivers the highest lifetime benefit to consumers.

The key decisions made & outputs delivered from each of these intervention decision-making phases are examined in greater detail in the following sections of this paper.

4.1 Phase 1 – Data Gathering

Effective asset management requires accurate, up to date asset condition information. This is a primary requirement of SHET's intervention decision-making process as, over time, normal degradation of asset condition can lead to an increased risk of asset failure. If unchecked, this can have a significant detrimental effect on the transmission network and the homes and businesses connected to it.

To ensure our understanding of current asset condition is accurate, SHET undertakes periodic inspection and testing of our assets to assess and measure their condition, in accordance with our inspection, maintenance and condition assessment policies & guidance documents.

During a visual condition assessment of a substation or linear route asset, an experienced engineering team member will record the current inspected condition of each asset and sub-component of that asset, using the SHET Cyberhawk, tablet-based recording system. This system has 2 separate areas; iHawk, for the storage of all overhead powerline asset information; and iSims for the storage of all substation and cable asset information.

A score of 1-4 (see Table 4) is applied to each item inspected and where the score is 3 or 4, additional information is recorded and a digital images of the observed condition taken.

Figure 13 – SHET Inspection, Maintenance & Condition Assessment Timescales

1	No visible/quantifiable deterioration or damage
2	Apparent normal wear, intervention to be done in the next refurbishment
3	Significant deterioration or damage that requires some specific action or indicates increased risk of failure in the medium term.
4	Serious deterioration or damage that requires specific action in the short term. Also applies to any item found to be missing which would normally be expected to be present.

Table 4 – Asset Condition Scoring methodology

Visual Condition assessments are then reviewed, within the Cyberhawk system, by a senior member of the SHET field engineering team before the asset condition information is loaded into the SHET Asset Database - Maximo.

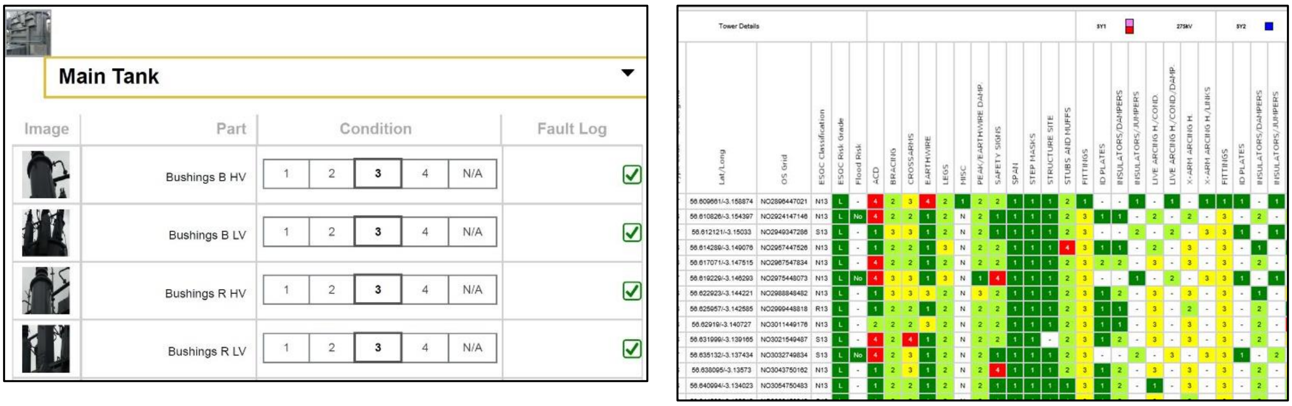

Figure 14 – Cyberhawk Data Inputs & associated Site Condition Matrix

In addition to visual condition assessments, SHET also undertakes inspections/testing to assess the internal condition of assets. This testing includes oil sampling & dissolved gas analysis for transformers & reactors and CORMON analysis of overhead line conductors & earth wires.

All SHET asset condition information, current and historical, is held within our Maximo asset database and is a key component in the decision-making processes used to identify and select the appropriate interventions to meet our asset management objectives.

4.2 Phase 2 – Risk-based Analysis

The risk-based analysis phase of our asset intervention decision-making process involves the calculation of the NARM for each lead asset. This process is detailed in section 3.2 of this paper and the output of this risk-based analysis phase is a series of NARM tables for each lead asset class, identifying the highest NARM score assets.

As previously stated, condition is the prime driver for SHET to consider intervention on an asset. The first step taken by the SHET Asset Management team in analysing the output of the NARM process is to determine the condition driver element of the NARM score for each asset.

Asset ID	Transformer Name	NARM £Risk Score	Probability of Failure Likelihood
100373342	GRID (2 WINDING) TFMR <> DYCE 132KV TRANSFORMER	£2,891,179	138%
100373434	GRID (2 WINDING) TFMR <> DYCE 132KV TRANSFORMER	£2,891,179	138%
100373592	GRID (2 WINDING) TFMR <> REDMOSS 132KV TRANSFORMER	£2,200,162	138%
100373502	SUPERGRID TRANSFORMER <> PETERHEAD 275KV TRANSFORMR	£1,978,648	138%
100373572	SUPERGRID TRANSFORMER <> PETERHEAD 275KV TRANSFORMR	£1,978,648	138%
100373497	GRID (2 WINDING) TFMR <> WILLOWDALE 132 TRANSFORMER	£1,433,602	94%
100373528	GRID (2 WINDING) TFMR <> WILLOWDALE 132 TRANSFORMER	£1,433,602	94%
100373532	REACTOR <> TEALING SGT3 CCT 33KV REACTOR	£661,979	85%
100373494	GRID (2 WINDING) TFMR <> BROADFORD 132 TRANSFORMER	£3,964,146	81%
100373435	GRID (2 WINDING) TFMR <> CLAYHILLS 132KV TRANSFORMER	£1,361,553	81%
100373492	GRID (2 WINDING) TFMR <> GLENAGNES 132 TRANSFORMER	£1,233,958	81%

Table 5 – Extract from SHET Transformer NARM table – filtered on Condition Score

This process removes those assets that are in good condition, but have a high consequence of failure, from consideration for intervention during the T2 period. The process also highlights those assets with low consequence of failure scores that are in poor condition and need to be considered for intervention during the T2 period – see Table 5 above.

4.3 Phase 3 - Optioneering

The next phase of the SHET asset intervention decision-making process (see Figure 12) involves the completion a number of different engineering assessments to:

1. Group potential asset interventions on a site/scheme basis within a detailed asset engineering condition report
2. Identify potential T3 enabling works that could be cost-effectively delivered at the same locations, within the T2 period
3. Consider the internal & external constraints on efficient delivery of the portfolio of proposed asset interventions and prioritise accordingly
4. Develop a range of intervention delivery options & undertake cost benefit analysis to determine the intervention that safely delivers the best lifetime benefit to consumers, within the deliverability constraints of the overall T2 Draft Business Plan portfolio of works

4.4 Optioneering Step 1 - Asset Engineering Condition Reports

The NARM tables (extract in Table 5) generated by the NOMs asset risk assessment process were reviewed by the SHET Engineering team to group the asset NARM scores on a site or linear route basis, forming an initial list of 43 asset intervention schemes for further development.

The engineering team then undertook detailed site inspections to:

- Review the asset condition information used in phases 1 & 2 against the current observed & measured asset condition on each site.
- Consider the range of potential asset interventions on each site that would maintain the condition & performance of the assets at the level required to maintain safe & secure operation of the network.
- As a responsible network operator, identify potential asset intervention options that could be brought forward from future regulatory periods as part of a single cost-effective project that minimises the impact of interventions to local stakeholder communities.
- Highlight potential constraints to be overcome in the delivery of the different asset intervention options identified.

The output of this process is a series of 43 Asset Condition Reports that provide the next phase of the SHET intervention decision-making process with a series of proposed risk-based intervention options, grouped on a site/linear route basis, to enable cost-effective delivery solutions to be developed & selected to deliver the highest lifetime benefit to consumers and ensure safe & secure operation of the transmission network.

Case Study: Port Ann-Crossaig 132kV Overhead Line

The Port Ann to Crossaig (PR1/PR2) 132kV overhead line (OHL) is located in Kintyre, connecting the Port Ann OHL Tee-off and Crossaig substation. Constructed in 1960, the circuits connected Inveraray to Carradale and were later tied in to Crossaig substation during its construction in 2015.

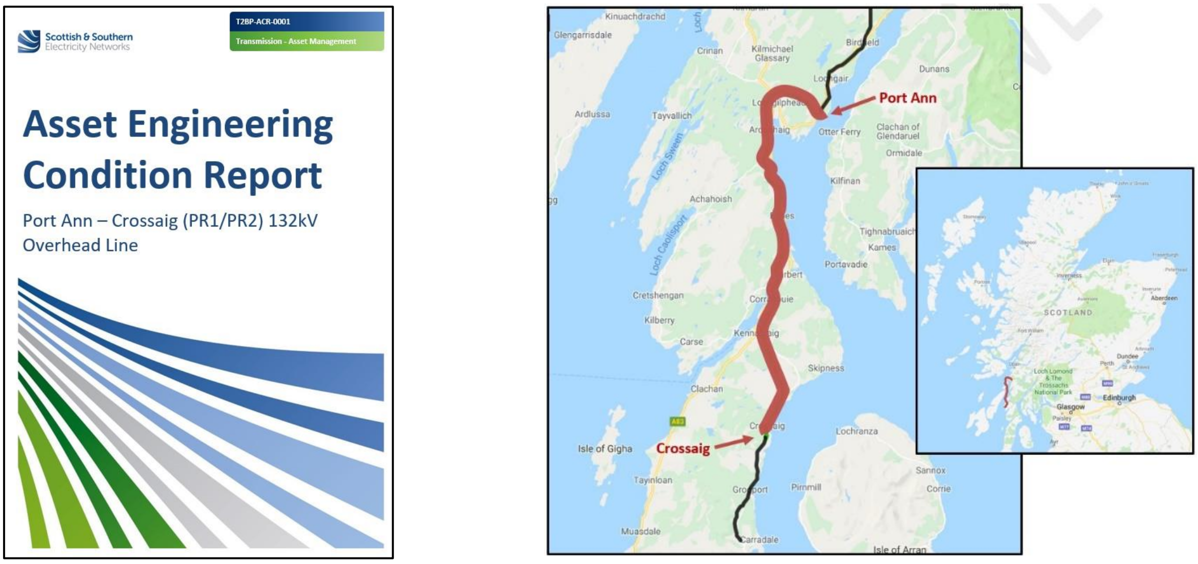

Figure 15 – Extract from Port Ann – Crossaig Asset Condition Report

A review of the asset condition information associated with Tower, Conductor & Fittings lead asset classes on this overhead line route produced the following results.

Towers

The overall condition of tower steelwork is poor with high levels of corrosion indicated throughout. A small number of damaged steelwork members are noted including one leg member. Replacement of any poor condition member should be addressed alongside a tower painting programme to preserve the remaining steelwork life.

Assessments carried out in 2018/19 have indicated the following corrosion condition:

Grade 1	Grade 2	Grade 3	Grade 4
1%	69%	19%	11%

Foundations

There are several foundations which require remedial works to address deterioration to both muff and stub concrete. Cracking, spalling and under-cutting have been identified which will require repair works to make right. Foundation assessment studies carried out in December 2014 identified the bitumastic coating to be poor throughout along with a number of additional historic design and construction issues relating to the below-ground foundation structure.

Visual assessment of the **tower foundations** has provided condition scorings of both foundation muffs and foundation stubs as follows:

Grade 1	Grade 2	Grade 3	Grade 4
61.5%	35.1%	1.8%	1.6%

Fittings
With the exception of one broken insulator dish, all other insulator sets are in sound condition both mechanically and electrically with only minimal rusting present.

There is significant deterioration on approx. 23% of U-bolts & shackles, which will require replacing .

The assessment of **fittings** has identified the following condition gradings based upon assessment of u-bolts and shackles:

Grade 1	Grade 2	Grade 3	Grade 4
76.9%	0%	17.0%	6.1%

Conductor
The phase conductors have been assessed in 2018 by testing of samples. This identified a remaining service life of 15-20 years indicating an expected end of service-life in 2033/38. All samples tested exceeded the required number of turns-to-breakage and minimum breaking load values. Grease coverage was found to be adequate and remained in a golden, pliable state.

There is no earth wire provision on the route.

Extract from External Consultant Condition Assessment Report
"The external surface of both conductor samples exhibited typical levels of grey discolouration caused by the surrounding environment and pollution effects. Internally the conductor was found to be relatively free from both debris' ingress and corrosion product. The conductor was found to be adequately greased throughout. This grease was overall both golden in appearance and pliable. There was no evidence of steel core strand degradation."

"When torsion tested, a new aluminium conductor strand is expected to give greater than 25 turns before failing. Both conductor samples achieved average turns to failure greater than 25. This suggests that no significant reduction in the ductility of the conductor strands has occurred. "

"The calculated breaking load of both conductor samples were found to exceed the British Standard specified minimum breaking load of 57.87kN for ACSR conductor of type Tiger."

"The thermal properties of the grease were found to be satisfactory, with no significant grease loss observed after prolonged exposure to 100°C."

If SHET were to consider this OHL route as a collection of individual assets only – the following interventions should be developed for delivery during the RIIO-T2 period:

a. Replacement of tower fittings including but not limited to u-bolts, shackles and links.
b. Surface preparation and repainting of tower steelwork.
c. Replacement of damaged steelwork.
d. Foundation remedial works to stubs & muffs
e. Replace broken insulator dish at tower 169.
f. Replace degraded tower signage.
g. Repair Anti-Climbing Device's as identified.

As a responsible Network Operator, SHET considers both the condition of the individual assets that comprise the overhead line route and the overall performance of the overhead line route within the wider SHET network, in our intervention decision-making processes. This approach is highlighted by two key route performance assessment analyses, within the Asset Condition Report:

1. There are significant issues with the protection arrangements and the general fault performance on the IAE/AEP/PR2 and IDW/DPW/PR1 circuits between Inveraray and Crossaig inclusive of the Port Ann to Crossaig line sections. The Circuits are some of the worst performing circuits on the network and require future **provision of an earthwire** and **Category 1 communications** link to address the identified limitations. The continued long-term use of the current protection arrangements is inadvisable.

2. The year 2013 saw failure of the overhead line system following a severe weather event in the Argyll and Bute region. A regional network outage was caused by the structural failure of multiple lattice support structures which were subsequently restored by installation of short sections of wood pole trident OHL within the impacted spans. The occurrence of this failure has highlighted **the higher 'risk of failure' present because of the inherent design limitations of the bespoke tower suite utilised in this construction**.

One of SHETs Guiding Principles for our stakeholder led, asset intervention decision-making process, outlined in Figure 3 of this paper, is to ensure that, as a minimum, our proposed interventions result in an asset that meets current engineering technical specifications, so the Project Optioneering phase (section 4.6) will address these key findings. To deliver our 'Responsible Operator' obligations, the Optioneering team will also determine if there are any Load-related drivers associated with the network that could impact this asset, to ensure that they are addressed to ensure minimal disruption to our Customers & Stakeholders.

4.5 Optioneering Step 2 - Project Deliverability Assessment

The initial prioritised intervention scheme list was taken to a project deliverability assessment review panel containing subject matter experts from all areas of the SHET business including: Asset Management, Project Development, Finance, Outage Planning, Capital Delivery, Commissioning & Operations.

The list of proposed interventions and their associated asset condition report were subjected to a comprehensive & rigorous review, by the expert panel, against a series of criteria associated with the overall deliverability of each intervention option.

These criteria included:

- An assessment of safety associated with the most cost effective and efficient methods of delivery for each of the proposed intervention options
- The impact of Load or Customer driven projects proposed for delivery on the network during the T2 period
- An assessment of system outages required to deliver each asset intervention and associated constraints with other proposed portfolio of T2 interventions on the network.
- Potential cost efficiencies that could deliver significant consumer benefits by grouping or clustering interventions.
- Internal and supplier resource requirements to efficiently and cost-effectively deliver each phase of the proposed intervention portfolio

The initial output of this detailed assessment process was the identification of 10 proposed asset interventions that could not be considered for further development during the T2 period. Table 6 identifies the specific interventions and the reason why no further asset-related intervention development works would be undertaken for the non-load element of the RIIO-T2 Business Plan.

In 9 of the 10 projects listed in table 8, the asset-related condition risk will be addressed by the intervention works proposed by load-related projects, within the SHET RIIO-T2 Draft Business Plan. The asset condition risk associated with the proposed Persley substation interventions will be managed through the use of a programme of asset inspection & condition monitoring interventions by our Field Operations team.

Proposed Intervention	**Reason for Removal**
Kintore/Persley/Peterhead 275kV	Inclusion within North-East Coast Load Strategy
Persley	Outages not available due to Kintore Scheme
Alyth / Kincardine 275kV	Inclusion within North-East Coast Load Strategy
Tealing / Lunanhead 132kV	Inclusion within North-East Coast Load Strategy
Kintore / Fetteresso / Alyth 275kV	Inclusion within North-East Coast Strategy
Fiddes / Brechin 132kV	Superseded by Load-Related Works
Craigiebucker / Fiddes 132kV	Superseded by Load-Related Works
Arbroath T / Brechin 132kV	Inclusion within East Coast Load Strategy
Tealing / Alyth 275kV	Inclusion within East Coast Load Strategy
Glenfarclas/Boat of Garten 132kV	Superseded by Load-Related Works

Table 6 – Proposed asset-related interventions – removed from T2 Business Plan

Following this initial filtering process, the project deliverability assessment review panel then geographically 'clustered' the remaining asset interventions to ensure that all potential delivery efficiencies could be explored during the detailed Optioneering & Cost-benefit analysis phase of the asset intervention decision-making process.

Scheme Cluster	No of Proposed Schemes in Cluster
Skye	7
Beauly - Deanie	6
Aberdeen	3
Dundee	2
Non-clustered Projects	18

Table 7 – Proposed Geographical Scheme Clusters

After the clustering was completed, a wider business review was carried out on the entire RIIO-T2 portfolio to consider further potential efficiencies of scale. This review highlighted a significant number of proposed works in the Skye region of the network, including the Skye Cluster listed in Table 7. It was determined that there was opportunity to make significant efficiency savings for the consumer if all these works were “ring-fenced” and managed as one, larger strategy. Accordingly, the Skye cluster was removed from the Non-Load Intervention Plan, leaving 29 schemes proposed for further development by the SHET Engineering team.

4.6 Optioneering Step 3 - Project Optioneering & Cost Benefit Analysis

The decision-making processes undertaken by SHET to this point have identified a portfolio of asset interventions to undergo further engineering assessment, to determine the most cost-effective way to safely deliver these potential projects.

This process, known as Optioneering, develops and costs all practical delivery methodologies for each of the intervention options identified.

These deliverability options will typically include asset refurbishment or replacement solutions as ‘do nothing’ or ‘maintain’ options will have been discounted due to the asset condition information assessment undertaken prior to optioneering.

It is at this phase that some potential asset intervention options may be rejected for a number of reasons, including:

- **Safety and the ability to undertake the works in a safe, efficient manner.**

  An example of this could be the design of the existing substation, built in the 1960s/70s, within a constrained area. In-situ replacement of the existing assets could result in excessive risk of infringing safety clearances to adjacent circuits.

- **Outage requirements and associated impact on the overall portfolio of works & customers.**

  An example of this could be the refurbishment option for a transformer. While refurbishment is a viable technical option, the outage timescales required to facilitate this option could have a significant and unacceptable adverse effect on customers connected to that section of the network.

- **Adverse environmental impact to local community & other stakeholders**.

  An example could be related to the in-situ replacement of assets within an urban environment. The noise and disruption caused by major construction works could be considered unacceptable by local communities and stakeholders.

A fully costed engineering solution is then developed for all remaining delivery options. In some cases, the most cost-effective & deliverable solution could involve the removal of assets that are in good condition. In all instances where this happens, SHET will look to redeploy the recovered asset, elsewhere on our network or retain the asset as a strategic spare.

Case Study – Beauly 275kV & 132kV Substation

The Asset Condition Report for Beauly 275kV & 132kV substation recommended the following interventions be considered and options developed:

- Replace SGT2, SGT4 and SGT6.
- Replace the 132kV substation with a new fully selectable double busbar with the addition of bus couplers and bus sections to improve network operability and resilience. This should include for appropriate associated ancillary plant and equipment to current specifications including the 132kV protection scheme. The protection replacement should include relevant remote end work.

The Engineering development team undertook a detailed optioneering analysis of the site and concluded that there were a number of alternative solutions available to meet the Asset Condition Report recommended interventions.

Option	Option Detail	Taken forward to CBA?
1	**In-situ replacement of SGT 2, 4 & 6 and offline GIS 132kV board build to west of existing**	**Yes**
2	**In-situ replacement of SGT2, 4 & 6 and offline GIS 132kV board build relocating telecoms building**	**Yes**
3a	**Offline replacement of SGT2, 4 & 6 and offline GIS 132kV board build to west of existing**	**No**
3b	**Offline replacement of SGT2, 4 & 6 and offline GIS 132kV board build relocating telecoms building**	**No**

The report identifies that options 3a & 3b do not go forward for further consideration, due to the limitations that the proposed cable installations would place on any future substation development.

4.7 Phase 4 – The Non Load Plan for RIIO-T2

The final phase of the SHET asset intervention decision-making process is the development of a Business Justification paper for each of the 29 proposed intervention schemes.

The Business Justification Paper brings together the key decisions and justifications, from each phase of the asset intervention decision-making process into a single document.

Each deliverable and costed intervention option will undergo a cost-benefit analysis to determine the overall lifetime benefit of the intervention to consumers.

The conclusion of the Business Justification paper is the intervention that SHET can evidence, provides the best lifetime value to consumers and forms part of the SHET RIIO-T2 Draft Business Plan.

Tables 8 & 9 identify the 29 schemes that comprise the £690M of proposed asset interventions SHET believe are necessary to deliver value to the consumer and ensure the safe and secure operation of the electricity transmission network.

Certain View - Non Load Related Schemes					
Scheme Name	Asset Category	Scheme Description	Output	RIIO-T2 Cost	Scheme duration
CGN/CGS (Charleston (Elmwood)/Glenagnes)	NLRE	Replacement of 3.6km 132kV UGC	NARM	inc below	2019-2023
Dudhope GSP	NLRE	Replacement of existing Tx's	NARM	inc below	2021-2026
Keith	NLRE	Replacement GIS switchgear	NARM	inc below	2021-2025
Kintore	NLRE	Replacement GIS switchgear & Tx's (x4)	NARM	inc below	2021-2025
Peterhead	NLRE	Replacement Tx's (x2)	NARM	inc below	2021-2025
Peterhead / Inverugie 132kV (8km DC tower line)	NLRE	Replacement tower fittings	NARM	inc below	2021-2024
Redmoss	NLRE	Replacement Tx's & Switchgear	NARM	inc below	2022 -2023
RFE/RFW (Redmoss/Clayhills)	NLRE	Replace existing 132kV UGC (4.8km)	NARM	inc below	2021-2024
Tealing (SGT and R3)	NLRE	Replace SGT3 & Reactor R3	NARM	inc below	2021-2026
Willowdale	NLRE	Replacement of GT(x2) & switchgear	NARM	inc below	2022-2026
Total				**£242 million**	

Table 8 – SHET Draft RIIO-T2 Non-Load Business Plan for Eastern Region

Certain View - Non Load Related Schemes					
Scheme Name	**Asset Category**	**Scheme Description**	**Output**	**RIIO-T2 Cost**	**Scheme duration**
Port Ann / Crossaig 132kV (49km DC tower line)	NLRE	Re-build of existing 132kV OHL	NARM	inc below	2021-2025
Sloy	NLRE	Replacement of 132kV GT's	NARM	inc below	2021-2024
Sloy / Windyhill East 132kV (15km DC tower line)	NLRE	Tower painting & earthwire replacement	NARM	inc below	2021-2023
Sloy / Windyhill West 132kV (15km DC tower line)	NLRE	Tower painting, replacement fittings & foundation repairs	NARM	inc below	2021-2023
Whistlefield / Dunoon 132kV (17km DC tower line)	NLRE	Re-build of existing 132kV OHL	NARM	inc below	2019-2024
Aigas PS	NLRE	Replacement of GT1 and associated plant	NARM	inc below	2022-2026
Beauly (SGTs) & Busbar	NLRE	GIS Substation Build & replace GT2/4/6	NARM	inc below	2020-2024
Beauly / Deanie 132kV (23km SC tower line)	NLRE	OHL full refurbishment	NARM	inc below	2020-2023
Broadford (Condition Driven GT1)	NLRE	Replacement of SGT1 & SGT2	NARM	inc below	2021-2026
Culligran PS	NLRE	Replacement of GT1 and associated plant	NARM	inc below	2022-2026
Deanie PS	NLRE	Replacement of GT1 and associated plant	NARM	inc below	2022-2026
Foyers	NLRE	Replacement of Gen Tx & swithgear	NARM	inc below	TBC
Glenmoriston GT1	NLRE	Replacement of GT1 and switchgear	NARM	inc below	TBC
Invergarry T 132kV (2.4km SC tower)	NLRE	Tower painting & Conductor replacement	NARM	inc below	2023-2025
Kilmorack PS	NLRE	Replacement of GT1 and associated plant	NARM	inc below	2022-2026
Quoich Tee	NLRE	Replacement disconnectors & Earth Switch	NARM	inc below	2022-2024
St Fillans	NLRE	Replacement of GT1 and associated plant	NARM	inc below	2019-2026
Tummel Bridge	NLRE	Replacement Tx's & Switchgear	NARM	inc below	2019-2026
Harris / Stornoway 132kV (58km Wood pole)	NLRE	Full rebuild with composite pole.	NARM	inc below	2018-2024
Total				**£448 million**	

Table 9 – SHET Draft RIIO-T2 Non-Load Business Plan for Argyll, Central & Western Isles Region

Scottish & Southern Electricity Networks

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