SSEN Transmission

RIIO-T2 Business Plan

Skye Overhead Line Reinforcement Strategy

1 Executive Summary

The Skye transmission network consists of a single 132kV overhead line that extends over 160km of challenging terrain from Fort Augustus 400kV substation to Ardmore on Skye. From Ardmore, there are two SHEPD owned 33kV subsea cables; one to Loch Carnan on South Uist and the other to the Isle of Harris. The 132kV transmission circuit continues from Harris to Stornoway. The security of supply on Skye and the Western Isles is dependent on the Skye circuit as the only connection to the main GB electricity grid.

The 9km line section from Fort Augustus to the Skye Tee point is of trident wood pole construction, completed in June 2017. From Skye Tee to Quoich, we are currently installing 19km of trident wood pole to replace single circuit steel lattice towers dating from 1956. The 64km line section from Quoich to Broadford is supported by double circuit steel lattice tower structures, strung on one side only, completed in 1980. The last 68km section from Broadford to Ardmore is of trident wood pole construction, built in 1989. Our rigorous asset assessment methodology demonstrates that there is a strong need for intervention on the 132km line section between Quoich and Ardmore before 2030.

In addition to asset risk, there are both demand and generation needs to be met on the Skye transmission network. To restore supplies during prolonged outages of the Skye transmission circuit, SHEPD relies on mobile and fixed diesel generators on Skye and the Western Isles. Given the light construction of the transmission line, over the most challenging terrain, its reliability is poorer than other lines. This line has an environmental impact due to the high carbon intensity of the backup diesel generators. Working with SHEPD, there is an opportunity to improve security of supply.

The amount of generation connected on the Skye circuit (137MW) exceeds the rating of the existing line, with an additional 177MW either contracted to connect of offered connection and a significant further volume having expressed interest to connect. In this Skye overhead line reinforcement strategy, we set out potential future generation growth scenarios to cover a credible range of possible outcomes, including net zero pathways.

In developing potential solutions to meet the identified need, we considered technical, environmental and geographic constraints on the design and safe operation of the assets along with views expressed by stakeholders. We have used a scenario-based pathway approach, where we look into the medium to long term network requirements and identify potential development pathways for the network. This allows us to compare incremental developments of the network to balance investment and operational costs, the risk of asset stranding, the economic and environmental impacts of frequent interventions, and impacts on end consumers. A cost benefit analysis (CBA) was undertaken on the shortlisted pathways to refine the list further. Based on the outcome of this analysis, further detailed analysis was undertaken considering line section capacity requirements, more localised environmental constraints and stakeholder feedback to date.

The outcome of this work is certainty over the need to intervene and economic appraisal confirms the net benefits of replacing the overhead line between Quoich and Ardmore as soon as possible. As part of our RIIO-T2 Business Plan we are proposing a two-stage regulatory framework for the approval of this capital investment:

1. In this strategy paper, we set out the evidence of a certain need for investment, along with the comprehensive approach we have taken to assessing the investment options.
2. A reopener mechanism that allows us to make a within-period application for the efficient cost of construction following the outcome of the statutory planning process.

We understand the concerns of some stakeholders about the construction of new transmission infrastructure between Fort Augustus and Ardmore. We remain committed to working with all stakeholders to find the solution that meets local community, generator, environmental and GB society needs.

Contents

2 Introduction

This paper sets out our plans to undertake the Skye network reinforcement work during the RIIO-T2 period (April 2021 to March 2026). The planned work covers the full 160km length of the Skye 132kV single circuit overhead line (OHL) from Fort Augustus substation to Ardmore on the Isle of Skye as shown in Figure 1.

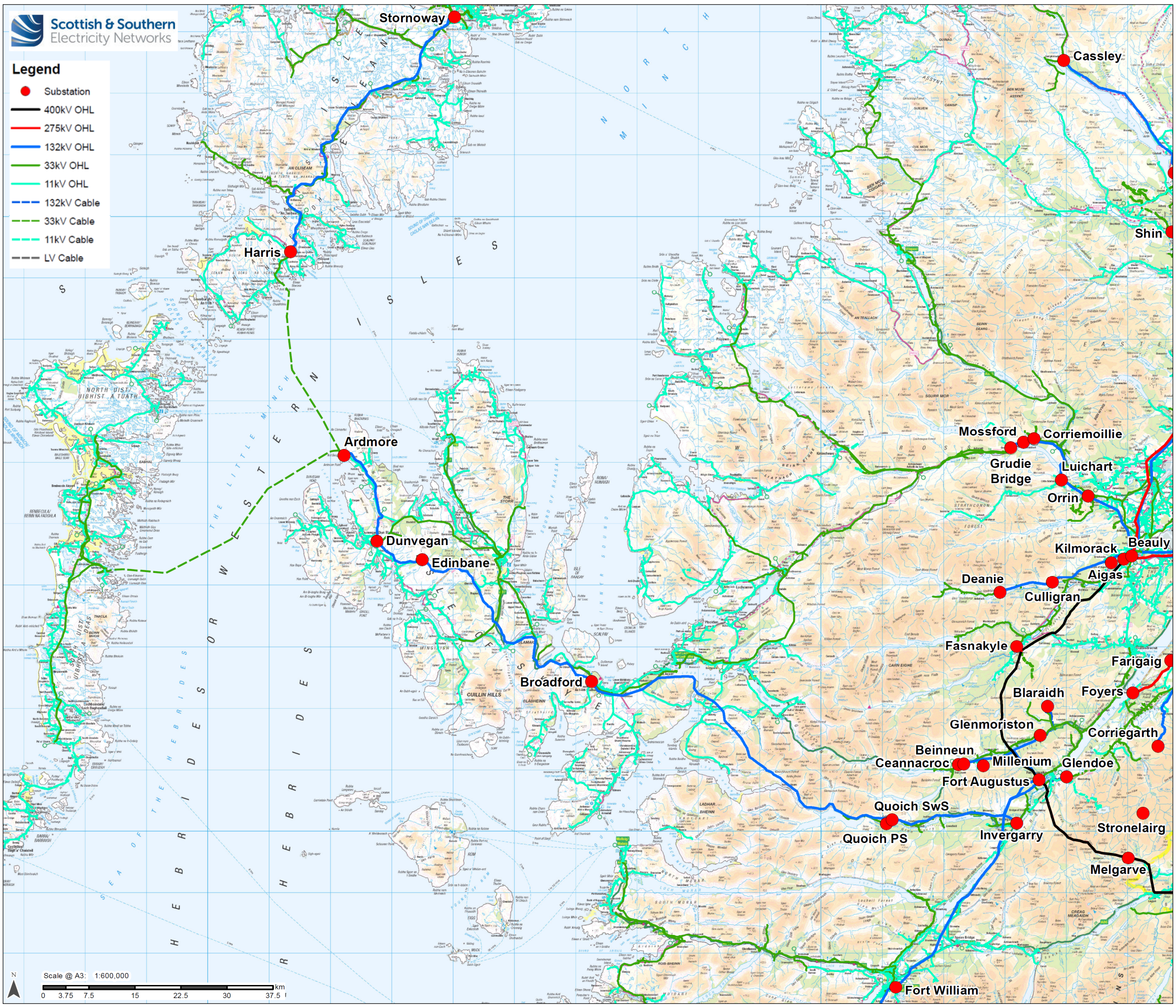


Figure 1. The Skye circuit overlaid on the geographical map, showing the connection to the Western Isles

The existing line is approaching the end of its economic life. Asset condition assessment of the line has identified the need to intervene in order to continue to safely operate the line and provide supply security on this part of the network. Separate to this, there is a requirement to increase the capacity of the line, mainly driven by requests from developers to connect renewable generation on the line, including on the Isle of Skye.

The strategy paper is structured as follows:

Section 3: Background
This section provides background information to the Skye reinforcement project. It describes the Skye transmission network and covers the network compliance position, previous network developments and recent performance issues of the line.

Section 4: Need
This section provides an explanation of the need for the planned works. It provides evidence of the primary and secondary drivers for undertaking the planned works. Where appropriate it provides background information and/or process outputs that generate or support the need.

Section 5: Optioneering
This section presents all the options considered to address the 'need' that is described in Section 3. Each option considered here is either discounted at this Optioneering stage with supporting reasoning provided or is taken forward for Detailed Analysis in Section 6.

Section 6: Detailed Analysis
This section considers in more detail each of the options taken forward from the Optioneering section. Where appropriate the results of Cost Benefit Analysis are discussed and together with supporting objective and engineering judgement contribute toward the identification of a selected option.

Section 7: Conclusion
This section provides summary detail of the selected option. It sets out the scope and outputs, costs and timing of investment and where applicable other key supporting information.

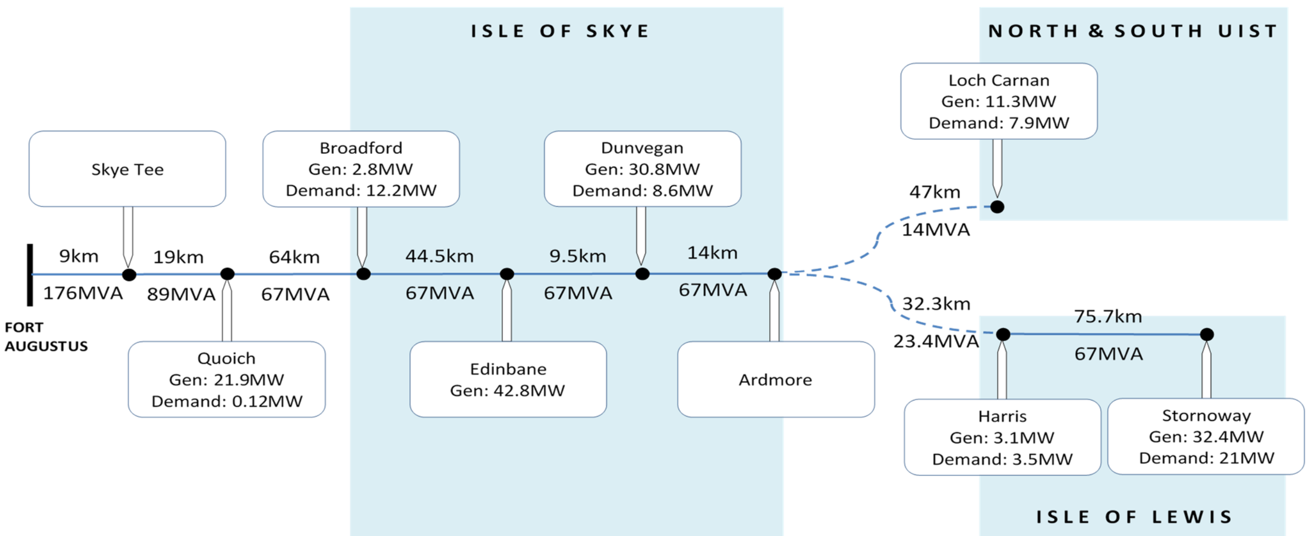
3 Background

This section provides background information to the Skye reinforcement project. It describes the Skye transmission network and covers the network compliance position, previous network developments and recent performance issues of the line.

The Skye transmission network consists of a single 132kV OHL extending over 160km of challenging terrain from the Fort Augustus 400kV substation on the mainland to Ardmore on the Isle of Skye. From Ardmore, there are two Scottish Hydro Electric Power Distribution (SHEPD) owned 33kV subsea cables; one to Loch Carnan on South Uist and the other to Harris on the Isle of Lewis. The line continues from Harris as a 132kV transmission circuit to Stornoway. The security of supply on Skye and the Western Isles is dependent on the Skye circuit as the only connection to the main GB electricity grid. To enhance supply security on the Western Isles, there are SHEPD owned backup diesel generators at Battery Point and Arnish (both connected at Stornoway) to support the Isle of Lewis and diesel generators at Loch Carnan and Barra to support the Uists. Additionally, SHEPD use mobile backup diesel generation to secure supplies on the Isle of Skye.

In June 2017, SHE Transmission completed the Skye Tee project in order to accommodate generation connections on the Fort Augustus to Fort William 132kV line. Prior to June 2017, the Skye circuit tee'd off the west circuit (FFW) of the Fort Augustus to Fort William 132kV double circuit OHL. As part of the Skye Tee project, approximately 9km of new 132kV single circuit OHL was established to connect Skye and the Western Isles directly to Fort Augustus, independent of the Fort Augustus to Fort William line.

Technical details of the Skye and Western Isles transmission network are shown in Figure 2, including the line section lengths, line ratings and the generation and demand connected at various locations along the line. The 9km section from Fort Augustus to the Skye Tee point runs in parallel to the Fort William line and is



Generation capacity at Stornoway excludes 39MW of diesel generation

Figure 2. Technical details of the Skye and Western Isles network

of trident wood pole construction, completed in June 2017. From Skye Tee to Quoich the 19km section is of a single circuit steel lattice construction and was completed in 1956. The 64km line section from Quoich to Broadford is supported by double circuit steel lattice tower structures, strung on one side only, completed in 1980. Construction of the 68km line section from Broadford to Ardmore is trident wood pole and was completed in 1989.

Due to the limited rating of the subsea cable to the Isle of Lewis, generation exports are managed to within the rating of the cable. This is essential for the continued safe operation of the cable. During times of high demand on Western Isles, the cable also presents power import constraints onto the Western Isles, resulting in the need to either reduce demand or start up local diesel generators in order to maintain supply to the Isle of Lewis. SHEPD is currently working on a flexibility services initiative[1] to manage the demand within the rating of the cable.

There is a significant volume of further generation capacity contracted to be connected on the Western Isles. To accommodate this, SHE Transmission has prepared and submitted a Needs Case to Ofgem for a High Voltage Direct Current (HVDC) link solution to connect the Western Isles to the main GB transmission network at Beauly substation in Inverness-shire. At this point, we have not yet secured approval from Ofgem to progress the link. We also note that although approximately 240MW of contracted generation capacity on Western Isles was successful in the third round of the Contracts for Difference, this alone may not be enough to make the HVDC link pass the economic threshold.

The 33kV subsea cables between Ardmore and Harris and between Ardmore and Loch Carnan were commissioned in 1990. SHEPD is assessing the condition of these cables and the results of this assessment are expected to be known by April 2020. It is expected that this cable will be approaching the end of its economic life in the near future. On replacement, of the cable, it is likely that the capacity of the cable will be increased, taking advantage of advances in technology which allow higher capacities to be realised on subsea cables in order to address known constraints and create headroom for growth. The sizing of the subsea cable would in part be dependent on the outcome of the Western Isles HVDC link needs case.

In addition to connected generation on Skye, the likely increase in rating of the subsea link to the Western Isles would result in higher levels of power flow on the Skye circuit. Due to the radial nature of the Skye circuit, the loading on the line increases towards the Fort Augustus substation.

The amount of generation connected to the existing Skye single 132kV circuit exceeds the rating of the existing line when considering the level of demand connected, making this part of our network non-compliant with the National Electricity Transmission System (NETS) Security and Quality of Supply Standard (SQSS). Based on the condition that National Grid Electricity System Operator is able to manage the generation on this line economically, we applied to Ofgem for derogation from the relevant criteria of the SQSS and this was granted in 2010[2]. Connection of additional generation beyond what was assessed at the

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[1] Scottish and Southern Electricity Networks flexibility services page: https://www.ssen.co.uk/FlexibleConnections/
[2] The Ofgem letter on the granting of the derogation is available online at https://www.ofgem.gov.uk/ofgem-publications/52816/100709shetl-western-isles-decisionpdf

time was contingent upon undertaking the necessary reinforcement to the line in accordance with the relevant criteria of the SQSS.

In November of 2018, a 1km long landslip occurred near the Loch Quoich Dam. The landslip struck and severed the 132kV Quoich to Broadford OHL resulting in supply interruption affecting the Isle of Skye and the Western Isles. The structures damaged by the landslip were replaced with a temporary trident wood pole diversion. The temporary restoration took 10 days from the time of failure, including time to carry out initial stabilisation works and regain access. A permanent bypass was completed in early summer 2019. This event demonstrated the vulnerability of the network on Skye and Western Isles and its dependency on backup diesel generation.

SHE Transmission has reviewed and updated its strategy for the Skye transmission network reinforcement based on asset condition information of the Skye circuit and following recent renewable developer interests in connecting renewable generation on Skye and the Western Isles. The Skye reinforcement strategy objective is to develop the best sustainable long-term solution with due consideration to the environment, security of supply and affordability, guided by stakeholder feedback.

4 Need

This section provides an explanation of the need for the proposed Skye reinforcement. It provides evidence of the primary and secondary drivers for undertaking the planned works. Where appropriate it provides background information and/or process outputs that generate or support the need.

We take a whole system long term view[3] when considering network needs. To meet future generation and demand capacity requirements and maintain security of supply, both the generation and demand backgrounds (load requirements) and the risk associated with the current asset condition of the existing overhead line (non-load requirements) were considered in developing the Skye reinforcement strategy. In order to reach a long-term economic solution, we must look beyond currently connected, contracted and scoping generation recognising the cost and environmental impact of any significant network augmentation in the short to mid-term.

4.1 Non-Load Need

Our paper on Net Zero – A Risk Based Approach to Asset Management[4] details our approach to risk-based asset management. In this approach, we compare the monetised risk of 'no intervention' against the intervention' options. While monetised risk is denoted as a financial figure, it is important to note that it is not "real" money and does not correspond to the cost that SHE Transmission would incur if an asset was to fail and these values are thus identified with R£ prefix.

In addition to assessing the risk reduction achieved from intervention in the short term, a long-term benefit is also determined. The long-term benefit is derived by consideration of the risk of the asset experiencing a catastrophic failure weighted by the probability that the asset will survive for the Options and "no intervention" scenarios. The lifetime benefit is an aggregation of the risk of all assets being considered within the option. The risk of each Option is then compared with the "no intervention" scenario. The "no intervention" scenario assumes that when the asset experiences a catastrophic failure the asset is replaced. Summary details of the asset condition, and specific scope and timescales where appropriate, are provided below.

Asset condition monitoring on the existing Skye circuit and a series of different condition assessments undertaken over the last twelve months indicate the need for intervention on the 132kV line between Quoich and Ardmore. Intervention is also required at various substations along the line. Risk Analysis was carried out to determine the need for asset intervention on the Skye project based on the Condition Based Risk Management (CBRM) methodology. Summary details of the asset condition, and specific scope and timescales where appropriate, are provided below based on the interpretation of Asset Health Indices shown in Table 1.

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[3] Our Enabling Whole Energy System Outcomes Policy is available online at https://www.ssen-transmission.co.uk/riio-t2-plan/enabling-whole-energy-system-outcomes-policy/

[4] Net Zero – A Risk Based Approach to Asset Management, SHE Transmission paper available online at https://www.ssen-transmission.co.uk/riio-t2-plan/a-risk-based-approach-to-asset-management/

Table 1. Health Indices used in CBRM and what they refer to in terms of decision making.

Actual Asset Life													Theoretical Life for Decision Purposes				
Normal Operation					Material Deterioration			End of Life					Projected End of Life				
1	2	3	4	5	5.5	6	6.5	7	8	9	10		11	12	13	14	15

4.1.1 Fort Augustus to Quoich

The section from Fort Augustus to Quoich consist of two subsections as follows:

4.1.1.1 Fort August to Skye Tee

The Fort August to Skye Tee section was recently rebuilt with 176MVA trident wood pole line as part of the Skye Tee project completed in 2017; and are no asset condition issues on this section.

4.1.1.2 Skye Tee to Quoich

The asset condition is driven by the conductor condition. The estimated remaining life of the asset is between 3 and 5 years (2022 – 2024). A project is in progress to replace this line section with a 176MVA trident wood pole line by 2021. The works will also operate as a bypass for any future Skye circuit works minimising construction outage time.

4.1.2 Quoich Tee Switching Station

The Quoich Tee Switching Station is proposed to be replaced between 2021 and 2026 based on asset condition. The short line section from the switching station to the Quoich power station and the generator substation do not require intervention on asset condition basis.

4.1.3 Quoich to Broadford

Results from the Quoich to Broadford line assessment indicate that this section will need to be replaced within the next ten years (by 2029). This existing line design is not economical to refurbish as much of the steel work would require replacement to satisfy design loadings and the outages required would be significant.

Table 2 shows that monetised risk for the Quoich to Broadford line section will more than double between 2019 and 2026, with the health index for the conductors and towers reaching a value of 7.45 and 7.77 respectively by the end of the RIIO-T2 period. According to Table 1, these health indices indicate that the conductors and towers are approaching end of life.

Table 2. Health indices and monetised risk for the Quoich to Broadford line section (average for line section)

Line section	Asset type	2019		2026	
		Health Index	Monetised risk (R£)	Health Index	Monetised risk (R£)
Quoich to Broadford	Fittings	0.60	71,028	1.20	75,056
	Conductors	5.5	101,543	**7.45**	224,975
	Towers	4.00	120,883	**7.77**	360,998

4.1.4 Broadford GSP substation

The original Broadford GSP substation was constructed in the 1950's. The site has undergone periods of refurbishment, notably Grid Transformer 1 (GT1) installation in 1978 and the 132kV circuit breaker replacement in 1989. The 132kV circuit breaker is of a type known to have a poor gas leakage performance and its asset health index indicates that it will be at the end of its life by 2026 as shown in Table 3, with the monetised risk tripling between 2019 and 2026.

Table 3. Health indices and monetised risk for the Broadford GSP

Site	Asset type	2019		2026	
		Health Index	Monetised risk (R£)	Health Index	Monetised risk (R£)
Broadford GSP	Transformer	3.21	4,704,586	3.21	10,3562,54
	Circuit breaker	6.43	52,876,007	**9.56**	153,142,350

4.1.5 Broadford–Edinbane–Dunvegan–Ardmore (BE1, ED1 and DA1)

The strength of the wood poles on the line sections between Broadford and Ardmore is deteriorating as the poles age. This is coupled with the deteriorating conductor health indices on these sections to determine the need to intervene in order to ensure security of supply.

Table 4 shows that the asset health indices for the conductors between Broadford and Ardmore range between 8.02 and 8.19 by 2026, meaning that they will need replacing by then based on the calibration of health indices shown in Table 1. It would not be economical to refurbish this line by replacing individual poles due to outage constraints. No need has been identified for asset replacement on the substations between Broadford and Ardmore.

Table 4. Health indices and monetised risk for the Broadford to Ardmore line section (average for each line section)

Line section	Asset type	2019		2026	
		Health Index	Monetised risk (R£)	Health Index	Monetised risk (R£)
Broadford to Edinbane	Poles	3.78	37,510	5.55	80,306
	Pole tops	3.21	52,874	4.65	127,243
	Conductors	5.59	61,838	**8.16**	165,511
Edinbane to Dunvegan	Poles	3.36	26,747	4.88	43,881
	Pole tops	3.28	54,973	4.76	133,131
	Conductors	5.52	59,037	**8.02**	155,336
Dunvegan to Ardmore	Poles	3.55	25,994	5.19	50,569
	Pole tops	3.06	34,715	4.42	81,945
	Conductors	5.62	45,590	**8.19**	121,706

4.2 Load Need

There are 2 key elements to the load driver for the Skye reinforcement project namely (i) to increase the capacity of the Skye transmission system to accommodate additional renewable generation seeking connection and (ii) to provide secure demand connection at Broadford GSP and overall improvement of supply security both on Skye and the Western Isles.

4.2.1 Need to accommodate generation growth

As set out in our paper, Planning for Net Zero: Scenarios, Certain View and Likely Outturn, the renewable generation connected to the north of Scotland transmission system will reach nearly 10 GW by March 2026 and the total generation will be 11.2 GW.

There is significant interest from renewable generation developers to connect to the network on Skye and Western Isles. Whether connection interests are at transmission or distribution level, ultimately their impact on the transmission system is significant and it is important to quantify the need for network capacity based on currently known information and a view of potential development consistent with the Net Zero pathways.

4.2.1.1 Connected, contracted and scoping generation

The north of Scotland transmission network has grown significantly over the past decade in response to the need to accommodate new, predominately renewable generation capacity. Looking forward, prevailing national policy objectives associated with achieving net zero greenhouse gas emissions by the middle of this century strongly indicate continued growth in renewable generation. This growth is already seen on Skye, where 170MW of new generation connections are in the scoping stage, with 177MW either contracted to connect or offered connection, and 137MW currently connected.

Table 5. Connected, contracted and scoping generation on the Skye and Western Isles

Project	Connection Point	Connected	Contracted	Offered	Scoping
Millennium South Wind	Millennium South		25		
Quoich	Quoich GSP	21.9			
Broadford	Broadford GSP	2.8	7.7		
Edinbane wind	Edinbane	42.8			
Glen Ullinish wind	Edinbane		42		
[redacted]	Edinbane			12	
[redacted]	Near Dunvegan/Edinbane				50
[redacted]	Near Dunvegan/Edinbane				50
[redacted]	Near Dunvegan/Edinbane				70
Ben Aketil	Dunvegan GSP	28			
Dunvegan GSP	Dunvegan GSP	2.8	0.5		
[redacted]	Dunvegan GSP			9.2	
[redacted]	Dunvegan GSP			40.8	
Glean Eoghainn wind	Dunvegan GSP		25		
Ardmore	Ardmore GSP		4		
Harris GSP*	Harris GSP	2.9	1.4		
Stornoway GSP*	Stornoway GSP	35.5	8.9		
TOTAL (MW)		**137**	**115**	**62**	**170**

* Harris and Stornoway import to Skye is limited by the existing subsea cable.
The table excludes large (10MW and above) contracted and scoping generation on the Western Isles

4.2.1.2 Meeting Net Zero

In May 2019, the Committee on Climate Change recommended[5] a new emissions target of net zero greenhouse gases by 2050 for the UK. In Scotland, the Committee recommended a net zero date of 2045, reflecting Scotland's greater relative capacity to remove emissions than the UK as a whole. The Committee's recommendation was accepted and put into legislation by both the UK and Scottish Governments.

To establish credible generation and demand scenarios for Skye, that also meet net zero ambitions, we used our North of Scotland Future Energy Scenarios[6] (NoS FES), namely, the most ambitious scenario Proactive Decarbonisation. This scenario sets out the credible maximum decarbonisation of the energy system in the north of Scotland predicated on the 1.5°C warming pathway consistent with net zero. However, the NoS FES

[5] The May 2019 Committee on Climate Change report, Net Zero – The UK's contribution to stopping global warming, is available online at https://www.theccc.org.uk/publication/net-zero-the-uks-contribution-to-stopping-global-warming/
[6] The North of Scotland Future Energy Scenarios are available online at https://www.ssen-transmission.co.uk/information-centre/industry-and-regulation/future-energy-scenarios/

does not look beyond 2030. To develop scenarios that go out to 2050, we combined elements of the Two Degrees and Community Renewables scenarios from the 2019 Electricity System Operator's (ESO's) Future Energy Scenarios (FES) to create a net zero proxy scenario[7]. Figure 3 shows the generation capacity scenarios out to 2050 for Skye and Western Isles including our view of net zero, which has been used in our determination of credible development pathways for the Skye reinforcement.

There is a significant volume of further large (10MW and higher) generation capacity contracted to be connected on the Western Isles. The proposed Western Isles HVDC link project from Beauly in Inverness-shire to Arnish near Stornoway on the Isle of Lewis would accommodate this generation as the most economical solution. This link project is dependent on the volume of generation on Western Isles that is ready to progress their connection schemes. The 33kV subsea cable between Ardmore and Harris does not have enough capacity to accommodate additional generation.

SHEPD is assessing the condition of their 33kV subsea cable between Ardmore and Harris. It is expected that this cable will be approaching the end of its economic life in the near future. On replacement of the cable, it is likely that the capacity of the cable will be increased, taking advantage of advances in technology which allow higher capacities to be realised on subsea cables in order to address known constraints and create headroom for growth. The sizing of the subsea cable would in part be dependent on the outcome of the HVDC link as well as the capacity available on the Skye circuit. In addition to connected generation on Skye, the increase in rating of the subsea link to the Western Isles will result in higher levels of power flow on the Skye circuit. Due to the radial nature of the Skye circuit, the loading on the line increases towards the Fort Augustus substation.

The Western Isles (WI) sensitivity shows what the generation volumes could look like if the Western Isles HVDC link did not progress. This also assumes that the 33kV subsea link between Ardmore and Harris will be constructed at a higher capacity to accommodate some, but not necessarily all, contracted generation on the Western Isles. In the WI sensitivity, it is assumed that the subsea cable is replaced with an approximately 150MVA 132kV subsea cable. This cable activity is outside the scope of the Skye reinforcement project.

[7] The National Grid ESO FES 2019 document is available online at http://fes.nationalgrid.com/media/1409/fes-2019.pdf - Chapter 6 provides more details on Net Zero.

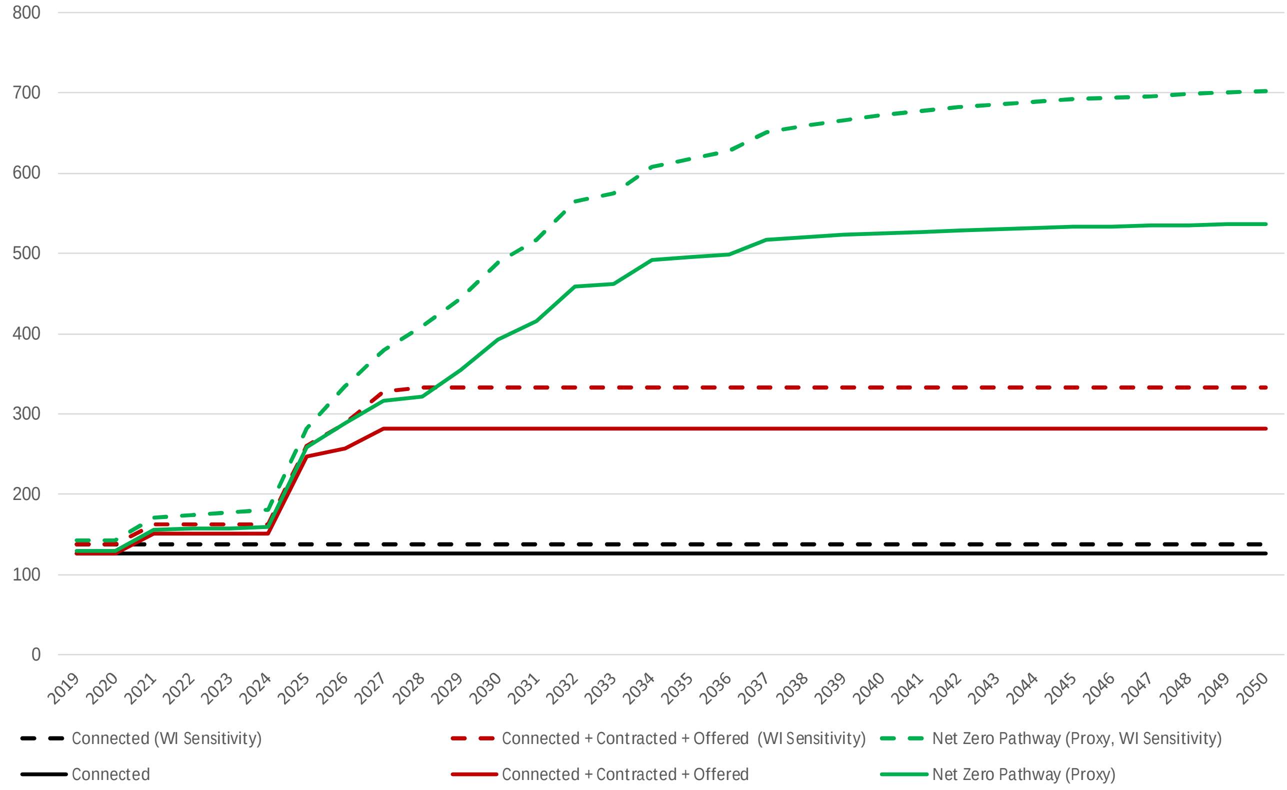

Figure 3. Generation scenarios for Skye out to 2050 (capacities in MW)

Figure 4 shows the generation capacities supported by the different Skye line sections for the considered scenarios. This shows significant volumes of generation compared to the capacity of the existing line. The figure also shows that the generation capacity supported, hence line loading, increases towards the Fort August end of the line.

Figure 4. Generation capacities supported by the different Skye line sections for the considered scenarios (capacities in MW)

4.2.2 **Need to provide security of supply**

The security of supply for Skye and Western Isles is mainly dependent on the single transmission circuit running from Fort Augustus. This is augmented by standby diesel generation and very limited distribution backfeeds from other points on the network. It is important to ensure that any reinforcement works also deliver improved security of supply by improving the reliability of the line as well as reducing the reliance on standby diesel generation.

4.2.2.1 Secure demand connection at Broadford

SHEPD has applied for, and signed a connection contract for, a firm demand connection at Broadford by 2024. Currently, there is a single 30MVA grid transformer at Broadford. A second transmission infeed is required to achieve the contracted security for the Broadford demand.

4.2.2.2 Security of supply on Skye and Western Isles

As there is only one line supplying Skye and the Western Isles, any outages on this line, whether planned or unplanned result in loss of supply. Table 1 shows the maximum and minimum demands at the Grid Supply Points supplied by the Skye circuit. The maximum coincident peak demand on Skye and Western Isles is 53MW which is small in comparison with the currently connected generation. There are currently no indications of strong customer demand increase in the foreseeable future beyond the most recently contracted demand of 10MW at Broadford..

Table 6.Demand supplied by the Skye 132kV single circuit line

Grid Supply Point	Maximum Demand (MW)	Minimum Demand (MW)
Quoich	0.12	0.07
Broadford	12.2*	2.64
Dunvegan	8.6	1.72
Ardmore (Loch Carnan)	7.9	1.68
Harris	3.5	0.35
Stornoway	21	3.46

* This is the existing demand and does not include the recently contracted 10MW demand.

There is limited capacity to serve demand at Broadford from the Grid Supply Point at Grudie Bridge, within SHEPD's network. Security of supply is mainly provided by generation (generation adequacy) and network redundancy (number of parallel network assets or a more reliable and flexible network). As there is significantly more generation on this network, and this is set to increase, the need to improve security of supply will need to be addressed via the network or other non-generation means such as flexibility solutions.

To restore supplies during prolonged outages of the Skye transmission circuit, SHEPD relies on mobile diesel generators on Skye and the diesel generation at Stornoway as well as diesel generation on the Uists – at Loch Carnan and Barra. Given the light construction of the transmission line over the most challenging terrain, its reliability is poorer than other lines. This line has an environmental impact due to the high carbon intensity of the backup diesel generators. As the line is coming to the end of its economic life, this presents an opportunity within this reinforcement strategy to improve its performance.

Should the Western Isles HVDC link project progress, this will help to improve the security of supply on the Western Isles by providing a second diverse route to meet demand there. Should the link however not progress, it is important to ensure that the Skye Reinforcement Strategy retains the optionality to provide a second circuit to the Western Isles in future.

5 Optioneering

We have considered asset condition-based need and load need together in the development of the Skye reinforcement strategy. We have also considered potential development pathways with and without the proposed Western Isles HVDC link in the future. Below are the key factors considered in the development of the strategy:

a) the asset condition of the line;
b) known and potential future generation capacity requirements;
c) security of supply on Skye and the Western Isles;
d) the possibility of the proposed Western Isles HVDC link;
e) economic and environmental aspects of different development pathways; and
f) stakeholder feedback received on relevant development work undertaken to-date.

5.1 A whole system approach to optioneering

We recognise the importance of a whole system approach to the development of the Skye network. In our paper, Enabling Whole Energy System Outcomes Policy, we outline how we consider a wide range of potential solutions to meet network needs, ranging from the more traditional asset solutions to innovative solutions that require us to work with the ESO and the Distribution Network Operator in our area, SHEPD, and third parties to deliver a whole system optimum solution to the benefit of consumers.

As explained in the ‘Need’ section, we used a range of credible future energy scenarios informed by stakeholders to determine the load need. These covered potential growth scenarios on the Isle of Skye and the Western Isles. In developing the solution to meet this need, we have engaged extensively with SHEPD, who own and operate the adjoining distribution network served by the Skye transmission line. SHEPD have demand customers on Skye and Western Isles, and we have discussed our respective network future development plans and their respective drivers. Some of the decisions SHEPD will need to make in the future relate to the security of supply when the fixed diesel generation on Western Isles retires as well as the 33kV subsea cables they own between Ardmore and the Western Isles. We are also engaging with the ESO on the system operational impact of our options. We continue to engage with a wide range of stakeholders including communities, statutory and other non-statutory bodies to ensure that the solution is delivered in a way that has minimal impact to the environment while providing a pathway to net zero in an economic manner.

5.2 Options considered

We considered a wide range of options, starting with non-asset solutions and minimal asset solutions including dynamic line rating, active network management and the impact of flexibility services. These are summarised below.

5.2.1 Consideration of smart and flexible options

Before considering asset solutions to meet the additional capacity needs beyond the baseline of meeting the non-load needs, we considered minimal build and commercial solutions.

5.2.1.1 Dynamic line rating

Due to lack of capacity on the existing line, we have considered the possibility of developing a dynamic line rating solution to potentially accommodate more generation. Given the asset condition of the line, it was considered that the capacity that would be released would be minimal. It is proposed however to trial dynamic line rating on the line to gather useful information for application on the Skye network in future and elsewhere on the network. Provision of additional capacity on the existing line on the basis of dynamic line rating was therefore ruled out at this time.

5.2.1.2 Active network management

Active network management releases capacity by allowing the network to operate close to its loading limits on the basis that any potential breaches are dealt with automatically in real time without manual operator action. On the basis that there is only one radial transmission circuit which is already constrained, it was concluded that active network management would not release additional capacity. This option was therefore not taken forward.

5.2.1.3 Flexibility services

In addition to the balancing mechanism actions already taken by the ESO on this line, we considered whether SHEPD's distribution-based flexibility services solutions through the Constrained Manage Zones (CMZ)[8] could potentially release capacity on the transmission system. CMZ offer a suite of options for customers in addition to traditional reinforcement and therefore potentially allow quicker connection and at a lower cost. While this may release additional capacity on the distribution system, it does not release capacity on the transmission network which is already "full". We are not progressing this concept on this network at this time.

5.2.2 **Consideration of asset options**

We also considered asset solutions over and above the assets required to meet the asset condition-based need. These are summarised below.

5.2.2.1 Interconnection to Grudie Bridge

As shown in the Need section, the loading of the Skye line is highest closes to Fort Augustus and reduces with distance from there. Noting the requirement to provide a second transmission infeed into Broadford to provide the contracted demand security, we consider the capacity of the distribution backfeed from Grudie Bridge GSP. Discussion with SHEPD indicated that the capacity of the existing 33kV line is very limited to due to the long distance from Grudie Bridge. Consequently, this backfeed cannot reach Broadford. SHEPD indicated that it would not be economical to upgrade the line. In addition to not being able to meet the demand security requirement at Broadford, this option would not provide capacity to accommodate load growth. Reinforcement would also be required beyond Broadford. This option has not been progressed at this stage

5.2.2.2 Interconnection to Corriemoillie substation

Similar to the interconnection to Grudie Bridge, we also considered a transmission interconnection to Corriemoillie substation at 132kV. This would be a new line over challenging terrain, with significant environmental impact. Additionally, the Beauly to Corriemoillie line would need to be built at a higher

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[8] More information on SHEPD's Flexible Connection Options and Flexibility Services can be found online at https://www.ssen.co.uk/FlexibleConnections/

voltage, with significant knock on impact to the Beauly 275/132kV substation to accommodate the increased power flow from the generation on Skye. This would at be at significant cost. It was considered it was environmentally responsible to focus on options which augment the existing assets or rely on already planned works to meet the load needs of the Skye network. This option was therefore not progressed further at this stage.

5.2.2.3 The proposed Western Isles HVDC link

Another option considered is predicated on the Western HVDC link Strategic Wider Works reinforcement progressing. This option would involve upgrading the Stornoway to Harris 132kV line and upgrading the subsea link between Harris and Ardmore to evacuate generation from Skye via Western Isles. We noted that asset intervention would still be required on the Skye circuit and additional capacity would still need to be provided on the 132kV circuit on Skye to allow the generation there to connect. Some technical issues were identified with the parallel operation of the Western Isles HVDC link and the 132kV alternating current (AC) Skye circuit which would require a normally open point to be established at some point. If the subsea link between Ardmore and Harris was upgraded to a higher capacity, the normally open point could be on Skye but without this, it would be at Harris. This option would also not meet demand security at Broadford. Due to the uncertainty around the Western Isles link, this option has not been progressed at this time.

5.2.2.4 Reinforcement of the Skye transmission line

This option is based on the requirement for non-load related intervention which requires work to be undertaken along the existing line as a minimum. A number of development pathways were considered to meet the non-load need and the load need comprising the generation connection capacity requirements and demand security. Within this broad option, a number of options were considered as building blocks to building development pathways. These are shown in Table 7 with further detail in Table 8.

Table 7: Options considered for the reinforcement of the Skye transmission line.

<table>
<tr><th rowspan="2">Option</th><th colspan="4">Line section</th></tr>
<tr><th>Fort Augustus – Quoich</th><th>Quoich - Broadford</th><th>Broadford - Edinbane</th><th>Edinbane – Dunvegan – Dunvegan - Ardmore</th></tr>
<tr><td>0 (baseline)</td><td>132kV Trident (Existing 176MVA circuit)</td><td>132kV Trident & 5km Steel Structures (176MVA)</td><td>132kV Trident (176MVA)</td><td rowspan="3">132kV Trident wood pole (176MVA)</td></tr>
<tr><td>1</td><td>2nd 132kV Trident (176MVA)</td><td>132kV Trident & 14km Steel Structures (2 x 176MVA)</td><td>132kV Steel Structures (348MVA)</td></tr>
<tr><td>2</td><td colspan="2" rowspan="3">132kV Steel Structures (2 x 348MVA)</td><td>132kV Steel Structures (348MVA)</td></tr>
<tr><td>3</td><td rowspan="2">132kV Steel Structures (2 x 348MVA)</td><td>132kV Steel Structures (348 MVA)</td></tr>
<tr><td>4</td><td>132kV Steel Structures (2 x 348 MVA)</td></tr>
<tr><td>5</td><td colspan="3">275kV Steel Structures (2 x 500MVA)</td><td>132kV Steel Structures (2 x 348MVA)</td></tr>
</table>

Table 8. Commentary on the options for the reinforcement of the Skye transmission line

Option	Description	Comments
0 Baseline	Baseline option to address asset condition driver based on single circuit 176MVA wood pole circuit (with a 5km steel structure section between Fort Augustus and Broadford) at 132kV.	Does not meet contracted demand security requirements at Broadford and not consistent with net zero pathways as any future significant upgrades will result in significant asset stranding in the near future. The terrain and altitude surrounding Kinloch Hourn is beyond the technical capability of the line technology. Structures between 11-14m in height and ~11 structures per km.
1	Additional wood pole section to make two wood pole circuits between Fort Augustus and Broadford with a 14km section of double circuit steel structures, single circuit on steel structures between Broadford and Edinbane and wood pole single circuit from Edinbane to Ardmore at 132kV.	Provides enough capacity to meet contracted generation in 2020s but does not provide enough headroom consistent with the level of generation interests on Skye and the Western, therefore not consistent with net zero pathways. The terrain and altitude surrounding Kinloch Hourn is beyond the technical capability the line technology. Structures between 11-14m in height. ~22 structures per km from Fort Augustus to Broadford, ~11 structures per km from Broadford to Ardmore.
2	Double circuit steel structures between Fort Augustus and Broadford, single circuit on steel structures between Broadford and Edinbane and wood pole single circuit from Edinbane to Ardmore at 132kV.	Provides sufficient capacity to accommodate contracted generation with headroom for future growth consistent with net zero. Structures with varying height, on average 26m tall from Fort Augustus to Edinbane, structures between 11-14m in height from Edinbane to Ardmore. ~4 structures per km from Fort Augustus to Edinbane, 11 structures per km from Edinbane to Ardmore.
3	Double circuit steel structures between Fort Augustus and Edinbane and single circuit on steel structures between Edinbane and Ardmore at 132kV.	Provides sufficient capacity to accommodate contracted generation with headroom for future growth consistent with net zero. Structures with varying height, on average 26m tall. ~4 structures per km
4	Double circuit steel structures between Fort Augustus and Ardmore at 132kV.	Provides sufficient capacity to accommodate contracted generation with headroom for future growth consistent with net zero. Structures with varying height on average 26m tall. ~4 structures per km. Limited flexibility to accommodate more generation from Western Isles.
5	Double circuit steel structures between Fort Augustus and Edinbane at 275kV and wood pole single circuit from Edinbane to Ardmore at 132kV.	Provides sufficient capacity to accommodate contracted generation with headroom for future growth consistent with net zero. Flexibility to accommodate more generation from Western Isles. Structures with varying height, on average 43m tall from Fort Augustus to Edinbane, 26m in height from Edinbane to Ardmore, ~4 structures per km. Requires voltage upgrades on substations along the line.

The development pathways approach allows us to compare incremental developments of the network to balance investment and operational costs, the risk of asset stranding, the economic and environmental impacts of frequent interventions, and impacts on end consumers.

In developing potential solutions to meet the medium to long term network need, we considered technical and geographic constraints on the design and safe operation of the assets based on the elements of the options described above to meet specific requirements along the different sections of the line. In addition to this, there are design decisions that may be influenced by the stakeholders, the two most significant of which are the type of overhead line construction and in a limited number of cases, both overhead line and cable options could be considered.

The initial development pathways considered were based on different combinations of options in Table 7 and these were reduced through a number of criteria including future incremental capacity needs and the Committee on Climate Change recommendation on the approach to build infrastructure to support net zero, cost benefit analysis and stakeholder feedback received to date. Further details on the development of the pathways are given in the Detailed Analysis section.

5.3 Development pathways considered

This section describes the solution options at high level, informed by stakeholder feedback and work undertaken to date. These are grouped into three main categories; minimal intervention, piecemeal approach and balanced strategic long-term approaches. The details provided below are intended to provide a broad view of the options we are carefully considering. More detailed information such as line routing or specific line support structures or cable dips is not covered here. Detailed information on technologies is also not covered here but it is worth noting that due to the cost of land and subsea cable technologies and associated substation equipment, it would not be viable to consider these for the entire line route. Instead, they will continue to be considered in short sections where they could address specific local issues subject to engineering considerations and the need for additional land infrastructure.

5.3.1 Baseline option

The baseline solution involves intervention to meet the asset condition need. While this solution will provide more capacity compared to the existing line, it will still require to be significantly augmented or replaced in the short to mid-term to meet the load requirements. Although this option does not meet the development pathways criteria, we considered it as a credible baseline solution against the very unlikely scenario that very little or none of the generation and demand developments materialise.

This solution involves the rebuilding of the entire line length from Quoich to Ardmore with trident wood pole single circuit (Option 0 in Table 7). While we continue to explore technologies to enhance capacity ratings of our assets such as higher temperature operation and dynamic line rating, it is unlikely that such enhancements will provide adequate capacity increases to meet the load requirements by the mid-2020s. Additionally, the single circuit would not provide the required demand security at Broadford.

5.3.2 Pathway 1 - Incremental approach

This pathway assumes that the first stage of the development of the Skye Reinforcement Strategy is the baseline option as described above. To address the capacity deficit in the short term, the next stage of this pathway would establish a new parallel circuit between Fort Augustus and Broadford with at least the same capacity as the first one (Fort Augustus to Broadford section of Option 2 in Table 7 as an incremental step). While this solves the capacity requirements up to Broadford in the mid-term, it does not provide sufficient capacity beyond Broadford by mid-2020s.

Several variants of this pathway have been considered to provide more capacity beyond Broadford, but it is unlikely this would be achievable without significant rebuild of the part of the line to Edinbane. Additionally, this stage of this pathway would not be able to accommodate more load by the early to mid-2030s; additional significant augmentation would be required on the section between Fort Augustus and Broadford.

While there may be opportunities to enhance the rating of the line in future based on innovative technologies, the level of capacity requirements will most likely exceed the capability of the assets even with such capacity enhancements, thereby triggering a significant rebuild of the line which will result in the initial line being decommissioned before the end of its life to make way for technologies capable of higher capacities. In this pathway, we see the need to carefully consider the environmental, stakeholder and economic implications of significant multiple interventions in the long term.

5.3.3 Pathway 2 - Balanced strategic long-term approach

The approach in this pathway is not to necessarily provide all the capacity required upfront. It aims to ensure that the development pathway is flexible to accommodate more capacity when it is required but without significant intervention on the assets or significant replacement of assets before the end of their life. The significant benefit of this compared to Pathway 1 is that it minimises disruptions to the environment while providing the flexibility to economically meet future requirements.

In this pathway, the section between Fort Augustus and Broadford would be built as a double circuit steel structure (single support structure carrying two circuits). In addition to providing higher capacity compared to wood pole structures, the steel structures have less maintenance requirements which means that there are less environmental impacts. This technology also provides better reliability performance for the customers on Skye and the Western Isles.

While there are a number of variants for this pathway, we have considered a significant variant between Broadford and Edinbane with regards to the technology of line assets. The two main options on this section are the trident wood pole line and steel structure. While the wood pole option is easier to construct and is not as high as the steel tower construction, its capacity is also limited, meaning that significant augmentation may be required before 2030. The wood pole option neither provides the flexibility to increase capacity nor to provide demand security beyond Broadford in the future. To address this issue, the steel structure option considers both single circuit and double circuit construction types with the initial requirement of one circuit based on known need. Steel structures, whilst higher would mean less structures would be required when compared to a wood pole option.

The line section between Edinbane and Ardmore would be built to trident wood pole. This is informed by the prospective capacity requirements on this section based on the generation scenarios considered.

5.4 Consideration of stakeholder views

Considerable stakeholder engagement has been undertaken based on the previous Skye reinforcement proposal prior to the review of this part of our network which has resulted in this Skye Reinforcement Strategy. While the objective remains the same, i.e. to provide economic and reliable capacity with due consideration to the environment, the approach we are taking in this strategy is guided by the pathways for net zero and ensues consistency in medium and long-term network development plans.

As a result of this review of our approach to the Skye network, we are engaging with stakeholders and will continue doing so to explain our approach and gather feedback on the outcomes of this approach. We will be seeking stakeholder views on shaping our plans to better reflect their needs.

Our engagement with SHEPD has highlighted the need to work closely together in stakeholder engagement on long term network development issues. We will be engaging with our local authorities to better understand their long-term plans, particularly in the area of whole system planning. Our engagement with the ESO has indicated the need to remain coordinated in our solution development to ensure that we consider a wide range of potential solutions, which may include commercial solution in addition to asset solutions.

At a recent stakeholder workshop held with statutory consultees on 4 November 2019, the consultees agreed with our approach to the identification of need and have expressed interest in contributing to, and shaping the development of the options. We recognise the environmental sensitivities of this project and will continue working with a wide range of stakeholders including communities, tourism and others. Stakeholder welcomed our plans to engage a line design consultant early on in the development process to ensure stakeholder input can be appropriately considered early in the engineering design process.

6 Detailed analysis

Given the early stage of the project, the CBA carried out to date has been high level. As development pathways are refined, we will carry out a detailed CBA on selected line sections considering section capacity requirements, localised environmental constraints and stakeholder feedback.

6.1 Assessment of potential development pathways

This sections explains the process through which the different combinations of options listed in Table 7 were reduced to these 3 broad approaches.

In developing the pathways, the options were arranged starting with one option and augmenting it in future as the capacity requirements increased until we reach the capacity requirements for 2045 (Net zero date for Scotland). At one end of the pathways is the very incremental approach which starts with the minimum capacity (e.g. the baseline) which would be augmented only to provide the next level of required capacity when it is required. The environmental and cost impact of this would be significant. On the other end of the pathways, the higher capacity options were introduced early, with minimum need for augmentation. While this would minimise the environmental impact, it could be costly and may not offer sufficient protection against the risk of asset stranding.

6.2 Development pathway analysis

In total sixty-six pathways were identified, but not all of these delivered on contracted generation. Cost estimates and programmes were developed for each of the development pathways. Nineteen pathways were identified to deliver capacity requirements for contracted generation, but only a small number delivered the capacity required for known scoping generation and the flexibility to accommodate generation growth.

6.2.1 Cost benefit analysis

We carried out Cost Benefit Analysis (CBA) on this list of options using least worse regrets (LWR) analysis. LWR is used in decision making whenever it is difficult or inappropriate to attach probabilities to possible future generation or capacity scenarios. The ‘regret’ is the difference in the value between the decision made and the optimal decision, given the realisation of a generation or capacity scenario. LWR provides a recommended investment option based on minimising the worst-case regret.

The original options each deliver different capacity combinations along the length of the line. To carry out LWR analysis, we required details of the initial costs to carry out the works in Table 7 as well as the incremental works and costs for each option to transition to higher capacities, as shown in Table 9.

Table 9. Illustration of development pathway building

Initial Option (base of development pathway)	Required capacity increasing in time				
	Capacity 1	Capacity 2	Capacity 3	Capacity 4	Capacity 5
option 0		Transition works	Transition works		Transition works
		Transition works		Transition works	
		Transition works		Flexibility solutions	Transition works
		Transition works		Flexibility solutions	Flexibility solutions
option 1		Transition works			Transition works
		Flexibility solutions	Transition works	Transition works	Transition works
option 2			Transition works	Flexibility solutions	Transition works
			Transition works		Flexibility solutions
option 3					Transition works
				Transition works	Flexibility solutions
option 4				Flexibility solutions	Transition works
				Flexibility solutions	Flexibility solutions
option 5					

- Grey cells indicate no transition works required, Transition works here refer to asset solutions.
- Flexibility solutions allow connected resources to make effective use of limited network capacity and may include commercial services

Initial CBA results indicated that more refinement was required for the model itself and in the way we capture the costs including carbon costs and environmental impact due to the reliance on diesel during planned maintenance outages and fault outages of the line. Stakeholder engagement suggests that these factors need to be considered in more detail. As such our CBA is being modified to accurately capture the impact of the different capacity scenario growth rates and the different capacity requirements along the line in order to determine the optimum incremental development pathway of the network to balance the risk of asset stranding against frequent intervention with the associated economic and environmental impacts.

To be able to shortlist the pathways, we placed emphasis on those pathways which satisfy the following set of criteria:

- The development pathway must be complete by 2045, in line with the Scottish Government's Net Zero ambitions
- The development pathway should avoid the replacement of structures constructed between 2021 and 2045 where there are significant environmental and economic implications in doing so.

The two criteria are informed by the Committee on Climate Change recommendation related to investment planning to support net zero; where upgrades occur, we need to ensure no future augmentation would be required prior to 2045. Ofgem, in its letter[9] to network companies following the Committee on Climate Change's May 2019 report on Net Zero, communicated its expectation that network companies' investment plans should be able to flex to support the net zero target in line with the potential range of net zero pathways. The criteria are also informed by our own objective to minimise our impact on the environment

6.2.2 Further work

Section 5.3 covers the 3 broad development pathways identified following this analysis. These are (i) the baseline approach (this will be used as the counterfactual in more detailed analysis), (ii) the incremental approach (Pathway 1) and (iii) the balanced long-term strategic approach (Pathway 2). We are considering different technologies, including wood pole and steel structure overhead lines and subsea cables for some sections. Cost, operational performance, stakeholder feedback and the differing environmental conditions of the individual sections of the line are also taken account. Within each pathway, there is a degree of flexibility for each of the individual sections in terms of technology and timing of investment.

To inform our decision on what investment we make in the short term, as we conclude our assessment and the project moves into the development phase, over the coming months we will carry out a detailed CBA focusing on individual line sections within the identified pathways considering specific section capacity requirements, localised environmental constraints and stakeholder feedback. The purpose of this exercise will be to meet the capacity requirements on this line, whilst balancing the needs of the local environment, community and the operational requirements of the infrastructure.

[9] https://www.ofgem.gov.uk/system/files/docs/2019/08/letter_to_networks_on_achieving_net_zero.pdf

7 Conclusion

Our rigorous asset assessment methodology demonstrates that there is a strong need for intervention on the 132km line section between Quoich and Ardmore before 2030. In addition to asset risk, there are both demand and generation needs to be met on the Skye transmission network:

- To restore supplies during prolonged outages of the Skye transmission circuit, SHEPD relies on mobile and fixed diesel generators on Skye and the Western Isles. Given the light construction of the transmission line, over the most challenging terrain, its reliability is poorer than other lines. This line has an environmental impact due to the high carbon intensity of the backup diesel generators. Working with SHEPD, there is an opportunity to improve security of supply.

- The amount of generation connected on the Skye circuit (137MW) exceeds the rating of the existing line, with an additional 177MW either contracted to connect of offered connection and a significant further volume having expressed interest.

In developing potential solutions to meet the identified need, we considered technical, environmental and geographic constraints on the design and safe operation of the assets along with views expressed by stakeholders. We have used a scenario-based pathway approach, where we look into the medium to long term network requirements and identify potential development pathways for the network. This allows us to compare incremental developments of the network to balance investment and operational costs, the risk of asset stranding, the economic and environmental impacts of frequent interventions, and impacts on end consumers.

A cost benefit analysis (CBA) was undertaken on the shortlisted pathways to refine the list further. Based on the outcome of this analysis, further detailed analysis was undertaken considering line section capacity requirements, more localised environmental constraints and stakeholder feedback to date. The outcome of this work is certainty over the need to intervene and economic appraisal confirms the net benefits of replacing the overhead line between Quoich and Ardmore as soon as possible. Two approaches to the development of pathways were identified in addition to the counterfactual position. These are the incremental approach and the balanced strategic long-term approach. We will be undertaking further work to refine our CBA to consider more closely local design constraints informed by stakeholder views as well as operational requirements of the assets.

We understand the concerns of some stakeholders about the construction of new transmission infrastructure between Fort Augustus and Ardmore. We remain committed to working with all stakeholders to find the solution that meets local community, generator, environmental and GB society needs.