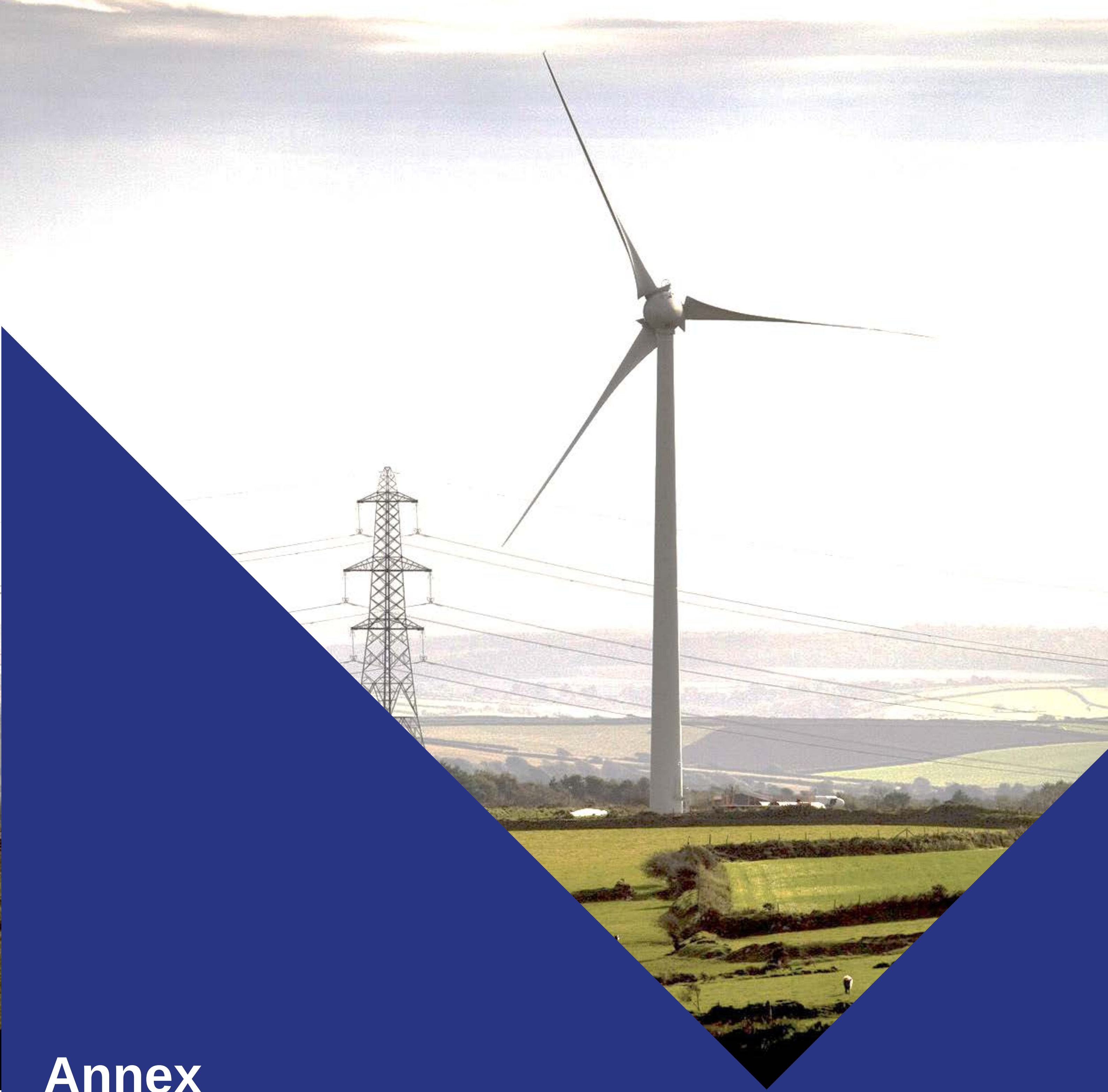

Annex

NGET_A9.09 – Overhead Line (OHL) Conductor and Fittings

December 2019

As a part of the NGET Business Plan Submission

nationalgrid

Engineering Justification Paper; Non-Load Related Overhead Lines: Lead Assets (Conductors and Fittings)			
Asset Family	Overhead Line (OHL) Conductors and Fittings		
Primary Investment Driver	Monetised Risk (OHLs & Fittings – Lead Assets)		
Reference	A9.09		
Output Asset Types	Lead assets: • Conductor • Fittings (insulators, spacers, dampers, etc) (Condition monitoring, condition assessment and plant status work & maintenance are not covered in this report)		
Cost **(T2 schemes proposal)**	OHL Conductor: £537.5m (excluding Tyne Crossing) OHL Fittings: £83.7m Total: £621.2m		
Delivery Year(s)	2021 - 2026		
Reporting Table	C2.2A		
Outputs included in RIIO-T1 Business Plan	Yes		
Spend Apportionment **(T2 schemes proposal)**	**T1 & prior**	**T2**	**T3**
	£18.314m	£602.122m	£0.744m
Completion of T1 schemes		£2.362m	
Development of RIIO-T3		£13.979m	
Total RIIO-T2	£18.314m	£618.462m	£0.744m

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CONTENTS

1 Executive Summary

This report justifies the RIIO-T2 asset intervention plan for Overhead Lines (OHL) Lead Assets (Conductor and Fittings) at a total cost of £621.2m (excluding the Tyne Crossing project which is covered in a separate Justification report, A9.12).

Conductors and Fittings play an important role in the electricity transmission system. If no action is taken then conductors and fittings would be at risk of condition-related failure leading to system outages (and potential blackouts), safety incidents, and increased maintenance costs.

In RIIO-T1 to date, we have achieved significant savings against our allowances, which have been shared with consumers. The current price control has seen significant innovations which have driven efficiencies, such as contracting synergies which have allowed us to combine delivery of routes.

There is a need for increased volumes of activity in this area in the RIIO-T2 period. Our RIIO-T2 plan is forecasting an increase in volume of both OHL Conductor and OHL fittings replacement by 83% and 45% respectively. The increase in volumes over the RIIO T2 period is reflective of an ageing population and a need to carry out an increased level of interventions to maintain a similar level of network risk to the RIIO-T1 period.

Our approach to estimating RIIO-T2 intervention volumes ensures that the key stakeholder requirements of maintaining current levels of network risk at least cost are met, thereby driving longer-term benefits for consumers. Our T2 plan is based on the output of a monetised risk approach, aimed at targeting the most critical and at-risk assets that demonstrate a poor asset health. The overall monetised risk position across OHL Conductor and fittings will remain flat but in order to optimise the total spend we have traded risk across categories. As a result of a trading of volumes between the Conductor and Fittings asset classes, we have reduced the overall cost of the plan by £39m.

The unit cost for OHL conductor has reduced from RIIO-T1 to RIIO-T2 (£[redacted]m to £[redacted]m[1]) because we have embedded learning from RIIO-T1 including efficiencies by combining delivery of the routes in close proximity.

The forecast average cost per km for T2 OHL fittings is higher than achieved in the T1 period due to three main reasons:

1. Asset condition of routes in T2 require an increased scope of intervention per km
2. Increase proportion of urban routes in our T2 plan
3. An increased number of Quad bundled ACSR conductors

Nevertheless, the targeted-fittings replacement approach developed in T1 will continue to address the components driving the highest probability of failure, leaving components with a low probability of failure and thus less risk. This approach has reduced our proposed spend by £134m in comparison to full fittings replacement.

We are confident that our plans represent value for money for consumers and customers. Our unit costs for RIIO-T2 projects have been built up based on our current understanding of the interventions we expect to make during the period. This draws on the knowledge of our team of in-house expert cost estimators in the E-Hub (Estimating Hub) which was established at the start of the T1 period.

Unit cost benchmarking shows us performing well against wider industry cost measures. The Targeted fittings approach means the unit costs for RIIO-T2 are less than [redacted]% of TNEI benchmarks.

[1] removing the costs for Tyne Crossing, which is not driven by asset condition. More details are provided in Justification Report A9.12 Tyne Crossing

Table 1 below summarises our performance in RIIO-T1, as well as the costs and volumes in our RIIO-T2 plan, across both costs and volume. Figures 1 and 2 show the drivers of the increase in annualised cost between RIIO-T1 and RIIO-T2 separately for conductors and fittings, demonstrating that this is driven largely by increased volumes in the next price control.

Table 1: Comparison of Conductor and Fittings interventions for the RIIO-T1 and RIIO-T2 periods

		T1 Allowance	T1 Actuals	T1 Forecast	T1 (all years)	T2 forecast	Annual average	Annual average (first 6 years)	Annual average
OHL Conductor	Total cost (£m)	578	479.3	53.06	532.39	535.9	66.5	79.9	107.2
	Total volume	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	Cost per unit volume	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
OHL Fittings	Total cost (£m)	222	40.0	14.22	54.2	82.5	6.8	6.7	16.5
	Total volume	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	Cost per unit volume	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Figure 1: annualised spend changes between RIIO-T1 and RIIO-T2 and drivers, OHL fittings

[redacted]

Figure 2: annualised spend changes between RIIO-T1 and RIIO-T2 and drivers, OHL conductors

[redacted]

2 Introduction

Overhead lines (OHLs) are used by electricity transmission companies as the preferred solution for connecting electricity infrastructure including power stations, High Voltage (HV) substations, and demand centres.

The conductor insulation is provided by air, so OHLs are generally considered to be the most cost-effective method of HVAC transmission. OHL transmission towers are normally double circuit and three-phase, with each phase on separate cross arms. National Grid Electricity Transmission predominately owns and operates OHLs at 275kV & 400kV. The key elements of OHLs are the conductor system and the tower. The conductor system is made up of the conductor and the conductor fittings, insulators, and insulator fittings. These are described below.

2.1 Conductors

OHL conductors are carried by ‘suspension’ towers via suspension clamps and ‘tension’ towers via a compression or wedge type anchor assembly. The conductors may be arranged in single configuration or in bundles of two, three or four subconductors to provide adequate current-carrying capability. The conductor types used on the NGET network are:

- Aluminium Conductor Steel Reinforced (ACSR),
- All Aluminium Alloy Conductor (AAAC),
- Aluminium Conductor Alloy Reinforced (ACAR),
- High Temperature Low Sag (HTLS),
- Aluminium Alloy Conductor Steel Reinforced (AACSR)
- Aluminium Conductor Composite Core (ACCC)

Earthwires are installed on the top of the tower and ‘shield’ the phase conductors from lightning strikes and provide a low impedance earth return path for fault currents.

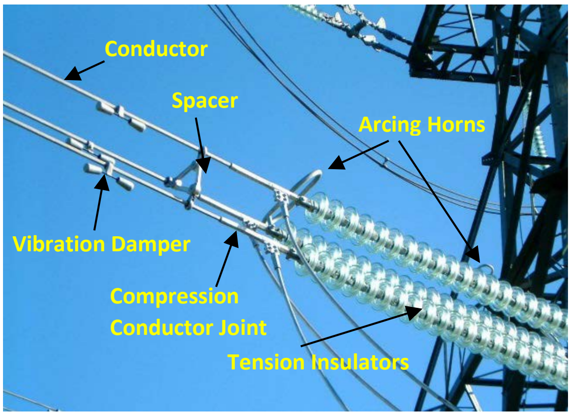
2.2 Conductor Fittings

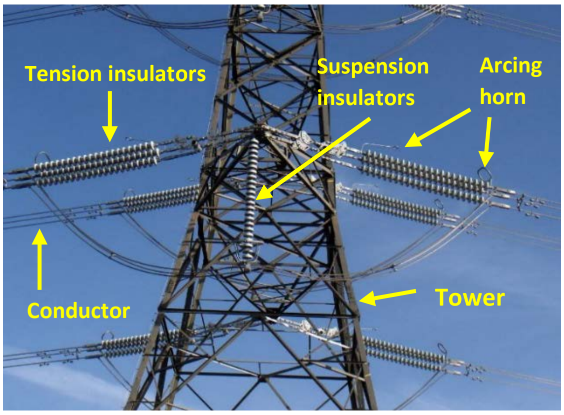
Conductor fittings include vibration dampers and spacers.

- Vibration Dampers are installed at a specified distance from insulator sets on all conductors to lessen the effects of aeolian (wind-induced) vibration which is low amplitude and high frequency in order to protect the conductor from wear.
- Spacer Dampers are installed throughout the spans of bundled conductors to prevent sub-conductor oscillation, maintain bundle separation and prevent conductor clashing.

2.3 Insulators and Insulator Fittings

Insulators provide electrical separation between the conductors and tower steelwork either through linking single units or one larger unit to provide adequate clearance between conductors and steelwork as an insulator set. Insulators are traditionally manufactured from porcelain or glass although more recently composite materials have been used. Composite insulators have been trialled on limited 'Fittings Only' refurbishments and are still being fully evaluated. Insulator fittings provide the connection between tower steelwork and insulators as well as insulators and conductor fittings, these fittings include arcing and corona management devices





3 RIIO T1 Volumes and Performance

Table 2 summarises the interventions carried out in RIIO-T1 by displaying the total volumes delivered (forecast until the end of RIIO-T1) and the total cost for each OHL subcategory and compares them to the T1 Allowance.

Table 2: summary of volumes and costs of OHL lead assets in RIIO-T1

		T1 Allowances	T1 Actuals	T1 Forecast	T1 (all years)	Annual average	Annual average (first 6 years)
OHL Conductor	Total cost (£m)	578	479.3	47.9	527.2	65.9	79.9
	Total volume (km)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	Cost per unit volume	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
OHL Fittings	Total cost (£m)	222	40.0	14.22	54.2	6.8	6.7
	Total volume (km)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	Cost per unit volume	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

The following section summarises our volume and unit cost performance per asset type against our allowance for the RIIO-T1 period.

There are cost drivers relating to project mix which are outside our control The four most significant factors determining the average cost per route kilometre (unit cost) of an OHL refurbishment are:

- **Length:** The longer the route, the less of a proportion factors such as project management overheads and site establishment contribute to the overall cost.
- **Location:** The location of a route is a major contributing factor to overall cost of the project. Compared to rural environments, urban environments have more complex access arrangements,

require increased security, reduced working hours to avoid disturbing residents, and greater cost associated with temporary working areas for laydown and site establishment.

- **System access constraints:** for example where outages are cancelled by the System Operator for system balancing reasons, necessitating replanning of outages.
- **Number of crossings:** In addition, spans over crossings such as rivers, roads, and railways, can often require significant amounts of scaffolding or the use of a catenary support system, and may require limited access while the crossing is temporarily closed.

Figure 3: unit costs for RIIO-T1 projects by rural/urban type and route length

[redacted]

3.1 OHL Conductors

Case Study: XT Route – A short span crossing the M25 motorway

The most expensive OHL project in T1 from a unit cost perspective was the XT Route, connecting West Weybridge 132kV and 275kV substations. The high unit cost is due to most of the main contributing factors detailed above being present at the route's location.

Urban

West Weybridge substations are surrounded by a residential area of Surrey and bisected by the M25.

Crossings

One of the five spans that makes up this route crosses the M25, including two hard shoulders, four lanes in each direction, and a central reservation. The motorway crossing required careful planning to ensure the safe operation of the road while the conductor was replaced, and involved the use of a catenary support system.

Length

At a route length of just 800m, this is one of the shortest OHL routes on the network. Although length-dependent factors, such as materials, surveys, and programme-related costs reduce in proportion to the route length, even shorter projects have a significant degree of fixed costs. The core project team members (including cost estimation, programme management, Health and Safety) require the same amount of input, and the site still requires a full establishment of contractors, materials and equipment.



Volume Performance: Extensive forensic assessment undertaken on conductors, along with condition monitoring technologies such as Linecor has enabled us to better understand the replacement priorities of assets in more detail than was previously possible.

Although conductor samples, (which involves physically removing a section of conductor for forensic analysis) will remain a key activity in order to increase our knowledge of OHL condition, Linecor technology (a non-destructive method for inspecting OHL Conductor) enables a more productive level of data collection to increase the confidence level of analysis done. Based on a 5 year inspection cycle, covering 10% of the system, 391 spans can be assessed for circa £300k vs 30 conventional conductor samples annually for the same cost. This approach results in over 13 times more data obtained, as well as having the added benefit of reducing the number of 'old to new' conductor joints installed when a sample is taken, that can become a weak point along the span.

This has resulted in:

- 5-year extension of the asset life of fully greased ACSR family conductors, and 10-year extension of the life of AAAC conductors. The life extension for fully greased ACSR conductors was only implemented in 2017, so has not enabled a reduction in T1 OHL Conductor volumes since the RIIO-T1 programme was largely delivered by this point. Life extensions will begin to drive benefits for consumers from RIIO-T2 onwards, allowing the deferral of asset replacement on [redacted]km of routes that would otherwise have required intervention during RIIO-T2 at an estimated cost of £204m.

- Increased replacement volumes as a result of the prioritisation of replacement of highest risk assets. We are planning to replace [redacted]km of OHL conductors, [redacted]% above our RIIO-T1 submission, by the end of the RIIO-T1 period.

Cost per Unit Performance: over the T1 period. OHL conductor replacements have been delivered with cost per unit [redacted]% lower than set in our T1 allowance. We are forecasting to maintain this level of cost per unit performance for the reminder of T1.

The main drivers behind the realised efficiency are the optimisation of delivery strategy and improved condition information (see 'Volume Performance' above) enabling more robust scoping. The optimisation of delivery includes contracting efficiencies, by combining delivery of routes in close proximity for example the 4YU/4YV circuits in South Wales and the 4YF/YF circuits on the South coast, and by utilising double circuit outages where possible, example on the EV route in Anglesey.

Several notable schemes in RIIO-T1 returned high unit costs due to the project cost drivers described above. These included routes such as the XT West Weybridge Interconnector (a very short urban route that crosses the M25 – see case study in box), the XA route (new Tees river crossing), and the ZFA/VT routes which are relatively short spans with a heavy urbanisation and multiple crossings of the central motorways (M5 & M6). The unit cost of these three projects are compared to the average cost of a rural OHL route project in Figure 4 below.

[redacted]

Figure 4: XT, ZFA/VT and XA route costs compared to average across project types

3.2 OHL Fittings

Volume performance: An extensive review of the condition and performance information of OHL fittings and improvement in our condition monitoring approach has enabled an extension to the technical life expectancy of spacers, dampers and glass insulators within the RIIO T1 period. Since the RIIO T1 plan submission, fittings interventions have changed between OHL Routes, based on condition assessments. [redacted]km of new routes have been added and interventions completed, [redacted]km of routes in the baseline plan have moved to the RIIO T2 period. Life extension has led to a 29% reduction in the volume of OHL fittings being delivered in the T1 period (see Table 2 above). Despite this volume reduction the overall risk position for OHL fittings will be lower at the end of RIIO-T1, due to more granular condition information and our improved condition monitoring enabling technical asset life extensions.

The development and use of the helicopter high-definition camera assessments (HDCA) has allowed us to be more selective in what we are replacing by obtaining a better understanding of the individual asset condition. The speed of the helicopter compared to foot patrol or climbing surveys has resulted in an increase in a route inspection cycle frequency from every 10 to every 8 years, which will enable a better understanding of the onset on significant unreliability curves due to enhanced condition data.

An example of a benefit of increased asset knowledge is tension fittings that may appear to be rusty, but over the life of the conductor show little or no wear. Previously these would have been replaced as part of a fittings scheme, but enhanced condition knowledge has shown this to be superficial, and now we only replace the insulators. This ‘targeted fittings’ approach reduces both the spares and labour costs of a project.

Unit Cost performance: a targeted fittings approach delivered by National Grid’s internal operations resources has provided savings in equipment, contracting and project management costs over the T1 period. This approach leaves on fittings with a remaining life that aligns to the existing conductor, whilst reducing the transmission network risk for a significantly reduced cost, benefiting the UK consumer in the longer term.

National Grid delivers OHL Fittings projects wherever possible using internal resource rather than using a main works contractor. The relatively simple nature of the targeted-fittings schemes can allow the work to be carried out safely and effectively by utilising our in-house teams of linesmen. This approach means that our linesmen retain a wider skillset, and reduces the overheads and fees associated with an external contractor.

As a result of these innovations, we have been able to reduce unit costs by [redacted]% compared to our RIIO-T1 allowances.

[redacted]

Figure 5: RIIO-T1 unit costs

4 INVESTMENT NEED

4.1 INVESTMENT DRIVERS

Feedback from our programme of stakeholder engagement indicates that consumers and customers want us to maintain network risk at current levels. If we do not intervene on assets during the T2 period and beyond, network (or asset) risk will rise. The rate of this rising risk, informs the volumes required to be replaced in any given period. This rate is informed by the probability of failure (PoF) and the consequence of failure (CoF), as set out in Ofgem's NARMs methodology.

Due to the large number of assets installed in the mid-1960s, along with the 55 to 70-year asset life of OHL conductors, a significant number of replacements fall over the T2 period, as their probability of failure increases.This combination of ageing assets and stakeholder requirements drives an increase in annual intervention volumes compared to RIIO-T1.

[redacted]

Figure 6: conductor and fittings installation and anticipated replacement dates[2]

4.2 APPROACH TO ESTABLISHING INTERVENTION NEED

We assess the need for intervention on an asset-by-asset basis. The key considerations feeding into our assessment are set out below for each asset type.

4.2.1 Overview

The RIIO-T2 plan for OHL Conductor and Fittings considers the activities required to address reliability and safety concerns associated with conductor systems. The planned interventions in RIIO-T2 are based on a monetised risk (NARMs) approach.

To identify and prioritise assets in need of intervention we apply an assessment of failure *likelihood* and then the impact that any failure may have on the electricity system, the safety of people and the environment. This impact is described as the *criticality* or *consequence* of an asset, should it fail in service.

Failure likelihood may simply be expressed as a probability up to 100% (or 1). This scoring system, which places assets into discrete bands of '1' to '4' was used for all Lead assets for RIIO T1. It was combined in a

[2] The anticipated replacement volumes are based on our expectation of equipment lifetime, and do not correspond directly to our annual intervention schedule, which is based on a detailed assessment of asset condition and smoothed to ensure the most efficient use of in house and supply chain resources.

matrix with an asset criticality score, again banded from 1 to 4 to arrive at 'Replacement Priorities'. The management of the volumes of assets in each replacement priority band was the basis for the capital plan submitted for RIIO T1 and one of the Network Output Measures in Special Licence Condition 2C.

The new approach developed for Lead assets and forming the basis of the Network Asset Risk Metric (NARM) achieves a greater level of maturity than the Criticality approach that preceded it. It does this in a number of ways:

1. A simple probability of failure for each asset provides for a greater resolution of asset risk of failure. The low number of discrete bands employed by the Criticality approach produces a lower resolution measure and doesn't allow for prioritisation within those bands.
2. By monetising the consequences of asset failures it is possible to measure whole network risk and enable decision making between different asset classes. The Criticality approach outputs volumes of asset 'Replacement Priorities'. It does not define a monetised impact of this risk and there is no equivalency between asset types. This impedes any network-wide measure of risk and prioritisation between asset classes.

Our approach can be summarised in the following table:

Table 3: summary of NARMS approach for identifying interventions

Principle	**Likelihood of Asset Failure**	**Consequence of Asset Failure**	**Risk is a function of Likelihood of an event and its consequence**
Monetised Risk	Each asset has a probability of failure. This probability is arrived at by use of an 'End of Life Modifier'. This is a score that maps an asset to a place on a probability of failure plot, specific to each asset class.	For each asset failure event there may be safety, system and environmental consequences- these are monetised.	The probability of failure of an asset multiplied by the probability of an event with a monetised consequence produces the monetised risk of asset failure. The monetised risk of asset failure can be aggregated to give us a whole network measure of risk, and allows us to make prioritisation decisions between different assets.

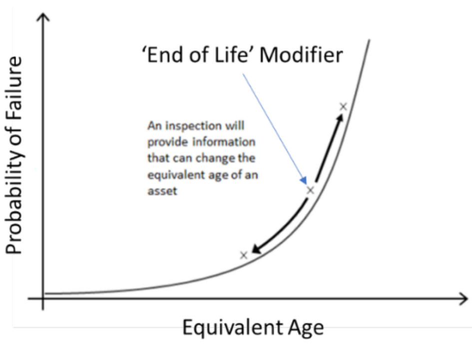


Figure 7: EOL modifier principle

This figure illustrates the principle of the End of Life Modifier. The rise in monetised risk is governed by an asset's probability of failure plot, the magnitude of the risk at any given point in time is a function of the probability of failure (variable) and the probability of an event with a monetised consequence (fixed).

Our monetised risk calculations are underpinned by detailed condition information for each of our assets.

4.2.2 Approach for OHL Conductors

The key factors considered when determining the need to replace an OHL conductor are asset condition and circuit criticality. The age of a conductor does not begin to generate a score until the asset has reached its anticipated life. An asset should not be prioritised for replacement based on age alone but there is a need to reflect the higher risk level that an older asset poses. The deterioration mechanisms of OHL conductors (wear/fatigue/corrosion) cause attrition and occur over time. Condition state can remain hidden underneath clamps or within the inner layers of conductor. A heightened level of uncertainty owing to conductor asset age should trigger action, in the first instance, a condition assessment.

For ACSR conductors, End of Life (EOL) is currently defined as when the aluminium strands demonstrate a tensile breaking load, 15% below a benchmark for a new piece of conductor. Tensile strength is considered alongside corrosion and other asset condition information such as Linecor surveys and defect information. It is understood that conductor deterioration is not linear and a hockey stick curve effect may be experienced towards the end of asset life. There is also growing evidence that EOL for some ACSR routes in benign operating environments will be caused by fatigue not corrosion.

Quad bundled conductors are more prone to damage in geographical areas where sub-conductor oscillation or aeolian vibration is experienced. Historically the damage is caused at spacer positions with the damage currently determining the EOL. This type of damage cannot be predicted generically and relies on local knowledge, experience and developing technologies such as wind and corrosion mapping.

For AAAC conductors, it is anticipated that corrosion will not be the life limiting process. Instead, it is likely that fatigue will ultimately cause a loss of strength.

Due to the implementation of innovative approaches such as Linecore at RIIO-T1 (see section 3.1 above) has given us a better understanding of asset condition, which has allowed us to extend conductor life. Life extensions will begin to drive benefits for consumers from RIIO-T2 onwards, allowing the deferral of asset replacement on £204m worth of routes that would otherwise have required intervention during RIIO-T2.

4.2.3 Approach for Fittings – Spacers & Dampers

These components are utilised to protect the conductor system from damage. Original spacers were typically rigid in construction however modern spacers now incorporate an element of damping ("spacer dampers"). Once their damping capacity is significantly reduced, conductor damage is more likely to occur at clamping positions, as the spacer damper starts to behave more like a rigid spacer. Again, it is the quad bundles that are particularly vulnerable. Poorly designed spacers and spacer dampers on quad bundles have resulted in many instances of conductor damage, and even failure. Spacer damper EOL is therefore defined in terms of the point at which effective damping ceases, i.e. the damping elements no longer meet the damping type test requirements and conductor damage occurs.

The functional EOL of spacers, spacer dampers and vibration dampers can therefore be summarised as the point at which the conductor system is no longer protected, and conductor damage starts to occur.

4.2.4 Approach for Fittings - Insulators

The EOL is defined as an increased risk of flashover or a decrease in mechanical strength due to corrosion of the steel pin. In the former case, a flashover may result in mechanical failure of the string and the threshold for unacceptable unreliability will depend upon the system criticality of the circuit and the potential consequences of a mechanical failure.

For composite insulators, the life estimate is a conservative one based on our lack of experience of this type of insulator. The EOL criteria are expected to be an increased risk of flashover or a significant loss of mechanical strength, but so far there no failures experienced on the UK at transmission voltages.

4.2.5 Inspection regime for conductors and fittings

The emergence and development of a variety of new condition monitoring and condition assessment technologies, techniques, and innovations over the RIIO-T1 period, have enabled National Grid Electricity Transmission to understand the replacement priorities of assets in more detail than was previously possible. This has enabled us to deliver RIIO-T1 outputs more efficiently at a lower cost, plan asset interventions at the optimal time and extend the operational life of assets, benefiting the UK consumer in the longer term.

National Grid Electricity Transmission introduced Linecore inspection technology to determine corrosion levels in the steel core of ACSR conductors. This technology has been used to increase EOL knowledge for ASCR conductor assets, which make up approximately 6,120 cct.km on the network, and this has been reflected within the monetised risk model.

Improved asset management practices and innovative technologies continue to be developed for OHL assets. Enhanced airborne camera technologies are being developed to complement helicopter surveys and replace the need for some climbing inspections, whilst development of the tools and processes for identifying defects such as hot joints continue. Other techniques such as wind energy and corrosion mapping are also being developed to understand which OHL routes are more prone to the effects of the environment in which they are located. This would enable National Grid Electricity Transmission to determine which OHL routes would require more frequent assessment and painting, thereby extending the life of the assets.

Table 4 below shows the frequency of inspection for conductors and fittings:

Table 4: inspection frequency for conductors and fittings

Inspection Type	Frequency
Foot patrol	Annually
Infrared assessment	Annually
High Definition Camera Assessment (HDCA)	6 years
Steelwork assessment	8 years
Conductor samples and other intrusive assessments (Level 2)	As required, triggered by assessment

Our EOL assessments are determined by the information gathered from our inspection and monitoring regime. More detail about the assessment framework we use to determine the EOL score for conductors and fittings is set out in Appendix C.

4.2.6 Increase in monetised risk during RIIO-T2

As set out in Section 4.1, stakeholders want us to maintain the current level of risk across our network, and the assets detailed in this report directly influence the reliability and security of supply of the network. If no action is taken then conductors and fittings would be at risk of condition related failure leading to system outages (and potential blackouts), safety incidents, and increased maintenance costs. By delivering the planned interventions, National Grid will be able to maintain safety and reliability, in line with Stakeholder feedback.

Figures 8 and 9 show the impact on monetised risk position for OHL Conductor and Fittings respectively if no interventions were carried out in RIIO-T2. Figure 10 provides an aggregate view across conductors and fittings. Monetised risk is disaggregated by voltage level.

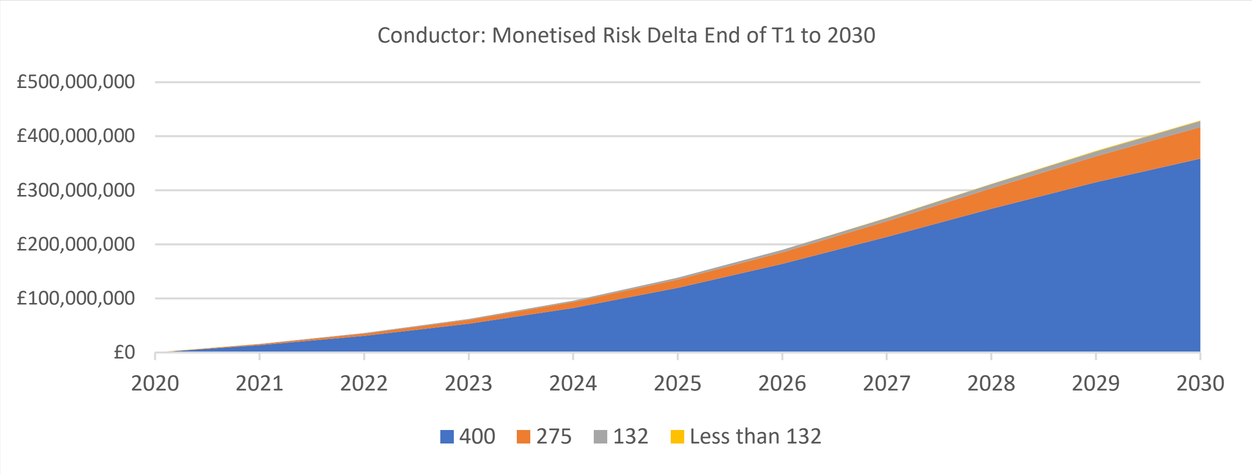


Figure 8: unconstrained monetised risk over time (conductors) by voltage level

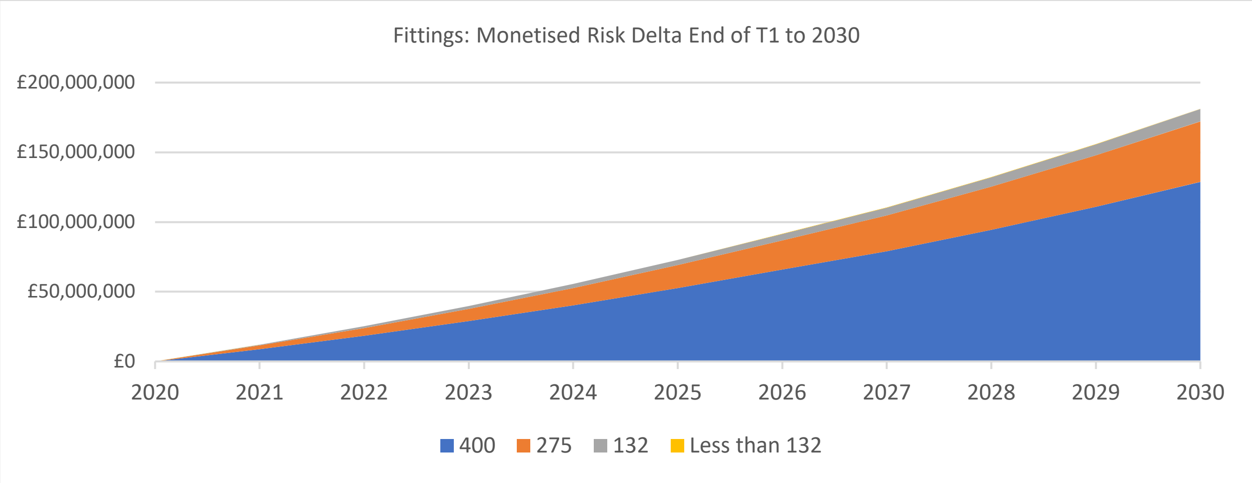


Figure 9: unconstrained monetised risk over time, fittings, by voltage level

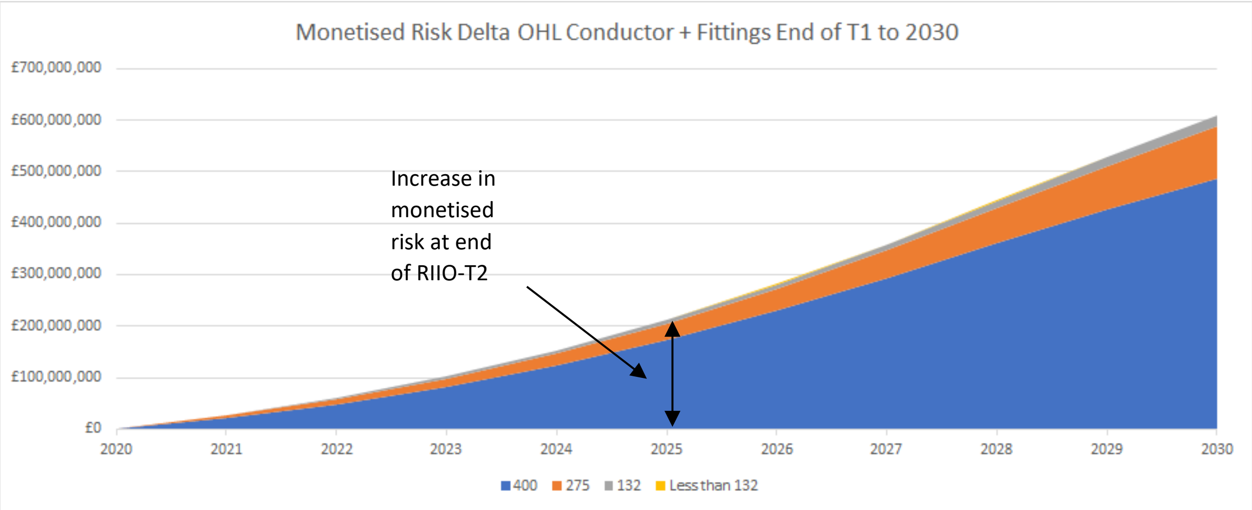


Figure 10: unconstrained monetised risk increase over time, fittings and conductors

The aggregate increase in monetised risk across fittings and conductors (as shown in Figure 10) over the course of the RIIO-T2 period is **£211m.** We show how we have arrived at an optimised bundle of interventions across Conductors and Fittings that mitigates this risk in the Optioneering section below (detail in Section 5.4).

5 OPTIONEERING

To determine the optimum mix of interventions to make on the OHL Conductor and Fittings portfolios, a CBA was undertaken to compare both a targeted-fittings approach, and a trading of assets between categories. We have analysed CBA output for each of the option together with a wider technical and stakeholder justification for the work proposed to be undertaken. Detail of our analysis and final outcome is presented below.

This justification report sets out the range of options we considered which needs to be considered in parallel with our quantitative assessment of the main options which are contained within Cost Benefit Analysis spreadsheet with the following reference: NGET_A9.09_OHL_CBA02_LEAD. Together they provide comprehensive engineering and economic justification for our proposed volumes and costs.

5.1 APPROACH TO ESTIMATING COSTS AND BENEFITS

5.1.1 Summary of overall approach

We have used a three-stage approach to identify the most cost-effective package of options for this paper.

1. Firstly, we have **identified potential intervention strategies** for conductors and fittings separately. This identified a 'long list' of intervention strategies which were then tested for feasibility/applicability. They include a 'Do Minimum' option for both conductors and fittings. We have not considered non-network or whole systems options here since these cannot substitute for the type of investment we are considering in this paper.
2. Once the set of feasible options for conductors and fittings has been established, we combine these into **packages of options** covering both conductors and fittings. Quantitative **Cost Benefit Analysis (CBA)** is carried out on these options packages to identify the most cost effective.
3. For the most cost effective option, the **volumes of conductor and fittings interventions are adjusted** in order to address deliverability concerns and identify further cost efficiencies while maintaining a constant level of network risk. CBA is also carried out for this additional options package.

We have included Investment Costs and Monetised Network Risk into our quantitative CBA, using the NPV calculation approach in the Ofgem template to arrive at an NPV estimate for each of the options packages.

We have not quantified wider societal benefits for each options package because these impacts are minor in the context of the overall costs of the investment package, and would not affect the choice of option. We therefore address societal impacts qualitatively in the analysis below.

Each asset type will have a different approach and options for intervention so we have conducted optioneering assessment for each of the asset sub types separately.

5.2 POTENTIAL INTERVENTION STRATEGIES

5.2.1 Conductors

The long list of potential options for conductor interventions is summarised in Table 5 below:

Table 5: summary of conductor intervention options

Option	Detail	Taken forward for full CBA?
1. Do minimum	A passive strategy is adopted where conductors are only replaced once failure has occurred	**Taken forward**
2. Partial conductor replacement	Potentially an alternative strategy to full conductor replacement, where specific spans along the OHL route have been found to contain conductor of a significantly different asset health than elsewhere along the route. However for this option to be considered as viable we would need to fundamentally change the way we gather asset health data in order to obtain data of sufficient granularity on the [redacted] individual spans on our network. Reaching this level of maturity in our asset monitoring will not be possible within the T2 timescales.	**Not taken forward** This option has been discounted for implementation in T2 due to immaturity of modelling and asset data capabilities. Further work will take place to explore the increase in capability of our data and systems as part of business as usual innovation to see if a positive cost cost-benefit output can be demonstrated.
3. Full replacement	Conductor replacement and full fittings replacement of full OHL routes based on monetised risk to maintain transmission network risk. The scope of works for a full conductor replacement requires replacement of the following: • Phase and earthwire conductors • Insulators • Insulator and conductor fittings • Tower steelwork to ensure structural integrity is maintained for an additional 40 years Additional scope of work if required includes replacement of; ▪ Anti-climbing devices ▪ Safety signs and information plates ▪ Replacement of fibre optic provision ▪ Concrete foundation muffs A monetised risk approach has been used to select assets requiring asset replacement. All interventions have been reviewed to ensure optimum timing between fitting and conductor interventions to ensure best overall value. Before the conductor is replaced, the circuit rating of the OHL is assessed to ensure the correctly-sized conductor and bundle is specified. Investment costs under this option are £548m.	**Taken forward**

Full replacement is therefore taken forward (along with Do Minimum) for inclusion in the combined Conductor + Fitting options packages.

5.2.2 Fittings

The long list of potential options for fittings interventions are summarised in Table 6 below:

Table 6: summary of fittings intervention options

Option	Detail	Taken forward for full CBA?
1. Do Minimum	Under this option, fittings are only replaced at failure.	**Taken forward**
2. Full fittings replacement (all components)	If conductors have a residual life of between 10 & 15 years, with the fittings being the life-limiting factor it is economic to replace to prolong the life of the conductor. This option involves replacing all fittings (e.g. insulators, spacers, vibration dampers and all items of hardware that support the phase conductor and earthwire, other than the towers and their foundations). Investment costs under this option are £218m.	**Taken forward**
3. Partial fittings replacement (targeted components)	Replacement of targeted fittings considers replacing only the fittings identified to be in worst condition whilst allowing the remaining fittings which are noted as being in an acceptable condition to achieve their remaining asset life, this has become NGET's default approach to an OHL fittings intervention in RIIO-T1. For each OHL circuit identified under a monetised risk output for fittings intervention, condition information was reviewed to assess which specific components (dampers, spacers, insulators, or linkages) should be targeted. We are therefore managing the components driving the high probability of failure, leaving assets with a low probability of failure and thus less risk. Investment costs under this option are £85m. The targeted fittings approach, delivered in-house, has enabled significant cost savings within the-T1 period and is expected to reduce T2 costs by £134m in comparison to a full fittings replacement intervention.	**Taken forward**

Partial and full fittings replacement are therefore taken forward (along with Do Minimum) for inclusion in the combined Conductor + Fitting options packages.

5.3 DEVELOPING OPTIONS PACKAGES

The intervention strategies identified as feasible give the following combinations across conductors and fittings, with a single 'Do Minimum' option across both conductors and fittings:

- Do Minimum (conductors and fittings)
- Full replacement (conductors) + Full Replacement (Fittings)
- Full replacement (conductors) + Partial Replacement (Fittings)

The results of our CBA for the three options packages are set out in Table 7 below. The assessment includes both the quantitative CBA results, as well as our assessment against other factors e.g. stakeholder priorities.

Table 7: CBA for feasible options packages

Option (lifetime)		Quantity (km)	RIIO-T2 Investment Cost (undisc, £m)	Total investment cost (£m, undisc)	NPV (disc, £m)	Monetised Risk (disc, £m)	NPV net mon. risk (disc, £m)	Decision
Do Nothing	CBA	0	N/A	N/A	N/A	N/A	N/A	REJECT
	Other considerations (stakeholder, engineering, societal benefits		Without investment, assets begin to fail, requiring expensive emergency interventions to meet security of supply. As it results, this option does not meet stakeholder expectations as risk increases and is not maintained at current levels. OHL fittings directly support the mechanical properties of the Conductor system, and a failure of individual component could lead to a subsequent failure of the conductor itself. This option has unacceptable safety impacts. If conductor was to catastrophically fail and a span fall to the ground, this could result in major disruption to the transport networks and pose a serious risk of injury or death. In addition, it would constrain Operations resources to emergency planning and affect system access for other works. Limits future system opportunities. Would lead to increased costs for future consumers.					
Full Refurbishment and Targeted fittings interventions with volumes as per monetised risk output	CBA	[redacted]km fittings [redacted]km conductor	640	658	-544	384	-160	TAKE FORWARD FOR RISK TRADING
	Other considerations (stakeholder, engineering, societal benefits)	Under this option, fittings interventions to be condition led and confidently pinpoint which components are driving the increased probability of failure. This option represents transition of innovative solution into business as usual which allow us to maintain extremely high reliability levels that our stakeholder require at the minimum cost. Very challenging to deliver given volume of conductor activity. Would not fully utilise internal operations staff given low volumes of fittings interventions. In terms of wider societal impacts: - Newer conductors would have a minor positive impact on losses, so replacing a greater volume of conductors under this option would reduce losses marginally compared to other options - Increased volume of conductor replacement may have a minor impact on number of noise complaints as 75% of RIIO-T2 conductor replacements are on the quietest type (Quad ACSR Zebra)						
Full refurbishment and full fittings with NARM trading	**CBA**	[redacted]km fittings [redacted]km conductor	743	766	-631	384	-247	REJECT
	Other considerations (stakeholder, engineering, societal benefits	Meets stakeholder requirements to maintain current risk levels. This would be the safest, minimum risk option when considering asset condition and risk to the public. Replacement of all fittings would result in longer time before the next intervention is required. However, replacing all fittings regardless of condition is not an efficient asset management strategy						

Full conductor replacement plus partial fittings replacement is therefore taken forward for Risk Trading (see below).

5.4 Risk trading

5.4.1 Deliverability considerations

Initial monetised risk outputs indicated that [redacted]km of OHL Conductor and [redacted]km of OHL fittings should be addressed in RIIO-T2 in order to mitigate the increase in network risk in RIIO-T2 across all OHL conductors and fittings assets (in the absence of intervention) that is identified in Section 4.2.6 above. These intervention volumes would therefore maintain network risk at current levels in line with stakeholder requirements.

However, looked at on a yearly basis from a deliverability perspective, conductor volumes would be challenging with supply chain and available external resource potentially struggling to deliver [redacted]km per year.

By considering the OHL portfolio holistically, trading of the overall NARM value between conductors and fittings could enable a smoother plan and addresses the concerns above, ensuring better deliverability and long-term procurement plans. It is appropriate to trade NARM values between conductors and fittings due to the interaction between these asset types.

5.4.2 Our approach to risk trading

We have therefore developed and assessed an option which allows for a more efficient balancing between conductors and fittings, in order to address delivery concerns and allow for a more effective use of internal resource.

We have built the plan not only to maintain overall network risk, but also to maintain risk within each of our asset categories. Accepting higher risk for asset categories may not result in lower reliability in the short-term, however over the long term it can become unrecoverable. Table 8 below shows the review we undertook to optimise the plan to manage risk associated with our overhead lines.

By reviewing the risk associated with each component, and using the new methodology to compare them, we can understand the effect a change in the volumes of fittings and conductor replacements has on overall risk and overall cost. Please see 'plan build' annex A9 for further detail how we have built the plan including consideration of trade offs between asset classes.

Table 8: summary of risk trading approach

Phase	Description
1. Start	Assess the volume and cost of conductor and fittings work required to maintain the same asset risk over the T2 period
2. Refine	Using the new methodology, we can then vary the volumes of work, and understand the impact on overall asset risk and cost.
3. Result	**Volume:** Reduction of conductor, increase in fittings **Costs:** Overall cost of the package of work is reduced **Risk:** The same overall asset category risk is achieved

5.4.3 Risk trading results

Table 9 below sets out a revised intervention package where risk is traded between the asset classes, leading to a greater volume of fittings interventions and fewer conductor interventions. The overall level of monetised risk after the trading remains the same, but also allows for a significant cost reduction of £39m. The planned volumes also align with our condition knowledge for OHL conductor and fittings populations.

Table 9: summary of investment cost and monetised risk position of OHL assets with and without trading

		Volume	Cost (£m)	T1 Risk Position (£m)	2025 Risk Position (£m)
Monetised risk output	Conductor	[redacted]	631	70	70
	Fittings	[redacted]	40.5	123	123
	Total	[redacted]	671.5	193	193
Trade risk between asset classes	Conductor	[redacted]	547.7	70	82
	Fittings	[redacted]	84.8	123	110
	Total	[redacted]	632.5	193	192
Variance	Conductor	[redacted]	-83.3	-	12
	Fittings	[redacted]	44.3	-	-13
	Total	[redacted]	**-39**	-	**-1**

This has been identified as the optimum delivery plan as it reduces the overall cost of overhead line lead-asset interventions across T2 by £39m, and also reduces the monetised network risk position by £1m. Further trading of asset types sees declining efficiencies between cost and risk position, and begins to reverse the deliverability issue, potentially requiring more fittings projects than can be delivered in-house, and not sustaining an external conductor replacement supply-chain leading to the loss of skilled labour for future price control periods.

Figure 11 shows that this plan narrows the overall risk differential between fittings and conductors over RIIO-T2. While fittings replacement investments will always be more economical than conductor replacements, it is important that we manage the overall risk positions of both the fittings and conductor populations. Timely fittings interventions are important to enable the conductor to reach its full asset life, however a fittings intervention does not have a direct impact on the anticipated asset life of a conductor. There is a need to continue with OHL conductor replacements to manage the overall population age and condition.

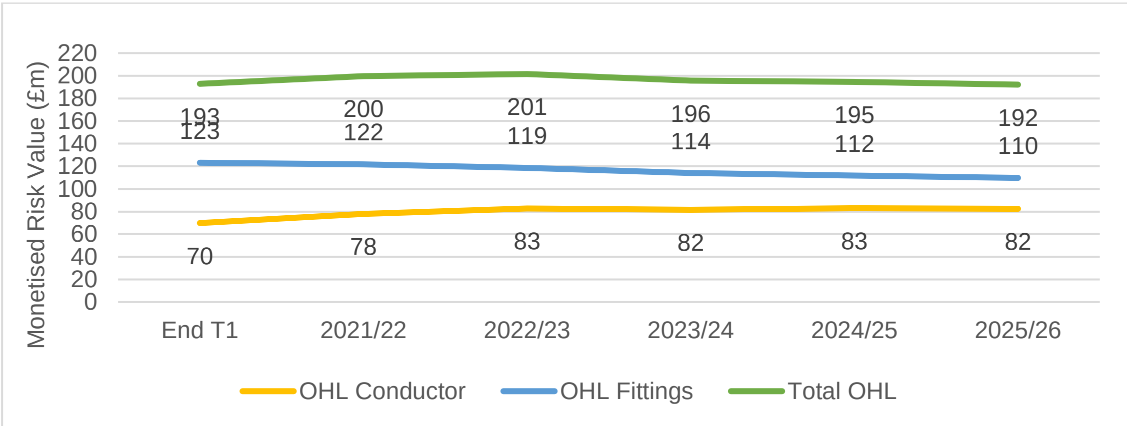


Figure 11: OHL lead assets monetised risk per year

5.4.4 How post-risk trading RIIO-T2 volumes mitigate network risk

In Figure 10 above, we identify that network risk across all conductors and fittings assets will increase by £211m in the absence of any intervention at RIIO-T2. Our proposed RIIO-T2 work volumes need to mitigate this monetised risk in the most efficient way in order to meet stakeholder priorities around risk and cost.

As set out in the previous section, our initial optioneering based solely on monetised risk output identified to mitigate the increase in unconstrained network risk in conductors and fittings separately, giving a constant level of risk over the RIIO-T2 period for both asset classes (see Table 9 above). In our optimised package, our fittings interventions mitigate more monetised risk than the increase in unconstrained network risk in fittings during RIIO-T2. The opposite is true for conductor interventions. Over conductors and fittings as a whole, the increase in unconstrained risk is mitigated by our interventions. This is explained in Figures 12-14 below:

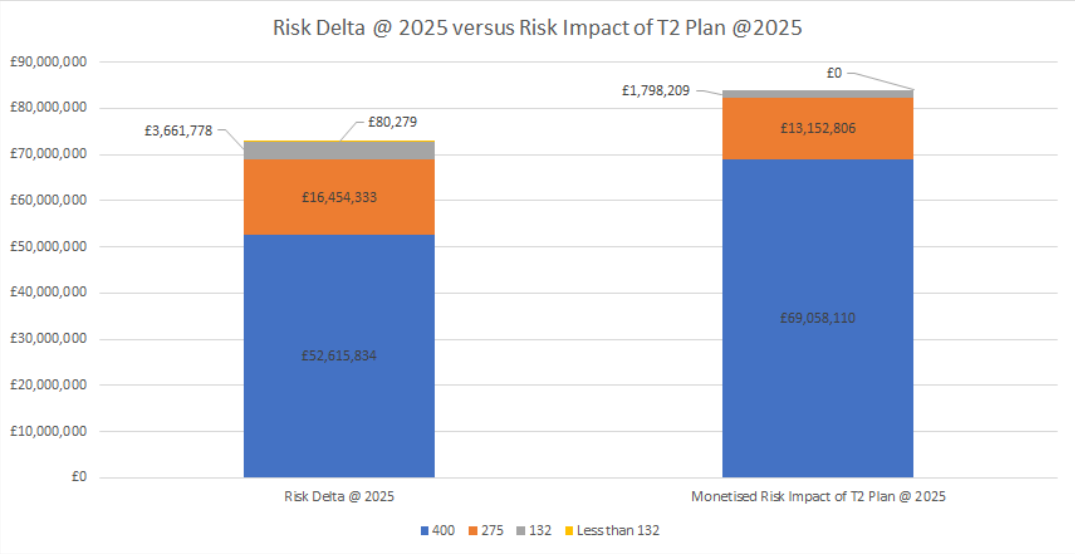


Figure 12: Risk mitigation from RIIO-T2 interventions (fittings) versus increase in unconstrained network risk

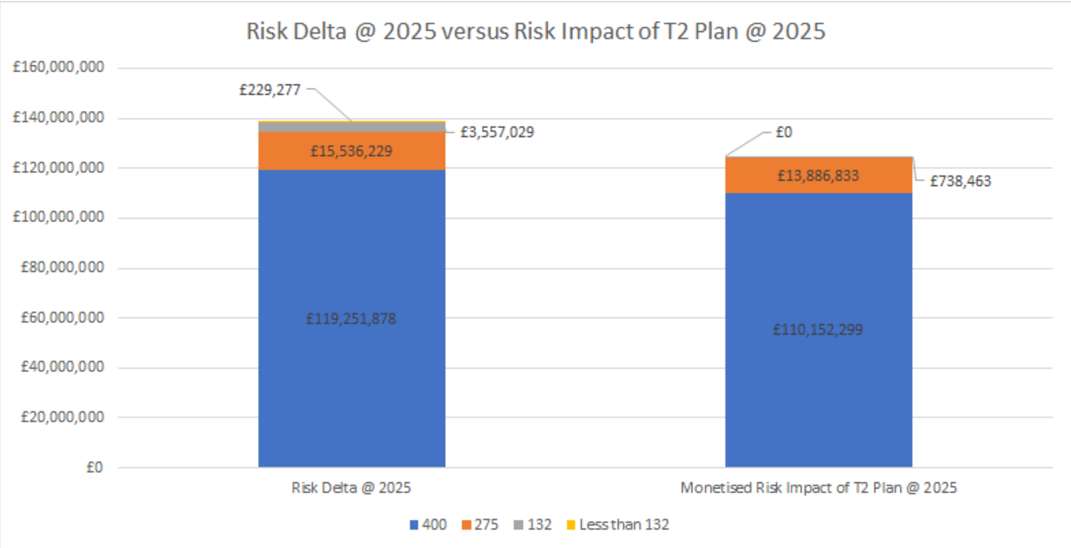


Figure 12: Risk mitigation from RIIO-T2 interventions (conductors) versus increase in unconstrained network risk

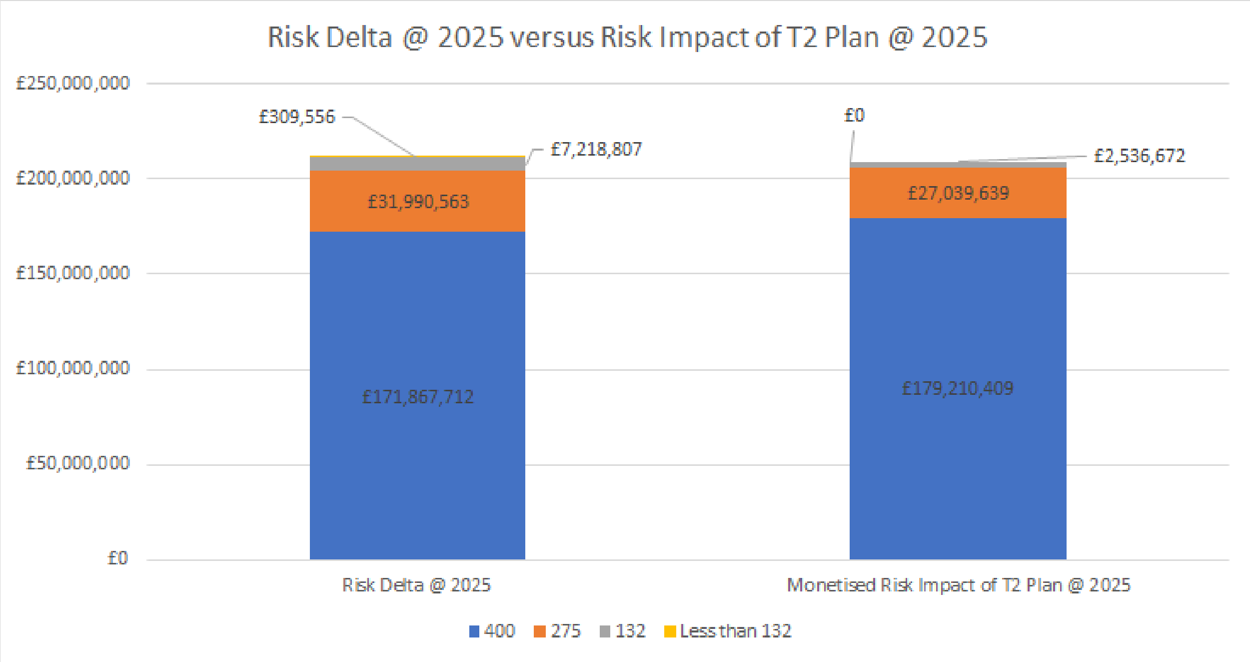


Figure 13: risk mitigation from RIIO-T2 interventions (conductors and fittings) versus increase in unconstrained network risk

A breakdown of the total OHL risk addressed by our interventions, is given in the charts below. Figure 15 shows a summary view of the monetised risk associated with the conductor assets we have identified for intervention during RIIO-T2, split by their EOL risk rating, and Figure 16 shows what is driving that EOL score. Figures 17 and 18 provide this information for fittings. Appendices A and B shows a detailed mapping of risk to OHL routes names for conductors and fittings respectively. These show the total monetised risk that is mitigated by the identified RIIO-T2 interventions for conductors and fittings: these correspond to the total monetised risk contribution in Figure 14 above.

Figure 15 – EOL mapping of interventions, conductors

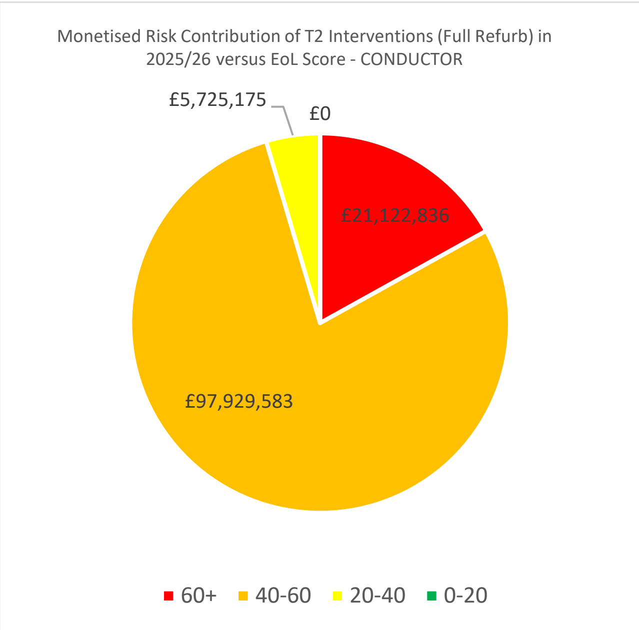


Figure 16- Main driver of EOL score, conductors

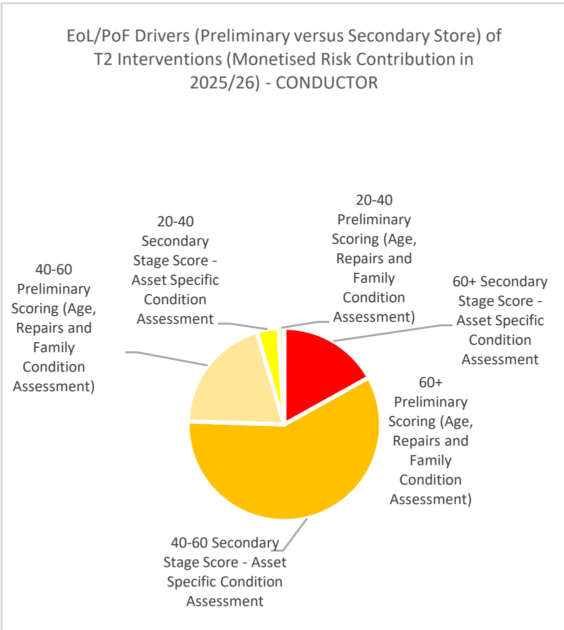


Figure 17: EOL mapping of interventions, fittings

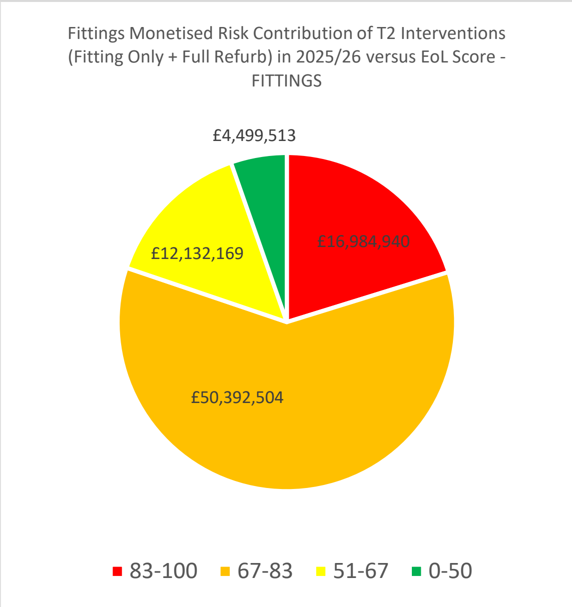
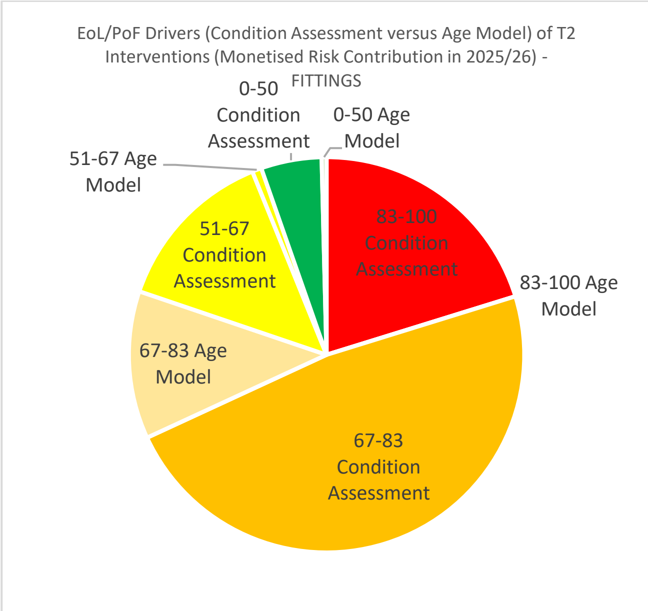


Figure 18: Main driver of EOL score, fittings



Appendices C and D provide details about the characteristics of the routes we have identified for intervention in RIIO-T2. We have used this information to show how the volume of interventions for conductors and fittings (in kilometres) sum to the mitigated risk below.

Table 10: mitigated risk and intervention volumes

	Fittings		Conductor	
Voltage (kV)	**Mitigated risk (£)**	**Length (km)**	**Mitigated risk (£)**	**Length (km)**
400	70,359,241	[redacted]	46,178,437	[redacted]
275	14,051,552	[redacted]	1,918,503	[redacted]
132	1,798,209	[redacted]	102,475	[redacted]
Total	**86,209,002**	[redacted]	**48,199,416**	[redacted]

Table 11 breaks these volumes down into subcategories and compares the volume of interventions against the total population on the network.

Table 11: lead assets (conductor and fittings) for delivery during RIIO-T2 period

Asset Type	Asset Sub-Type	Asset Designation	Size of Population (cct.km)	Interventions in RIIO-T2 (cct.km)
OHL Fittings	Conductor Fittings, Vibration Dampers, Spacers, Spacer dampers	Single	[redacted]	[redacted]
		Twin	[redacted]	[redacted]
		Triple	[redacted]	[redacted]
		Quad	[redacted]	[redacted]
	Insulators and Linkages	Brown Porcelain	[redacted]	[redacted]
		Grey Porcelain (No Zinc Collar)	[redacted]	[redacted]
		Grey Porcelain (Zinc Collar)	[redacted]	[redacted]
		Glass	[redacted]	[redacted]
		Composite/Polymer	[redacted]	[redacted]
	Fittings Total			[redacted]
OHL Conductor	Aluminium Conductor Steel Reinforced (ACSR)	Core Only Lynx	[redacted]	[redacted]
		Fully Greased Lynx	[redacted]	[redacted]
		Core Only Zebra	[redacted]	[redacted]
		Fully Greased Zebra	[redacted]	[redacted]
		ACSR Conductor Total	[redacted]	[redacted]
	Non-ACSR	AAAC/ACAR	[redacted]	[redacted]
		Non-ACSR Conductor Total	[redacted]	[redacted]
	Conductor Total		[redacted]	[redacted]

After Risk Trading, the RIIO-T2 plan represents an increase in OHL conductor and OHL fittings replacement volume by [redacted]% and [redacted]% respectively over period, compared to RIIO-T1.

There are [redacted]km of OHL circuits on the network, and if the annual average of [redacted]km planned for T2 is extrapolated out, it would take 54.7 years to reconductor the entire network. This timeframe is very close to the expected life of a core-only greased ACSR conductor (55 years), which form the majority of the interventions planned for T2. When this conductor type has been fully replaced in circa 2030, it is expected that annual average volumes can decrease to match the greater expected life of fully-greased ACSR and AAAC conductors.

Table 12 below shows the CBA results for the post-risk trading option versus the option with volumes based on initial monetised risk outputs:

For lead assets, such as Conductors, as well as the direct costs of investment, the NPV also accounts for:

- Changes in Monetised Risk because of interventions (benefits vs Do Minimum baseline, shown separately in tables below)
- Safety impacts: preventative measures captured within investment costs (benefits versus Do Minimum baseline captured in NPV)

Table 12: CBA for risk trading lead option (shown versus equivalent without risk trading

<table>
<tr><th>Option</th><th></th><th>Quantity (km)</th><th>RIIO-T2 investment cost (undisc, £m</th><th>Total investment cost (£m, undisc)</th><th>NPV (disc, £m)
B21</th><th>Monetised Risk (disc, £m)</th><th>NPV inc mon risk (disc, £m)</th><th>Decision</th></tr>
<tr><td rowspan="2">Full Refurbishment and Targeted fittings interventions with volumes traded for maximum efficiency</td><td>CBA</td><td>[redacted]km fittings
[redacted]km conductor</td><td>621</td><td>602</td><td>-512</td><td>384</td><td>-128</td><td rowspan="2">RECOMMEND</td></tr>
<tr><td>Other considerations (stakeholder, engineering, societal benefits</td><td colspan="6">Greater deliverability by trading NARMs volumes between conductors and fittings
Meets stakeholder requirements to maintain current risk levels
In terms of wider societal impacts:
- Decrease in conductor volumes compared to initial monetised risk output will reduce disruption to 3rd parties and environmental impact.
- Likelihood of fittings failure is higher than conductor, so addressing a greater volume of fittings minimises safety risk although all options considered pose minimal risk
- Conductor replacement with modern equivalent may have increased noise</td></tr>
<tr><td rowspan="2">Full Refurbishment and Targeted fittings interventions with volumes as per monetised risk output</td><td>CBA</td><td>[redacted]km fittings
[redacted]km conductor</td><td>640</td><td>659</td><td>-544</td><td>384</td><td>-160</td><td rowspan="2">REJECT</td></tr>
<tr><td>Other considerations (stakeholder, engineering, societal benefits)</td><td colspan="6">Wider considerations for this option are covered in Table 7 above</td></tr>
</table>

6 ASSESSMENT OF COST EFFICIENCY

The costs and volumes in our RIIO-T2 plan (as well as those for RIIO-T1) are set out in the table below:

Table 13: Comparison of conductor and fittings interventions for RIIO-T1 and RIIO-T2

		T1 Allowance	T1 Actuals	T1 Forecast	T1 (all years)	T2 forecast	Annual average	Annual average (first 6 years)	Annual average
OHL Conductor	Total cost (£m)	578	479.3	47.9	527.2	547.7	65.9	79.9	109.5
	Total volume	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	Cost per unit volume	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
OHL Fittings	Total cost (£m)	222	40.0	14.2	54.2	82.5	6.8	6.7	16.5
	Total volume	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	Cost per unit volume	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Below we explain the drivers of the differences in unit costs between price controls and show that our costs are efficient.

The estimating methodology for capital projects is based around a standard and consistent approach. This is controlled by an in-house, central estimating team (e-Hub) within Capital Delivery Project Controls. The detail of this methodology can be found in NGET_A14.09_Internal Benchmarking of Capex unit costs.

6.1 OHL CONDUCTORS

The following graphs are aligned with Ofgem's requirements for reporting capital costs in the Business Plan Data Template, i.e. they exclude development, design and project management costs. **For this reason, they are systematically lower than all the unit costs discussed previously in this report.**

6.1.1 How we have built up RIIO-T2 unit costs

Overall, removing the costs for Tyne Crossing, which is not driven by asset condition and covered in Justification Report A9.12 Tyne Crossing, the costs per unit for OHL conductors have reduced from T1 to T2, by approximately 8% (see Table 13 above).

The costs for RIIO T2 intervention are lower than T1 because we have embedded the innovations and efficencies developed and delivered in the T1 period in to the baseline costs for our T2 plan e.g. optimisation of delivery strategy (including contracting efficiencies, improved condition information enabling more robust scoping). In addition there are fewer shorter complex routes which have incurred disproportionately high unit costs in the T1 period.

Our unit cost estimates for RIIO-T1 and RIIO-T2 projects are set out in Figure 19 below, as well as averages across all projects in each price control. RIIO-T1 costs are based on actual project information where possible, while RIIO-T2 costs have been estimated using the approach set out in this section. The unit costs for OHL Conductor Replacement have been compared to the unit cost benchmarks provided by TNEI Services (see Figure 20). This shows that National Grid's unit costs for RIIO-T2 Interventions are lower than the industry benchmark.

[redacted]

Figure 19: Unit costs of RIIO-T1 and RIIO-T2 conductor schemes against RIIO-T1 and RIIO-T2 averages and external TNEI benchmark

[redacted]

Figure 20: OHL conductor unit costs versus TNEI benchmark, split for high and low voltage projects

In Table 14 below, we explain the cost drivers for RIIO-T2 projects that are significantly higher or lower than the RIIO-T2 average:

Table 14: RIIO-T2 unit cost outliers, conductors

Route	Unit Cost (£m/km)	Outlier	Volume (km)	High cost drivers					
				Full	Short	Urban	Quad	Crossings	Intervention scope (%)
31219 LLWE-WHSO OHL refurb SD SE routes	[redacted]	Below							33kV Route will have far cheaper equipment than high voltage and also be much easier to install (lighter). Due to these factors we are also looking to get this delivered in-house by ET Ops, which will reduce overheads and tender costs etc.
32204 HAMH-COVE/WILE 4ZWW full reconduct	[redacted]	Above				✓	✓	✓	In 2017, the work on this route had to be put on hold due to various issues with protected nesting birds, third parties cancelling outages (including Network Rail), and grantor issues disrupting the works. [redacted] km out of [redacted] km was delivered. The remaining works are due to be completed at the beginning of next year, but it has meant a full de/remobilisation, and the storage of materials and equipment for 2 years.
33621 CHCR- HARK T REFURB (138-162)	[redacted]	Below	[redacted]						Single conductor. As with the 33kV route, the lower voltage means the equipment is cheaper and lighter, which reduces unit costs. These two routes also require uprating (load-related driver), so can be bundled with that for efficiency.
33620 GRET-HAWK-HARK AL REFURB (57-68)	[redacted]	Below	[redacted]						Single conductor. As with the 33kV route, the lower voltage means the equipment is cheaper and lighter, which reduces unit costs. These two routes also require uprating (load-related driver), so can be bundled with that for efficiency.
4VY COWL-CULJ-DIDC & COWL-DIDC OHL Full Refurb	[redacted]	Above	[redacted]				✓	✓	The quad-configured route, with a few road/rail crossings (requiring scaffolding or the use of a catenary support system) pushes this unit cost slightly above average,
4VC (274-314) DRAX-THTO OHL Full Refurb	[redacted]	Above	[redacted]				✓	✓	The quad-configured route, with a few road/rail crossings (requiring scaffolding or the use of a catenary support system) pushes this unit cost slightly above average,

Route	Unit Cost (£m/km)	Outlier	Volume (km)	High cost drivers					
				Full	Short	Urban	Quad	Crossings	Intervention scope (%)
100478 - DRAKELOW - WILLINGTON EAST ZS004-ZS041	[redacted]	Above	[redacted]					✓	Urban, short, and lots of crossings
FERRYBRIDGE B - BRAM- HARR OHL PHG78-132	[redacted]	Below	[redacted]						Twin route, fairly long length, rural location. 275kV route so lower rating required (smaller conductor).
32105 GRETNA - HAWICK - HARK OHL repl (2	[redacted]	Below	[redacted]						Single conductor. As with the 33kV route, the lower voltage means the equipment is cheaper and lighter, which reduces unit costs.
ZDA Disconnected HIGM-STOB OHL Full Refurb or Removal	[redacted]	Above	[redacted]		✓	✓			(T3 route so not reviewed as part of the JR) This route is disconnected so when it comes to delivery a CBA will be conductor to determine whether route removal or replacement is the most cost-effective solution in order to maintain the safety of the line. The very short route will mean a much higher proportion of costs is related to overheads and site establishment.
PELHAM - RYE HOUSE - WALTHAM CROSS YP213 / PELHAM - RYE HOUSE YP111	[redacted]	Above	[redacted]		✓	✓			(T3 route so not reviewed as part of the JR) This very short route will mean a much higher proportion of costs is related to overheads and site establishment.

6.2 OHL FITTINGS

The following graphs are aligned with Ofgem’s requirements for reporting capital costs in the Business Plan Data Template, i.e. they exclude development, design and project management costs. **For this reason, they are systematically lower than all the unit costs discussed previously in this report.**

We have commissioned TNEI Services to benchmark our unit costs for fittings against wider industry measures. This analysis is set out in Figure 21 below. For full replacements, our unit costs for RIIO-T2 are significantly below industry standards, although limited significance can be drawn from this as the sample contains a single, short project, as shown in Figure 24 below. TNEI had no equivalent benchmark for targeted fittings replacement. We are industry-leading in our extensive use of targeted replacements of particular components as opposed to the standard practice of full replacement, meaning our average unit cost of £[redacted]m/km (across targeted and full replacement) is well below the industry average (full replacement).

[redacted]

Figure 21: average unit costs over RIIO-T1 and RIIO-T2 (targeted and full replacement) versus TNEI benchmark [3]

Nevertheless, overall the unit cost per for T2 OHL fittings is [redacted]% higher than achieved RIIO-T1 unit costs (although [redacted]% lower than T1 allowances). This is in large part due to inherent characteristics which we cannot influence, in particular:

- The asset condition of the routes; routes in T2 require a higher level of intervention per circuit kilometre due to their asset condition. Our assessment of asset condition on each route (and therefore the scope of the intervention required) is based on detailed condition monitoring (for intervention scope for RIIO-T2 projects, see Figure 22 below).
- An increased number of urban routes have been identified for intervention increasing the complexity i.e. more major crossings and challenging access which increases investment costs.
- An increased number of Quad bundled ACSR conductor routes for which the engineering solutions are more expensive due to increased materials required and the increased programme.

Changes in the project mix from RIIO-T1 to RIIO-T2 are set out in the figure below:

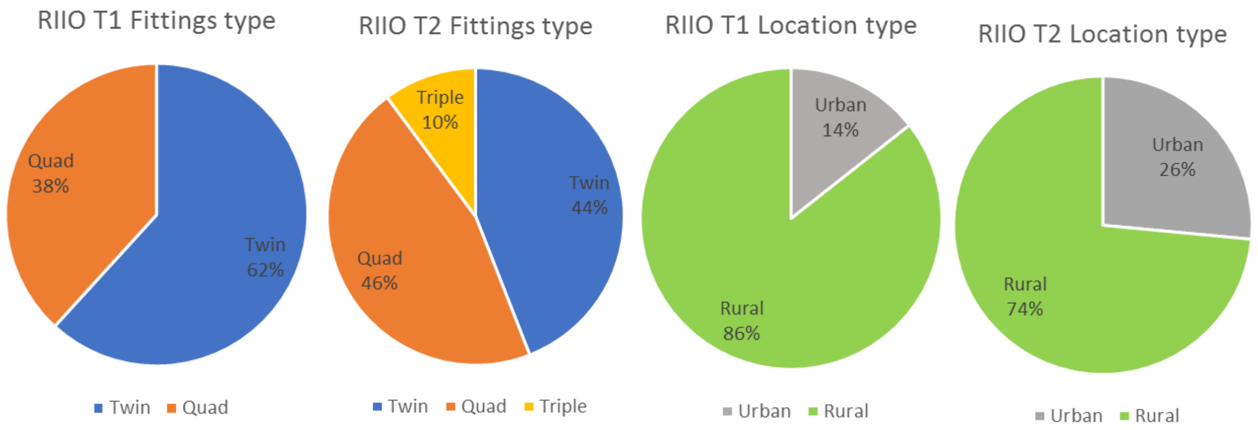


Figure 22: project type mix, RIIO-T1 and RIIO-T2

[3] To enable comparison to TNEI benchmark we show unit cost of full fittings interventions in RIIO T1 and an estimated cost for undertaking full fittings in RIIO T2

Figure 23: data on intervention level on each route

[redacted]

Asset condition and scope:

Through condition monitoring of our assets, we have built up a detailed view of the level of intervention required for each route.

Costs for the targeted fittings annual bundles in the RIIO T2 plan are costed based on this condition information.

The chart to left represents this information as a percentage of total route length that requires intervention.

A comparison between RIIO-T1 and RIIO-T2 fittings unit costs is shown in Figure 24 below. This shows the average unit costs for RIIO-T1 projects (shown separately for targeted and full fittings). For RIIO-T2 projects, it shows unit costs for individual projects as well as averages across targeted and full fittings, as well as the Standard Deviation to give an indication of variations in RIIO-T2 project costs. This shows that, although the characteristics of projects result in higher unit costs than in RIIO-T1, the move to a greater proportion of targeted fittings means that the higher costs of full replacement are avoided.

The project cost estimates for fittings in Figure 24 have been developed using the same rigorous, evidence-based approach as outlined in Section 6.1 for conductors.

Costs for the targeted fittings annual bundles in the RIIO T2 plan are costed based on condition information, involving a review of the EOL score for each fitting component (dampers, spacers, linkages, insulators and earth wire fittings). Fittings with an EOL score which indicates asset condition is such that there would be concerns over asset performance, safety and reliability have been planned for replacement (EOL>50) (see Section 4 for more information around how we ascertain intervention need). The condition information identifies that across all routes an average of 50% fittings need to be replaced. This 50% assumption has therefore been used to provide a standardised unit cost build up across the fittings annual investment bundles.

A standardised approach has also been taken for surveys, vegetation clearance and access, variation to this standard cost build up has only been applied where there is known complexity e.g. urban difficult access. Some OHL Fittings schemes shown in Figure 24 below exist as standalone Project numbers. This is due to the driver for these routes having existed prior to the adoption and output of Monetised Risk and already existing in our systems before RIIO-T2 plan build. When the approach for an annual portfolio bundle of work was proposed and used to set up the remaining RIIO-T2 fittings routes, it was decided to leave the existing projects in place for audit purposes and due to them already incurring small amount of spend.

[redacted]

Figure 24: OHL fittings unit costs (RIIO-T1 and RIIO-T2)

In the table below, we explain the cost drivers for RIIO-T2 projects that are significantly higher or lower than the RIIO-T2 average:

Table 15: RIIO-T2 unit cost outliers, fittings

Route	Unit Cost (£m/km)	Outliers	Length (km)	Justification	High cost drivers					
					Full	Short	Urban	Quad	Crossings	Intervention scope (%)
[redacted]	[redacted]	Above	[redacted]	Full fittings Very short complex route multiple crossings	✓	✓			✓	100
[redacted]	[redacted]	Below	[redacted]	long route predominately rural				✓		63
[redacted]	[redacted]	Below	[redacted]	long route predominately rural				✓		63
[redacted]	[redacted]	Above	[redacted]	Quad route crossing trainline and M62				✓	✓	49
[redacted]	[redacted]	Above	[redacted]	Urban route with some difficult access required through residential areas. Some significant road crossings			✓		✓	50

7 Assumptions, Risks and Contingency

The key risks and uncertainties which will affect RIIO-T2 volumes and costs are set out below:
Cost Estimation - When producing a cost estimate for an OHL intervention several assumptions must be made across the entire route length. For conductor replacement interventions, these include an allowance for earth wire refurbishment, tree cutting, tower muff refurbishment, scaffolding, temporary fibre diversion, steelwork strengthening, foundation repairs, tower furniture replacements, access, and security, based on a percentage likelihood of these being required. All tower painting costs are captured within the non-lead OHL report (NGET_A9.09A).

For a fittings-only replacement, the cost estimate includes an allowance for tree cutting, tower furniture replacements, access, and security, but assumes no scaffolding, no muffs/foundations work, steelwork, or earthwire fittings replacement is required.
If any of the above factors vary significantly from the average, such as a greater degree of steelwork degradation or land access issues on a particular route, this could result in a variance to the cost estimate, but it is assumed on a portfolio level this will balance out.

Costs are based on rates and actual costs from incurred on T1 investments. Full refurbishment costs are built up from final investment costs for delivered investments which were competitively tendered and awarded as contracts. Fittings interventions are procured internally, so unit costs are based on historical rates and actual costs. While early stage design and development work on RIIO-T2 projects underpins the cost estimates in this paper, there will be some variation on assumptions once the full extent of works is known.

Deliverability – As explained in Section 5.4.3 above, RIIO-T2 will see significant volume increases to meet the need of maintaining a safe and reliable network. Our preferred investment strategy (where volumes of conductor and fittings interventions are adjusted using a risk trading approach) aims to address any delivery concerns and ensure efficient use of in-house resources. We will continue to actively engage with 3rd party stakeholders and the supply chain during the development phase of conductor replacement works.

System Access - Asset failure or faults on the distribution or transmission network may affect the availability of outages. Delays or cancellations may result in under delivery of interventions required to achieve Monetised Risk targets or additional costs. These risks will be mitigated as much as possible through early engagement with the NG ESO and DNO's where applicable.

Where assets do behave differently than anticipated, we will adopt Ofgem's framework proposal for managing asset health risk. This enables us to take the latest asset condition information into account while delivering the agreed network risk output.

Contingency- No route specific contingency has been applied to any of the Cost benefit analysis calculations or forecasts in the main business plan. The Cost Book on which our analysis is based (see Section 6 above) reflects the average of actual delivered costs.

Edge effects- this JR justifies total spend of £618m during the RIIO-T2 period. The vast majority of this spend is in relation to outputs to be delivered during RIIO-T2, however there is a small amount of spend associated with outputs in RIIO-T1 and RIIO-T3. The main schemes are:

- **4ZWW (£2.4m spend in RIIO-T2):** The driver for this investment is asset condition, this is a T1 investment. The remaining spend on this investment is less 10% of the overall value of the scheme. The works on this OHL route where not able to be completed in the original planned outage window due to grantor access and bird nesting. The remaining works therefore had to be deferred in to 2020. Therefore, there is a small amount of spend during the T2 associated with this investment.
- **4ZB (£8m spend in RIIO-T2):** This is a T3 investment the driver for the investment is asset condition. The OHL circuit is important to the network export/importing electricity out of North Wales. The condition assessment of this route is based on conductor samples. It has been selected for replacement based on the monetised risk methodology. This investment is planned early in the 2026 outage season therefore all detailed design, procurement activities and site mobilised will need to completed in the T2 period.

8 CONCLUSION

This report justifies our T2 OHL lead-asset replacement plan, based on a monetised risk approach, at a total cost of £621.2m over the 5-year T2 period, including development costs in T1.

Section 3 summarises our cost and volume performance at RIIO-T1. This shows that we have achieved significant savings against our allowance, resulting from both cost and volume efficiencies, which are driving savings for consumers. These efficiencies reflect the implementation of innovative technologies such as Linecore, which have given us a much enhanced understanding of asset health and allowed interventions to be targeted where the need is greatest.

Section 4 sets out the investment need at RIIO-T2, covering investment drivers and our approach to identifying where interventions are required based on the NARMs methodology. This gave an indication of [redacted]km of OHL Conductor replacement together with [redacted]km OHL Fittings replacement to maintain network risk level was expected given the age profile of our OHL assets.

Section 5 sets out our approach to identifying the appropriate intervention strategy for fittings and conductors. For conductors, a Full Replacement strategy has been identified as the feasible option. For fittings, both a full fittings approach and a targeted fittings approach have been identified. These options were taken forward for full CBA, which identified Full Replacement (conductors) and Targeted Fittings as the option with the highest Net Present Value (NPV). In order to ensure our RIIO-T2 plan is deliverable by the market and maximise the utilisation of our internal resources, the Conductor/Fittings mix has been optimised through 'Risk Trading': this has enabled us to reduce overall network risk by £1m and reduce the cost of our overall T2 plan by £39m from the initial NARMS position. Driven by stakeholder priorities to maintain risk across our asset base flat and in line with NARMS methodology we are planning to replace:

- [redacted] cct.km of OHL conductor at a cost of £535.9m.
- [redacted] cct.km of OHL fittings replacements, at a total cost of £82.5m.

Section 6 explains how we have built up our unit cost assumptions underpinning this plan, and shows why they are efficient. For conductors, it shows that unit costs at RIIO-T2 are lower than for RIIO-T1, reflecting the embedding of innovative approaches from the current price control as well as a greater proportion of lower cost urban routes. We also show that our unit costs for RIIO-T2 compare favourably to wider industry benchmarks. For fittings, we explain why the unit cost for RIIO-T2 is higher than for RIIO-T1, reflecting asset condition, more urban routes and a requirement for more complex engineering solutions driven by a greater proportion of quad bundled ASCR conductor routes. We also show independent analysis from TNEI showing that RIIO-T2 unit costs for fittings are well below wider industry benchmarks.

Section 7 identifies potential risks to the deliverability of the proposed investments, and how we propose to mitigate these. It also sets out potential sources of uncertainty in our cost estimates.

Appendix A: asset characteristics and condition (conductors) with monetised risk at end of RIIO-T2 without intervention

Conductor EoL Score	Description
60-100	Definite evidence exists of serious problems with the Overhead Line (OHL) circuit. The problems have been identified and it is considered that they will lead to an unacceptable condition in a relatively short period of time (5 years). This unacceptable condition is likely to lead to failure. No cost effective repair method is available and so refurbishment or replacement is the most economic solution.
40-60	Evidence exists of a problem with the OHL Circuit, possibly with a specific section that is particularly problematic. The Circuit would be expected to deteriorate to Priority 1 within 5 years. Medium level of faults or defects, some requiring additional monitoring and/or ad-hoc component replacement.
20-40	Low level of faults or defects - some known to cause failure.
0-20	Good condition - no known specific or general life limiting problems.

**This is not related to AHI*

This list has been redacted.

Appendix B: asset characteristics and condition (fittings) with 2026 monetised risk at end of RIIO-T2 without intervention, split by voltage level

Fittings EoL Score	Description
83-100	Definite evidence exists of serious problems with the Overhead Line (OHL) circuit. The problems have been identified and it is considered that they will lead to an unacceptable condition in a relatively short period of time (5 years). This unacceptable condition is likely to lead to failure. No cost effective repair method is available and so refurbishment or replacement is the most economic solution.
67-83	Evidence exists of a problem with the OHL Circuit, possibly with a specific section that is particularly problematic. The Circuit would be expected to deteriorate to Priority 1 within 5 years. Medium level of faults or defects, some requiring additional monitoring and/or ad-hoc component replacement.
51-67	Low level of faults or defects - some known to cause failure.
0-50	Good condition - no known specific or general life limiting problems.

**This is not related to AHI*

This table has been redacted.

Appendix C: EOL score drivers for conductors and fittings

The highest probability of failure scores in OHL conductors are driven by condition data in what is termed the ‘Second Stage Score’. Physical samples of OHL conductor are the primary driver for this score. For the condition assessment to be valid for an OHL route, each of the environment categories present need to be sampled. Where no sample exists, the age model is the primary driver for EoL assessment. This utilises number of conductor repairs, joint type and condition assessment from the family to derive a score. This is capped to a maximum EoL of ‘40’.

	‘Preliminary Scoring Stage’			Secondary Scoring Stage	
EoL Assessment Factor	**Age**	**Repairs**	**Joints**	**Conductor Sample**	**Corrosion Survey**
EoL Assessment Input	**Time spent in service**	**Indicator of the environment duty of the asset**	**Record of conductor clamps that are oval or hexagonal compression**	**Physical sample of conductor wire retrieved from a clamping position within a span**	**Survey of galvanising layer of steel-cored conductors**
Asset Inventory Data	Asset type/ install date	NA	Record of joint types	NA	
Condition Data	Secondary Stage Score results from family	NA		Conductor sample scoring records (output of visual, mechanical and metallographic analysis)	‘Line Cor’ and ‘Cormon’ surveys of OHL spans
Performance Data	NA	Defect Records	NA	NA	NA
Operational Duty Data	NA				
Operating Environment Data	Asset Location Class (affects predicted asset life curve of conductor)	NA			

The highest probability of failure scores in OHL fittings are driven by condition data. The primary source of this is visual assessment from the helicopter-mounted, high definition camera assessment. Where no sample exists, the age model is the primary driver for EoL assessment, capped at an EoL score of 70.

EoL Assessment Factor	**Age**	**Level 1 Condition Assessment**	**Current Defects**	**Level 2 Condition**	**Failure History**	**Environment Modifier**
EoL Assessment Input	**Time spent in service**	**Non- intrusive, visual surveys**	**Record of outstanding defects (e.g. wear/ corrosion)**	**Assessment Intrusive condition assessment requiring direct contact with asset**	**Record of failures within assets of the same family (e.g. porcelain insulators without zinc collar)**	**A multiplier based on environment type**
Asset Inventory Data	Asset type/ install date	NA			Asset type	Asset location (longitude/latitude)
Condition Data	NA	High Definition Camera Assessment	Annual Foot Patrol High Definition Camera Assessment	Insulator Resistance Testing	NA	NA
Performance Data			Defect Records		Failure Records	
Operational Duty Data	NA					
Operating Environment Data	NA					Asset location class