OVERHEAD CONDUCTOR FAILURE RISK MITIGATION

Case for investment FY23 – 29
(Pre-optimisation)

August 2022

Investment Title	**Condition based replacement of overhead conductor**
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Pre RIT-D	☐
Final CFI (Pre-optimisation)	☒
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1. Executive summary

1.1 Recommendation

This case for investment (CFI) recommends investment in replacement of *overhead conductor linear assets* across the network during the period of FY23 – FY29 to address the reliability, bushfire and safety risks associated with this equipment failing whilst in service.

It is noted that this CFI is recommending these investments to be included into the portfolio risk-based asset investment planning and optimisation process during the period of FY23 – FY29.

This CFI has been prepared in parallel with a resilience CFI “HV Distribution Network Resilience and Bushfire Ignition Risk Mitigation”. Since the two CFI’s are looking at the same assets, a review of any overlaps have been performed and removed from the recommended proposed works.

The total cost of the proposed works is estimated to be $26.7 million (reduced from $30.0 million prior to the removal of the overlap) in real FY23 terms.

Within this recommended program of works, each asset has been assessed individually for the risk it presents. Furthermore, this is an on-going program with no material change proposed across the asset type and the highest cost credible option at each site falls below the threshold for application of the Regulatory Investment Test for Distribution (RIT-D) (currently $6.0 million). Therefore, the RIT-D is not applicable to this on-going program.

A further allowance of $6.1 million is proposed for the replacement of overhead conductors that fail unexpectedly and in a non-repairable manner during the FY23 - FY29 period giving a total proposed investment of $36.1 million.

1.2 Identified need

Endeavour Energy has 28,031 kilometres of overhead conductor’s (excluding customer service lines) currently in-service represented across 365,744 unique linear assets which operate at voltages ranging from 415 volts up to 132,000 volts. Failure of an overhead conductor may cause risks for persons and property near to and possible loss of supply to customers. The possible consequences of failure include:

- Reliability impacts: due to loss of supply along feeders and hence the customers supplied by the feeders;
- Bushfire impacts: where failures lead to a phase to ground fault between the conductor/s and the ground or a grounded object, there is potential for arcing to ignite nearby combustible materials. Additionally, where a failure leads to a phase-to-phase fault, arcing between the conductor phases can lead to the ejection of molten metal which also has the potential to ignite combustible materials, typically on the ground below. The ignition of fires under certain environmental conditions have potential to lead to catastrophic bushfire risk consequences including loss of life, loss of assets such as buildings and damage to the ecosystem;
- Safety impacts: where a failed overhead conductor remains energised on the ground or caught on an object or structure, there is a potential risk of electrocution to members of the public should they come in contact with the conductor or object/structure which is energised. Electrocution has the potential to cause injury ranging from minor and major injuries to loss of life; and
- No significant environmental, financial or regulatory compliance consequences have been experienced or are anticipated for future failures of overhead conductors.

1.3 Options analysis

There are limited options for the use of non-network solutions for replacing the functionality of an overhead conductor linear asset under the assumption that the feeder in which they service is still required. A separate body of work has identified the limited number of feeder sections in which a non network option is a viable consideration across the Endeavour Energy network. The outputs of these two pieces of work will be overlayed as part of the project optimisation / selection works to ensure the best outcome is achieved. Considering the small number of initially identified locations (e.g. less than 12) the impact on the wider overhead conductor linear assets replacement program is considered to be insignificant at this stage. The underlying assumptions behind this will continue to be reviewed and updated.

Therefore, this document will assume that for *overhead conductor linear assets,* the only option available for addressing the failure risk of individual overhead conductors in a proactive planned manner which is considered to be credible is retirement followed by the replacement of the conductor with a modern equivalent conductor.

Table 1 below summarises the outcomes of the cost-benefit assessment for the overhead conductor replacement of Endeavour Energy's fleet of 365,744 overhead conductors compared to the counterfactual case. The summary shows the impact of investment in the replacement of overhead conductors whose net present value (NPV) of intervention reaches its maximum value in the FY23 - FY29 period.

Table 1 - Option economic evaluation summary

Option	Option type	Volume of inter-ventions	Residual risk ($M)	PV of benefits ($M)	PV of investment ($M)	NPV ($M)	Rank	Comments
Run-to-failure	Counter-factual	-	710.5	-	-	-	2	Excessive risk
1. Replace overhead conductor	Network	1,489	625.1	85.4	27.8	57.6	1	Preferred option

1.4 Recommended option

Recommended option is Option 1 for the replacement of 1,489 overhead conductors with a modern equivalent conductor, subject to project optimisation.

The NPV of the proposed interventions is unique to each overhead conductor and varies from $112 to $779,000 with an average of $38,500 across the 1,489 assets proposed for intervention during the period. The total NPV of the proposed program is $57.6 million.

The benefit to cost ratio (BCR) for each overhead conductor varies from 1.7 to 27.8 and averages 3.1 across the 1,489 overhead conductor interventions.

1.5 Budget

The total cost of the proactive replacement works is estimated to be $26.7 million in real FY23 terms.

The additional funding required for overhead conductors that are likely to fail in service is $6.1 million giving a total for the recommended funding of $32.8 million.

2. Purpose

The purpose of this document is to seek endorsement of the case for investment (CFI) for managing the risks posed by aged overhead conductors throughout the distribution and transmission network.

This CFI is recommending these investments to be included into the portfolio risk-based asset investment planning and optimisation process during the period of FY23 – FY29.

This case for investment (CFI) recommends both the proactive intervention for replacement of the identified overhead conductors during the FY23 – FY29 period and provision of additional capital for the reactive replacement of overhead conductors that may functionally or conditionally fail unexpectedly during the period.

This CFI will be grouped together with any other related CFI's (e.g. 132kV oil filled cables) and rolled up into an asset class plan (ACP) to provide an overall view of the asset classes performance at a macro level. ACP's will also be fed into system strategy documentation to view this CFI / ACP in the context of the entire network (e.g. by feeder, substation and/or region) to understand its contribution to the overall networks performance.

3. Identified needs and/or opportunities

3.1 Background

Overhead conductors are a vital component of the network and provide a physical medium to safely transmit electricity under normal supply load and transient fault conditions. For Endeavour Energy's network, the distribution of electricity is typically between TransGrid bulk supply points through to end-of-line residential, commercial and industrial customers.

Endeavour Energy own 28,031 kilometres of overhead conductor in-service represented by 365,744 unique overhead conductor linear assets. Each overhead conductor linear asset represents a unique segment of overhead conductor of varying length. The boundaries of each unique segment are determined primarily by it physical section termination points where the length of conductor is of similar age, conductive material and stranding size.

Currently, within Endeavour Energy's network there are 60 different kinds of overhead conductor's in-service which vary in construction configuration, metal type and size. Furthermore, each of these kinds of conductors can also be operating at low voltage, high voltage or transmission.

For the purpose of the evaluation, these conductor variations have been broadly categorised into 114 asset types. This is summarised in Table 2 below.

Table 2 – Overhead linear assets summary

Voltage classification	Quantity of asset types	Quantity of linear assets	Route length (km)
Low voltage distribution (LV) (upto 415V)	33	278,364	13,718
High voltage distribution (HV) (11kV – 22kV)	48	76,057	11,244
Transmission (TR) (33kV – 132kV)	33	11,323	3,069
Total	**114**	**365,744**	**28,031**

Historically, programs applicable to the overhead conductor asset class have primarily been reactive in their identification of asset requiring intervention. In recent years proactive programs such as *DS011 –*

High voltage steel mains replacement (2014 – 2021), *DS414 – Copper distribution mains replacement* (2015 - 2019), and *DS422 – High voltage distribution bushfire mitigation* (2020 - 2023) have been carried out to manage the risk posed by overhead conductors on the network. These programs have targeted steel mains and hard drawn copper conductors identified to be in poor condition and targeted high bushfire risk areas suitable for augmentation to covered conductor thick (CCT) for mitigation of bushfire ignition risk.

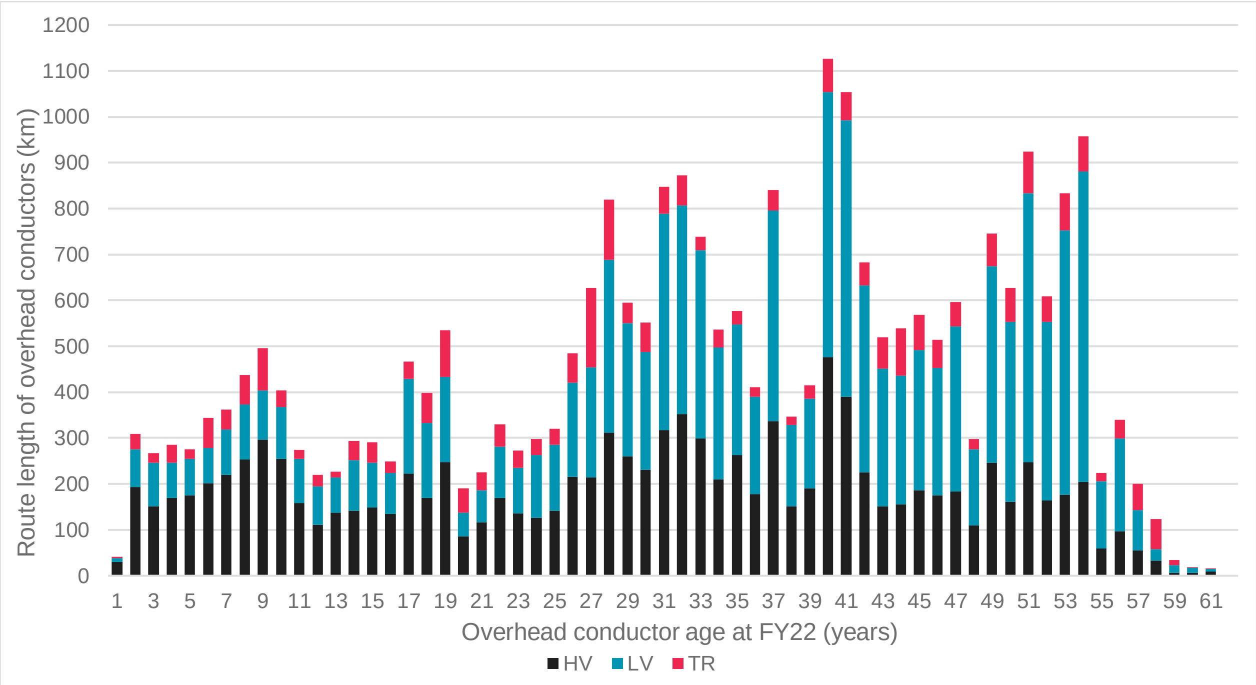
In accordance with maintenance standard MMI 0001 – Pole and line inspection and treatment procedures, overhead conductors are inspected on 5.5-year cycle [1]. MMI 0001 includes visual inspection of conductors using stabilised binoculars to monitor the condition of assets.

Maintenance works carried out in accordance with MMI 0001 include minor repairs and replacements, however, typical condition based capital works identified from these routine inspections include complete or partial replacement of sections of corroded or damaged conductors.

As well as the typical overhead line inspections outlined above, condition based capital works may also be identified through thermal vision inspections MMI 0032, overhead transmission line routine inspection MMI 0012 and pre-summer bushfire inspections MMI 0034 [2] [3] [4] .

The age profile for the overhead conductor linear asset class is shown in **Error! Reference source not f ound.** by operating voltage classification.

Figure 1 – Age profile by operating voltage for overhead conductor linear assets



3.2 Risks and identified need

Overhead conductors have several long-term failure modes which can result in an unassisted failure if left unidentified. The three primary long-term failure modes for overhead conductors are outlined below:

- Corrosion: loss of material in metal conductor strands due to oxidisation leading to pitting and reduction in the diameter of conductor strands resulting in loss of mechanical strength.
  There are two main types of conductor corrosion:
  - Atmospheric corrosion: due to exposure to substances in the environment such as oxygen, carbon dioxide, water vapour, sulphur and chlorine compounds; and
  - Galvanic corrosion: an electromechanical bimetallic corrosion process which occurs between conductor strands with different metals which are in contact and in presence of moisture and electric potential.

- Fretting fatigue: development of cracks in the conductor strands decreasing the fatigue strength of the conductor and eventually leading to a mechanical failure. Fretting occurs at the contact area between two materials which are subject to regular motion such as aeolian vibration. Due to the connection arrangements of conductors to support systems such as insulators, clamps and vibration dampers, fretting fatigue failures often occur at these locations.
- Annealing: reduction in mechanical tensile strength of a conductor due to exposure to elevated temperatures which trigger a metallurgical process of rearrangement or diffusion of atoms within the conductor. Annealing is typically caused by the operation of a conductor at elevated temperatures during normal loading and/or under fault conditions. Annealing can also occur due to conductor exposure to high temperatures during bushfires.

From FY17 onwards Endeavour Energy has experienced on average 56 unassisted functional failures of overhead conductors per year. As this asset class continues to age it is expected that with no intervention this level of failure will continue to increase over time.

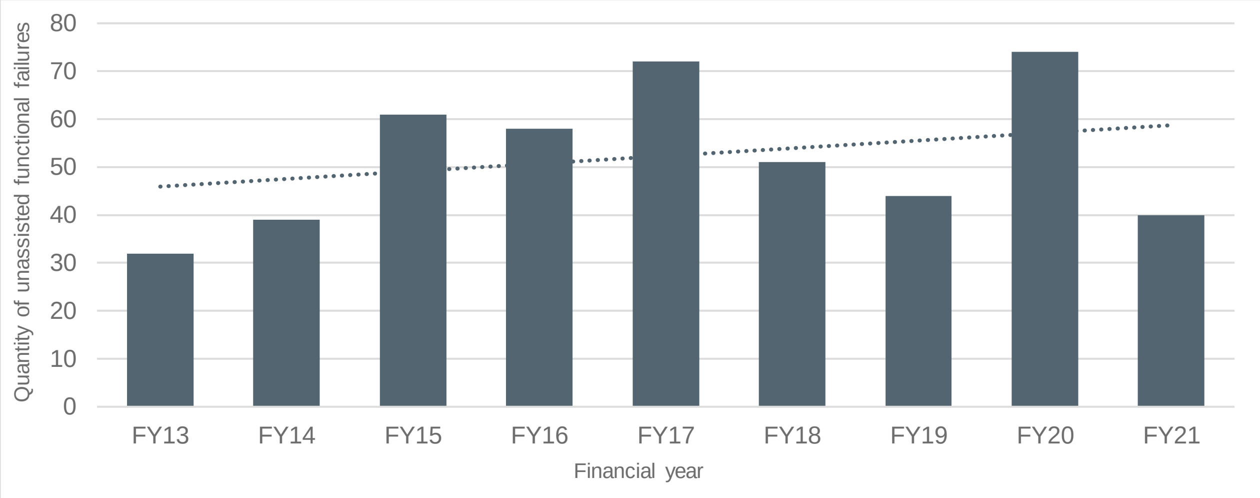
The possible consequences of failure include:

- Reliability impacts: due to loss of supply along feeders and hence the customers supplied by the feeders;
- Bushfire impacts: where failures lead to a phase to ground fault between the conductor/s and the ground or a grounded object, there is potential for arcing to ignite nearby combustible materials. Additionally, where a failure leads to a phase-to-phase fault, arcing between the conductor phases can lead to the ejection of molten metal which has the potential to ignite combustible materials, typically on the ground below. The ignition of fires under the correct environmental conditions have potential to lead to catastrophic bushfire risk consequences including loss of life, loss of assets such as buildings and damage to the ecosystem;
- Safety impacts: where a failed overhead conductor remains energised on the ground or caught on an object or structure, there is a potential risk of electrocution to members of the public should they come in contact with the conductor or object/structure it is energising. Electrocution has the potential to cause minor or major injuries and loss of life; and
- No significant environmental, financial or regulatory compliance consequences have been experienced or are anticipated for future failures of overhead conductors.

Maintenance procedures are in place to control this risk through periodic overhead line inspections however, identification of corrosion, fretting fatigue and annealing in conductors can be impractical to visually identify and any oversight in identification of poor condition conductors leads to an increased risk of failure.

Figure 2 below provides the number of historical functional failures each year.

Figure 2 – Annual quantities of overhead conductor unassisted failures



Refer Appendix B for further detail of the assessed failure consequences.

4. Consequence of nil intervention

4.1 Consequences of nil capital intervention

The nil intervention case involves not carrying out any capital works. Therefore, overhead conductors would be operated until they have failed and are then retired and not repaired or replaced and includes the following course of action.

- Continue time-based maintenance and carry out repairs where possible after minor failures;
- Nil replacement of tangible sections of overhead conductor after non-repairable/destructive failures;
- Provide alternate supply to customers through back feeding where possible (transferring load to adjacent feeders); and
- Provide supply to customers by hiring and operating generators where customers are unable to be back-fed through the network.

The consequences of this would include:

- The consequences of failure for each overhead conductor as noted in 3.2 above; and
- Failures lead to extended loss of supply while alternate arrangements are made;
- Where suitable alternative network supply is not available, portable generators will remain in use for an extended period;
- Potential for overload of adjacent feeders during peak periods requiring generator support; and
- Loss of redundancy for adjacent feeders will lead to customer outages during planned and unplanned work on those substations.

Note that the impact of these consequences depends on the ongoing integrity of the surrounding network to allow failed overhead conductors to be partially offloaded for perpetuity. Under a nil intervention scenario, the risk costs would increase exponentially over time as other supporting elements in the network also failed and were not replaced. These exponential additional risk costs have not been modelled or included in the assessments as part of this CFI.

On this basis, the reactive replacement and repair of overhead conductors which fail will be undertaken, subject to an assessment of the ongoing need for the asset, and the nil intervention case will not be considered further in this CFI.

4.2 Counterfactual (business as usual)

The business as usual (BAU) "counterfactual" scenario includes operating the overhead conductors until they fail and then repair of the conductor after failure, providing its service is still required. Nil proactive capital intervention is carried out.

The scope of works under the BAU include:

- Maintenance:
  - Overhead line inspections (5.5 yearly); and
- Reactive repair after failure.

Currently, "failure" refers to the inability of the overhead conductor to perform its required function as a consequence of the condition of the asset:

- Failures disruptive to the supply of electricity;
- Catastrophic failures of equipment or subcomponents such as the conductor, sleeves or splices;
- Failure of the overhead conductor to maintain minimum clearance heights under normal operation and fault conditions; or
- Failure of the overhead conductor to perform its rated duty.

Conditional failures occur when sections of conductor are identified as containing the following defects as per Endeavour Energy's maintenance instruction MMI0002 *Distribution Overhead Defect Handbook* [5]:

- Broken or damaged conductor where physical separation of conductor strands is visible; and
- Major corrosion indicating conductor deterioration, showing signs of severe pitting and rust.

Sections of overhead conductors which are identified as conditionally failed are typically scheduled for replacement or repair in accordance with mains maintenance instruction MMI0002 [5].

For the purpose of this assessment only costs that have occurred due to a functional failure has been considered. A summary of the risk presented by the counterfactual case is shown in Table 3 below. All costs are in real FY23 terms and are present values (PV). A discount rate of 3.26% has been used throughout the economic evaluation.

Table 3 – BAU risk cost summary

Risk category	PV of residual risk ($M)	Risk proportion (%)
Safety	2.8	0.4
Reliability	518.6	73.0
Bushfire	189.1	26.6
Total	**710.5**	**100**

As noted in Table 3 above, the residual risk presented by the BAU case totals $710.5 million. The residual risk value presented by each segment of overhead conductor ranges from $0 to $1.36 million and averages $2,000 across the fleet of 365,744 linear assets.

The higher risk values are considered to be excessive and indicate the need for the higher risk segments of overhead conductor to be retired in order to mitigate the risk and that options for intervention should be considered to provide for the continuity of service required of these linear assets.

5. Options considered

5.1 Risk treatment options

Before assessing the network intervention option, consideration has been given to a range of alternative approaches which could possibly contribute to addressing the risk presented by overhead conductors. These approaches are summarised in Table 4 below.

Table 4 – Overhead conductor risk treatment options

Option	Assessment of effectiveness	Conclusion
Additional maintenance to extend the life of the existing asset	Maintenance procedures are unable to further extend the life of an overhead conductors. The ongoing management and maintenance of overhead conductors typically involves routine overhead line inspections for defects. Current practices still result in on average 56 unassisted failures p.a.	No technically feasible solution
Reduce the load on the asset through network reconfiguration, network automation, demand management or other non-network options	The risk of failure due to corrosion and fatigue is relatively independent of load. A minor reduction in the consequences of failure could be achieved by transferring load from any of the feeders in which overhead conductors are installed however, these options are very limited within the low voltage and high voltage distribution network. Overhead conductors provide a physical medium to distribute electricity from one place to another on the distribution and sub-transmission network, there are no practicable non-network solutions for replacing the function they provide.	No technically feasible solution
Reactive repair and/or replacement of overhead conductors after conditional or functional failure	This approach forms part of the business-as-usual practice but does not entirely mitigate the impact of failures. The historical observed quantities of unassisted functional failures are inclusive of Endeavour Energy's existing BAU practice. Unidentified conditional failures which lead to functional failures are not avoided under a purely reactive repair approach. Furthermore, repairs where a small section of new conductor is joined into an existing larger section of conductor post failure do not typically improve the overall condition and future probability of failure across the larger segment of conductor.	Technically feasible solution but does not effectively mitigate the risk of future failures
Staged replacement to maintain option value and reduce the consumer's long-term service cost	Replacement of overhead conductors.	Recommended approach for further consideration.

5.2 Non-network options

There are limited options for the use of non-network solutions for replacing the functionality of an overhead conductor linear asset under the assumption that the feeder in which they service is still required. A separate body of work has identified the limited number of feeder sections in which a non network option is a viable consideration across the Endeavour Energy network. The outputs of these two pieces of work will be overlayed as part of the project optimisation / selection works to ensure the best outcome is achieved. Considering the small number of initially identified locations (e.g. less than 12) the impact on the wider overhead conductor linear assets replacement program is considered to be insignificant at this stage. The underlying assumptions behind this will continue to be reviewed and updated.

Therefore, network options have been considered which include intervention to address the identified need.

5.3 Credible network options

Option	Description	
Proactive Replacement	Replacement of overhead conductor linear assets based on condition.	Credible option considered and has progressed for further assessment

Replacement of overhead conductor linear assets based on condition is considered a credible network option.

5.3.1 Overhead conductor replacement

Under this option, the intervention includes the complete replacement of overhead conductor linear assets in a planned proactive manner with a like-for-like equivalent conductor.

The per kilometre unit rates used for estimating the cost of replacement for overhead conductors vary with operating voltage and conductor type. The unit rates which have been assumed for this assessment are outlined in Appendix B and includes:

- Project Management;
- Design;
- Materials;
- Labour and plant; and
- Traffic management.

These values are estimates based on past programs and ongoing experience of replacing similar type conductors within Endeavour Energy's network over the past 3 years.

5.4 Economic evaluation

5.4.1 Option 1 – Overhead conductor replacement

This option identifies 1,489 overhead conductor linear assets totalling a route length of 307 kilometres whose NPV at time of proposed replacement is positive and reaches a maximum value during the FY23 – FY29 period. This option presents a residual risk of $625.1 million and provides a benefit of $85.4 million compared to the counterfactual case. The PV of the cost of the option is $27.8 million and the NPV overall is $57.6 million.

The NPV of the proposed interventions is unique to each overhead conductor and varies from $112 to $779,000 with an average of $38,500 across the 1,489 assets proposed for intervention during the period.

The benefit to cost ratio (BCR) for each overhead conductor varies from 1.7 to 27.8 and averages 3.1 across the 1,489 overhead conductor interventions.

Table 5 below provides a summary of the residual risk presented by this option. Refer Appendix A for details of the overhead conductor linear assets identified for intervention during the FY23 – FY29 period under this option.

Table 5 – Option 1 residual risk summary

Risk category	PV of residual risk ($M)	Risk proportion (%)
Safety	2.4	0.4
Reliability	452.0	72.3
Bushfire	170.6	27.3
Total	**625.1**	**100**

5.5 Evaluation summary

Table 6 below summarises the outcomes of the cost-benefit assessment for overhead conductor replacement options for Endeavour Energy's fleet of 365,744 compared to the BAU case. The summary shows only the impact of investment in overhead conductors which reach their maximum NPV for intervention during the FY23 - FY29 period.

Table 6 – Option economic evaluation summary

Option	Option type	Volume of inter-ventions	Residual risk ($M)	PV of benefits ($M)	PV of investment ($M)	NPV ($M)	Rank	Comments
Run-to-failure	Counter-factual	-	710.5	-	-	-	2	Excessive risk
Replace overhead conductors	Network	1,489	625.1	85.4	27.8	57.6	1	Preferred option

As shown in Table 6, overhead conductor replacement provides a higher NPV overall and will deliver the highest overall value and is therefore the preferred option.

The “Risk Model Framework” documentation outlines in detail the process used for determining the economic evaluation for any given asset (repairable or non-repairable). The document outlines the calculation of the inputs (e.g. PoF, LoC and CoC) as well as the NPV calculation methodology and the selection of the optimal timing.

5.6 Economic evaluation assumptions

There are a wide range of assumptions of risk, their likelihoods and consequences which support the cost benefit assessment associated with this program. Refer Appendix C for details of these assumptions.

5.7 Sensitivity and scenario analysis

A scenario assessment has been carried out on the various elements of the risk and cost assumptions used in the economic analysis in order to test the robustness of the evaluation.

Three scenarios have been assessed:

- Scenario 1 - discourages investment with low benefits and high capital costs;
- Scenario 2 - represents the most likely central case based on estimated or established values;
- Scenario 3 - encourages investment with the high benefits with low capital costs.

The values for each of the variables used for each scenario are shown in Table 7 below.

Table 7 – Summary of scenarios investigated

Variable	Scenario 1 – low benefits, high capital costs	Scenario 2 – central values	Scenario 3 – high benefits, low capital costs
Capital cost	10% increase in the estimated network capital costs	Estimated network capital costs	10% decrease in the estimated network capital costs
Value of risk (combination of consequence of the failure risk and the likelihood of the consequence eventuating)	10% decrease in the estimated risk and benefit values	Estimated risk values	10% increase in the estimated risk and benefit values
Weibull distribution end-of-life failure characteristic	10% increase in the Weibull scale parameter (increases the mean time to failure for the asset)	Estimated Weibull parameters based on available failure data and calibrated to observed failure rates	10% decrease in the Weibull scale parameter (decreases the mean time to failure for the asset)

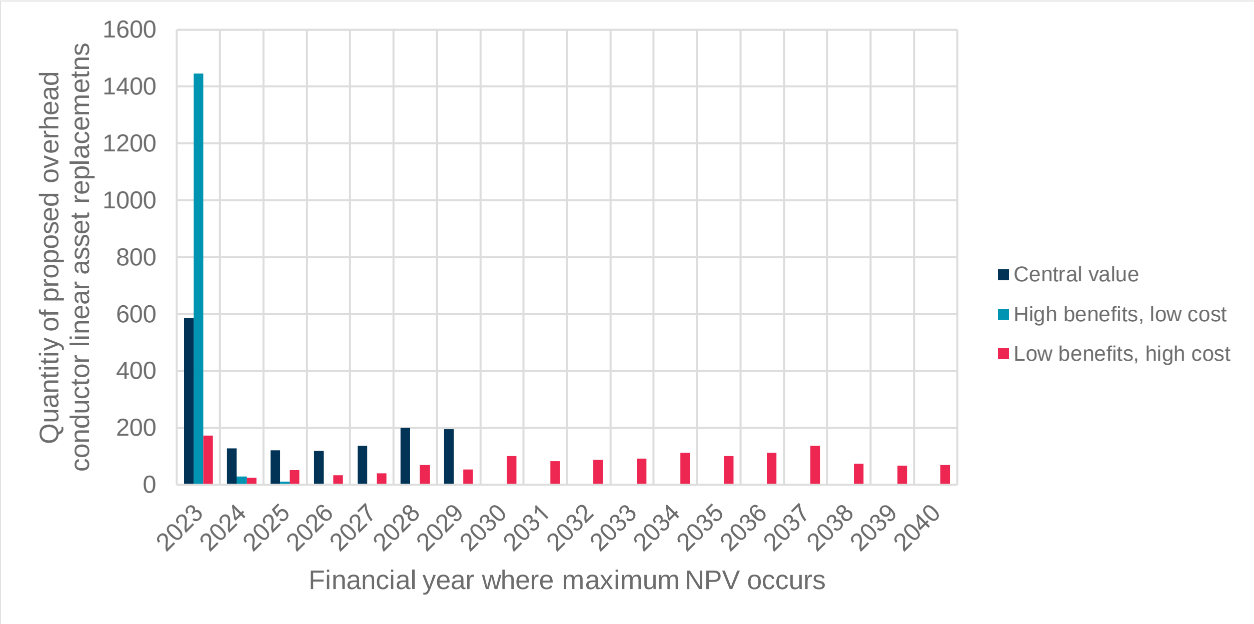
The impact on the preferred option (Option 1) NPV is shown in Table 8 below and the resultant spread of replacement years to give the maximum NPV for each of the 1,489 overhead conductor linear assets identified for replacement under the preferred option is shown in Figure 3.

Table 8 – NPV of scenario analysis for the preferred option (Option 1)

Scenario	NPV of preferred option ($M)
Scenario 1 – Low benefits, high costs	16.5
Scenario 2 – Central risks and costs	57.6
Scenario 3 – High benefits, low costs	181.3
Average	**85.1**

Each scenario reduces the risks posed by the 1,489 overhead conductor linear assets with an average NPV of $85.1 million across the three scenarios analysed.

Figure 3 - Option 1: maximum NPV replacement years for the three sensitivity scenarios



Further analysis found when individually adjusting, capital cost and value risk inputs, each had minimal contribution to the proposed financial year that the assets maximum NPV occured. In this assessment, sensitivity lies around the Weibull end-of-life element. This assessment has been able to rely on historical overhead conductor failure data over the FY12-FY21 period to assist in determining the Weibull parameters.

Figure 3 illustrates the optimal timing of each 1,489 recommended assets for replacements based on the year in which their NPV is maximum across each of the three tested scenarios.

All high benefit, low-cost replacement cases fall within FY23 to FY26, while the low benefit, high-cost cases are spread between FY23 and FY40 with the highest quantity of replacements residing in FY23.

Across all three scenarios, the year of maximum NPV is skewed towards FY23, which is the earliest year that the works can now be practically carried out. On this basis it is concluded that the assessment is robust and points to an appropriate level of investment for Option 1.

6. Preferred option details

6.1 FY23 – FY29 scope and timing

The preferred option is Option 1, which includes replacement of 1,489 overhead conductor linear assets during FY23 – FY29.

The overall cost of the proposed program is estimated to be $30.0 million (in real $ FY23 terms). A contingency is not proposed to be applied as there are multiple sites in the program and the estimated costs are based on mean values with individual site's costs evening out to the mean across the program.

Note: All overhead conductors which are currently approved for replacement and whose works are in progress have been removed from the fleet of assets. Therefore, the proposed investment within this CFI only includes assets not currently approved for replacement.

6.2 Additional scope and timing

A further 1,309 overhead conductor linear assets totalling a route length of 249 kilometres were identified whose NPV at the time of proposed replacement is positive and reaches a maximum value within a 10-year forecast period (FY30-FY34). These 1,309 investments total a further $24.6 million (in real $FY23 terms) and have been identified as additional scope for inclusion in the investment portfolio optimisation process.

6.3 Investment summary

6.3.1 Planned proactive works

A summary of the investment proposed to be submitted for portfolio optimisation is shown in Table 9 below.

The overhead conductor replacement costs vary between.

All costs are in real FY23 terms.

Table 9 – Summary of investment for optimisation

Intervention type	Route length (km)	Quantity of interventions	Total costs ($M)
LV Overhead Conductor Replacement (NPV Max FY23-FY24)	2.1	23	0.3
HV Overhead Conductor Replacement (NPV Max FY23-FY24)	150.2	685	12.5
TR Overhead Conductor Replacement (NPV Max FY23-FY24)	1.8	8	0.7
Subtotal FY23-FY24	***153.5***	***716***	***13.5***
LV Overhead Conductor Replacement (NPV Max FY25-FY29)	2.9	35	0.4
HV Overhead Conductor Replacement (NPV Max FY25-FY29)	138.4	668	11.5
TR Overhead Conductor Replacement (NPV Max FY25-FY29)	12.0	70	4.5
Subtotal FY25-FY29	***153.8***	***7723***	***16.5***
LV Overhead Conductor Replacement (NPV Max FY30-FY34)	6.6	77	1.0
HV Overhead Conductor Replacement (NPV Max FY30-FY34)	235.6	1195	21.0
TR Overhead Conductor Replacement (NPV Max FY30-FY34)	6.8	37	2.6
Subtotal FY30-FY34	***249.0***	***1,309***	***24.6***
Total	**556.3**	**2,798**	**54.4**

This CFI has been prepared in parallel with the “HV Distribution Network Resilience and Bushfire Ignition Risk Mitigation” CFI. Since the two CFI’s are looking at the same assets a review of any potential overlap in recommendations has been conducted. The same asset, PoF and LoC data (excluding factoring in new climate change modelling) has been used in both CFI’s. Since the same assets are under review and the benefits associated the proposed resilience CFI are higher than those in this CFI, all overlaps will be removed from the recommendations made in this proposal.

Intervention type	Original Scope		Overlap		Revised Scope	
	Route length (km)	Total costs ($M)	Route length (km)	Total costs ($M)	Route length (km)	Total costs ($M)
LV / HV / TR Overhead Conductor Replacement FY23-FY24	*153.5*	*13.5*	*24.5*	*2.52*	***129.0***	***10.98***
LV / HV / TR Overhead Conductor Replacement FY25-FY29	*153.8*	*16.5*	*5.3*	*0.76*	***148.5***	***15.74***
LV / HV / TR Overhead Conductor Replacement FY30-FY34	*249.0*	*24.6*	*18.4*	*2.89*	***230.6***	***21.71***
Total	556.3	54.4	48.2	6.17	**508.1**	**48.23**

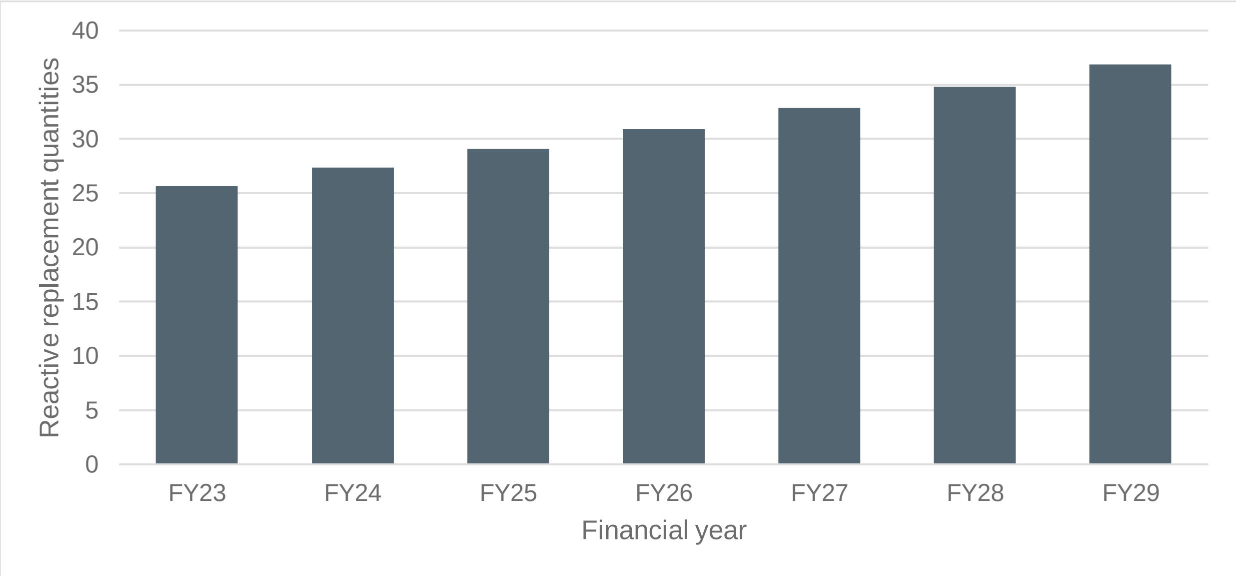
The overlap between the two program equates to 9% of the overall route length and 11% of the intervention costs over the FY23 to FY34 period.

6.3.2 Reactive investment

Reactive modelling for the FY23 -FY29 period has forecast a further 218 overhead conductor linear assets to reach a state of conditional failure or functional failure requiring capital investment for rectification. It is to be noted that the overhead conductor linear assets proposed for proactive retirement as part of this CFI have been excluded from the reactive modelling across this period.

Figure 4 below shows the forecast trend of reactive investment likely to be required for the replacement of failed overhead conductor linear assets into the future.

Figure 4 – Forecast reactive replacement quantities FY23-FY29



A reactive replacement cost, which takes account of the likelihood of minor repair works and excludes the economic costs of a failure has been assessed across the fleet of overhead conductors to give an annual forecast of reactive funding requirements. To accommodate this eventuality, it is proposed that additional funding of $6.09 million (in real$ FY23 terms) be made available for reactive replacement of overhead conductor linear assets during the FY23 – FY29 period.

Table 10 below, summarises the proposed reactive funding forecast.

All costs are in real FY23 terms.

Table 10 – Reactive replacement forecast

Conditional Failures leading to capital replacement works	Forecast quantity of failure interventions	Forecast reactive investment ($M)
Regulatory control period (FY23-FY24)	53	1.47
Regulatory control period (FY25-FY29)	165	4.62
Total	**218**	**6.09**

6.4 Project scope of works

6.4.1 Overhead conductor replacement

The proposed scope of works includes replacement of the selected overhead conductors in accordance with Endeavour Energy design and construction standards MDI 0031 and MCI 0005 [6] [7].

As a result of conductor type and commissioning date inaccuracies within Endeavour Energy's GIS database, proposed scope which is identified to be in an acceptable service condition for the foreseeable future (5-10 years) is to be raised with the Asset Performance team for further investigation.

These data inaccuracy are expected to be on both sides of the equation (e.g identifying work potentially not required and missing potential justified replacements), therefore the proposed overall replacement expenditure is expected to be accurate.

7. Regulatory investment test

Within this recommended program of works, each asset has been assessed individually for the risk it presents. Furthermore, this is an on-going program with no material change proposed across the asset type and the highest cost credible option cost at each site falls below the threshold for application of the Regulatory Investment Test for Distribution (RIT-D) (currently $6.0 million). Therefore, the RIT-D is not applicable to this on-going program.

8. Recommendation

It is recommended that Option 1 for the proactive replacement of overhead conductor linear assets where the intervention timing indicates that maximum NPV is between FY23-FY34, be included in the PIP FY23 and to proceed to the investment portfolio optimisation stage.

With an allowance for a further $6.09 million (in real $ FY23 terms) within the FY23-FY29 period for the reactive replacement of overhead conductors that reach a state of conditional failure requiring capital investment for rectification (e.g. found to be in a poor condition indicative of imminent failure and/or no longer capable of performing its function).

9. Attachments

Appendix A – Details of recommended scope for optimisation

Appendix B – Risk assessment variables

10. References

[1] Endeavour Energy, "MMI 0001 - Pole and line inspection and treatment procedures," 2016.

[2] Endeavour Energy, "MMI 0028 - Thermovision of distribution and transmission lines," 2014.

[3] Endeavour Energy, "MMI 0034 - Pre-summer bushfire inspections," 2016.

[4] Endeavour Energy, "MMI 0012 - Overhead transmission line routine inspection," 2019.

[5] Endeavour Energy, "MMI 0002 Distribution Overhead Defect Handbook," 2021.

[6] Endeavour Energy, "MDI 0031 Overhead Line Design," 2017.

[7] Endeavour Energy, "MCI 0005 Overhead construction standards manual," 2017.

[8] Australian Energy Regulator, "D19-2978 - AER - Industry practice application note - Asset Replacement Planning," AER, 25 January 2019.

[9] "The Energy Charter," theenergycharter.com.au, January 2019.

[10] Endeavour Energy, Substation Maintenance Instruction : Zone and transmission substation accomodation - SMI106 Amendment 12, 31 August 2016.

Appendix A – Details of recommended scope for optimisation

Scope with maximum NPV between FY23-FY34, shown in order of descending BCR, then descending NPV can be found in attached MS Excel spreadsheet:

Appendix A – Details of recommended scope for optimisation.xlsx

Appendix B – Summary of key risk assessment variables and assumptions

General variables and assumptions

Parameter	Value	Description/justification	Source/assumptions
Population	365,744 linear assets (28,031 km)	Number of overhead conductor linear assets in service in Endeavour Energy's (EE) network	GIS database. GIS_FID = 126, reticulation = OH
Annual conditional failures - leading to capital replacement works (excl OPEX repairs)	31	Defective equipment as identified and categorised as per MMI0002.	Ellipse defect workorder records LA reactive expenditure v3.fmw FME workflow
Annual functional failures	59	A functional failure is considered to be an unassisted failure of the conductor, causing safety, reliability, and/or bushfire impacts.	EE outage management system (OMS) / ADMS
Discount rate (WACC)	3.26%	Weighted average cost of capital for EE	Regulated rate. Applied to all risk and investment values used in the cost-benefit assessment.
Base year of investment	FY23	All investments for budgeting purposes are expressed in real FY23 dollars	For inclusion into the FY23 PIP after optimisation
Calculation horizon	55 years	The timeframe over which the cost-benefit analysis is performed	Repairable V1.0 algorithm
Maintenance costs	$0 p.a.	Maintenance costs due to overhead line inspections are excluded from the condition-based assessment as there is no material impact on the assessment outcome	Ellipse workorders
Planned intervention costs – replacement of overhead conductor	LV Covered: $95,626/km LV HDCU: $239,000/km LV Generic: $73,748/km HV ACSR: $73,748/km HV SC/GZ: $73,748/km HV CCT: $73,748/km HV HDCU: $239,000/km HV ABC: $180,000/km HV AAC 7/***: $85,211/km HV AAC 19/***: $116,456/km HV AAAC 7/***: $85,211/km HV AAAC 19/***: $116,456/km TR: $379,500/km	Replacement of existing overhead conductors like-for-like. Note: Replacement of HV ABC assumed CCT as the new conductor type. Replacement of HDCU assumes modern equivalent standard conductor as the new conductor type.	This estimate is based on actual costs of previously delivered works and includes: - Project Management - Design - Materials - Labour and plant - Traffic management
Failure modes	Broken conductor	The main failure mode for overhead conductors is a mains-down event where a broken conductor impacts the ground. This leads to phase to earth fault leading to uncontrolled energy discharge. The energy discharge has the potential to cause fire ignition of surrounding combustible materials, poses a threat to members of the public and causes an outage.	OMS / ADMS data 2012 -2021 Ellipse

Parameter	Value	Description/justification	Source/assumptions
Asset age	Varies for each overhead conductor linear asset	Calendar age based on the in-service date compared to the year of assessment (2022) Where in-service date of the overhead conductor is not available, the in-service date is assigned the most common pole commissioning date of poles supporting "like conductor types" in the area.	Ellipse nameplate data GIS Job place date SAP installation date Spatial analysis

Weibull failure probability parameters

Parameter	Value	Description/justification	Source/assumptions
α (Alpha)	- AAAC 7/2.50 - 69.8 - AAAC 7/4.50 - 87.7 - AAC 19/3.25 - 112.7 - AAC 19/3.75 - 115.2 - AAC 19/4.75 - 126.6 - AAC 7/3.00 - 104.6 - AAC 7/3.75 - 135 - AAC 7/4.50 - 112.5 - ACSR 3/4/1.68 - 92.1 - ACSR 3/4/2.50 - 64 - ACSR 30/7/3.00 - 138 - ACSR 30/7/3.50 - 112.9 - ACSR 54/7/3.00 - 141.5 - ACSR 6/1/2.50 - 82.5 - ACSR 6/1/3.00 - 116.3 - ACSR 6/1/3.75 - 165.8 - ACSR 6/4.75 + 7/1.60 - 108.2 - HDCU 19/2.00 or 7/0.136 or 19/0.083 - 108.6 - HDCU 19/2.57 - 99.9 - HDCU 7/0.104 or 19/0.064 - 114.2 - HDCU 7/1.75 - 101.9 - HDCU 7/2.00 - 83.5 - HV ABC - 30.5 - HV CCT - 66.2 - LV ABC - 89.3 - LV UNKN - 142.7 - SC/GZ 3/2.00 - 98.6 - SC/GZ 7/1.63 - 102.5 - TR UNKN - 94.4 - AAAC Generic - 74.8 - AAC Generic - 114.4 - ACSR Generic - 103.3 - HDCU Generic - 102.4 - SC/GZ Generic - 106.1 - LV Covered - 40 - HV UNKN - 100.9	The "scale" parameter used for calculating probability of failure	Estimated to correlate predicted quantity of annual unassisted functional failures with the actual recorded quantity of annual failure rates being experienced.
β (Beta)	- AAAC 7/2.50 - 3.6 - AAAC 7/4.50 - 3.6 - AAC 19/3.25 - 3.6 - AAC 19/3.75 - 3.6 - AAC 19/4.75 - 3.6 - AAC 7/3.00 - 3.6 - AAC 7/3.75 - 3.6 - AAC 7/4.50 - 3.6 - ACSR 3/4/1.68 - 3.6 - ACSR 3/4/2.50 - 3.6 - ACSR 30/7/3.00 - 3.6 - ACSR 30/7/3.50 - 3.6 - ACSR 54/7/3.00 - 3.6 - ACSR 6/1/2.50 - 3.6 - ACSR 6/1/3.00 - 3.6	The "shape" parameter used for calculating probability of failure function.	The generalised wear-out function shape for a normal distribution is 3.6. Weibull Curve generator_5.xlsm

Parameter	Value	Description/justification	Source/assumptions
	- ACSR 6/1/3.75 - 2.5 - ACSR 6/4.75 + 7/1.60 - 3.6 - HDCU 19/2.00 or 7/0.136 or 19/0.083 - 3.6 - HDCU 19/2.57 - 3.6 - HDCU 7/0.104 or 19/0.064 - 3.6 - HDCU 7/1.75 - 3.6 - HDCU 7/2.00 - 3.6 - HV ABC - 3.6 - HV CCT - 3.6 - LV ABC - 3.6 - LV UNKN - 3.6 - SC/GZ 3/2.00 - 3.6 - SC/GZ 7/1.63 - 3.6 - TR UNKN - 3.6 - AAAC Generic - 3.6 - AAC Generic - 3.6 - ACSR Generic - 3.6 - HDCU Generic - 3.6 - SC/GZ Generic - 3.6 - LV Covered - 3.6 - HV UNKN - 3.6		
ψ (Gamma)	All Asset Types - 0	The “shift” parameter which gives a failure free period at the start of the asset’s life.	In lieu of automated fitting of the shape parameter, the shift parameter was set to zero to allow automated one parameter fitting of the scale parameter

Safety risk inputs

Parameter	Value	Description/justification	Source/assumptions
Value of a fatality	$4,800,000	Value of statistical life (VoSL)	GNV1119
Value of a major injury	$2,400,000	50% of VoSL	GNV1119
Value of a minor injury	$758,400	15.8% of VoSL	GNV1119
Safety Public – LoC By level of public presence (1 to 4)	Level 1 - $4333 Level 2 - $2145 Level 3 - $675 Level 4 - $653 Level 1 – Highly trafficked Level 2 – Moderately trafficked Level 3 – lowly trafficked Level 4 – Rarely trafficked	LV Safety CoC Fatality: 80% Major injury: 15% Minor injury: 5% Disproportionate factor: 1 Qty of people impacted: Level 1: 3 Level 2: 2 Level 3: 1 Level 4: 1 LoC: 0.0008% to 0.0273%	Public safety modelling EE Network Public Safety Likelihood.kml
	Level 1 - $3100 Level 2 - $1127 Level 3 - $63 Level 4 - $35 Level 1 – Highly trafficked Level 2 – Moderately trafficked Level 3 – lowly trafficked Level 4 – Rarely trafficked	HV Safety CoC Fatality: 90% Major injury: 10% Minor injury: 0% Disproportionate factor: 1 Qty of people impacted: Level 1: 3 Level 2: 2 Level 3: 1 Level 4: 1	Public safety modelling EE Network Public Safety Likelihood.kml

Parameter	Value	Description/justification	Source/assumptions
		LoC: 0.0001% to 0.0204%	
	Level 1 - $3193 Level 2 - $1134 Level 3 - $37 Level 4 - $7 Level 1 – Highly trafficked Level 2 – Moderately trafficked Level 3 – lowly trafficked Level 4 – Rarely trafficked	TR Safety CoC Fatality: 100% Major injury: 0% Minor injury: 0% Disproportionate factor: 1 Qty of people impacted: Level 1: 3 Level 2: 2 Level 3: 1 Level 4: 1 LoC: 0.0001% to 0.0222%	Public safety modelling EE Network Public Safety Likelihood.kml

Reliability risk inputs

Parameter	Value	Description/justification	Source/assumptions
Duration of interruption	LV: 3.3 hours HV: 3.1 hours TR: 2.3 hours	Average outage durations based on historical OMS / ADMS outage records.	OMS / ADMS data 2012 -2021
Loss of supply to customers - LoC	LV: 100% HV: 100% TR: 1%	1% likelihood of loss of load when N-1 supply security is available	RisCAT - 1% likelihood the alternate supply path will not be available due to maintenance, or failure.
Load factor	70%	Load assumed to be lost is 70% of the summer maximum demand value for the supplied substation(s)	Source – studies by Protection Manager.
Load impacted	Varies based on the estimated load of supported by section of conductor	PowerFactory load flow analysis for feeder loads. MDI readings for distribution substation loads. Network Planning distribution feeder loads.	Spreadsheets based on 2021 PowerFactory load flow analysis results. Endeavour Energy specific VCRs.xlsx
VCR	Varies based on the customer make-up supplied by a section of overhead conductor	Value of customer reliability for an occasional short-term outage. This value varies based on the make-up of customer types supplied by the section of overhead conductor.	Endeavour Energy specific VCRs.xlsx

Bushfire risk inputs

Parameter	Value	Description/justification	Source/assumptions
Bushfire LoC	Bushfire ignition risk LoC varies by voltage classification and conductor insulation: ABC HV - 10% ABC LV - 5% Bare HV - 13%	Likelihood that a conductor failure will ignite a small fire:	Based on historical fire start data. Fire Database.xlsx

Parameter	Value	Description/justification	Source/assumptions
	Bare LV - 6% Bare TR - 20% CCT HV - 2%		
Bushfire CoF	Bushfire ignition risk CoC varies by location	Likelihood and consequence that a small fire would be realised into a large bushfire with financial impacts.	Bushfire ignition risk CoC modelling based on the Phoenix Fire Characteristic Simulations

Financial risk inputs

Parameter	Value	Description/justification	Source/assumptions
N/a			

Environmental risk inputs

Parameter	Value	Description/justification	Source/assumptions
N/a			

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