HV DISTRIBUTION NETWORK RESILIENCE & BUSHFIRE IGNITION RISK MITIGATION

Case for investment FY23-FY29
August 2022

Investment Title	HV distribution network resilience and bushfire ignition risk mitigation
<< project # / code >>	
Portfolio	Repex
CFI Date	25/08/2022
Pre RIT-D	☐
Final CFI	☒
Other	☐

Version control and endorsements

Version	Date	Comments
0.1	5 August 2022	Issued for review
0.2	25 August 2022	Issued for approval for inclusion within the optimisation process

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1. Executive summary

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

To ensure the electrical network is more resilient to climate change, escalation factors accounting for change in future risk have been applied to Endeavour Energy's existing asset risk framework for assessment of HV distribution overhead conductor linear assets. The application of climate change escalation factors shift forward the optimum timing of intervention for asset investments. The investments which are brought forward improve Endeavour Energy's network resilience to future climate conditions.

This CFI was prepared in parallel with the overhead conductor asset class CFI "Overhead Conductor Failure Risk Mitigation". As these two CFI's examine the same assets, a review of overlaps between proposed scopes has been conducted and the identified overlaps have been removed from the works proposed within the "Overhead Conductor Failure Risk Mitigation" CFI.

High voltage overhead conductors are a vital component of Endeavour Energy's distribution network which provide the physical medium used to transmit electricity though to our customers.

Endeavour Energy own and operate 11,000 kilometres of HV distribution overhead conductors represented across 76,000 unique linear assets which operate at voltages ranging from 11,000 volts to 22,000 volts. For the purpose of this CFI a unique linear asset is determined primarily by its physical section termination points where the length of conductor is of similar age and asset type in alignment with how segments of conductor are recorded within Endeavour Energy's asset management systems.

Overhead conductors have several long-term failure modes which can lead to an unassisted failure if left unidentified. The primary failure modes observed across overhead conductors are corrosion and fretting fatigue. From FY17 onwards Endeavour Energy has experienced on average 56 unassisted functional failures of overhead conductors per year. As these assets continue 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 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 network and community assets 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.

Due to the functionality overhead conductors provide, there are typically no practicable non-network solutions for replacing the service they provide where the functionality of the conductor is maintained. Therefore, for this assessment only network options have been considered to address the identified need.

Non-network options such as installation of a stand-alone power system as an alternative to the upkeep of the network should be considered on a site-specific basis during detailed design works with consideration to all existing network assets that comprise an overhead distribution feeder.

Repair of overhead conductors are currently carried out as part of Endeavour Energy typical business as usual approach. This CFI considers network replacement options for addressing the failure risk of overhead conductors in a proactive planned manner:

1. Replacement of an HV overhead conductor: If it is assessed that the functionality of the conductor is still required, it is replaced with new equivalent bare conductor; and
2. Replacement of an HV overhead conductor: If it is assessed that the functionality of the conductor is still required, it is replaced with new equivalent covered conductor thick (CCT); and

High voltage overhead conductor linear assets are identified for proactive intervention at the time when the net present value of the intervention reaches its maximum value. Where this occurs for option 2, replacement with covered conductor thick (CCT) in the period of FY23 – FY29, the interventions have been included in this program. As a result, it is proposed 855 overhead conductor linear assets totalling 211km in route length are retired and replaced with covered conductor thick (CCT) during the FY23 – FY29 period. The HV overhead conductor linear assets proposed for replacement represent approximately 1.9% of the total current population of overhead conductors across the HV distribution network and approximately 0.75% of the total current population of overhead conductors across the network.

The net present value (NPV) of the proposed replacement option is unique to each section of overhead conductor and varies from $426 to $19.6 million with an average of $667,000 across the 855 assets for intervention during the period as proposed. The total NPV of the proposed program is $570 million.

The total cost of these works is estimated to be $38.1 million in real FY23 terms, and it is recommended that the program be approved for consideration in the FY23-29 Portfolio Investment Plan (PIP) for optimisation.

A further 332 overhead conductor sites are NPV positive and provide their maximum NPV across the second half of the 10-year investment period (FY30-FY34 period) and are also put forward for optimisation. These 332 investments total a further $14.66 million (in real FY23 terms) giving a total investment for optimisation of $52.75 million.

The project cost of the credible options fall below the threshold for application of the Regulatory Investment Test for Distribution (RIT-D) (currently $6.0 million) and therefore the RIT-D is not applicable to this program.

This recommendation is made on the basis that the preferred solution represents the highest economic value (economic benefit) compared to other credible network and non-network options.

2. Purpose

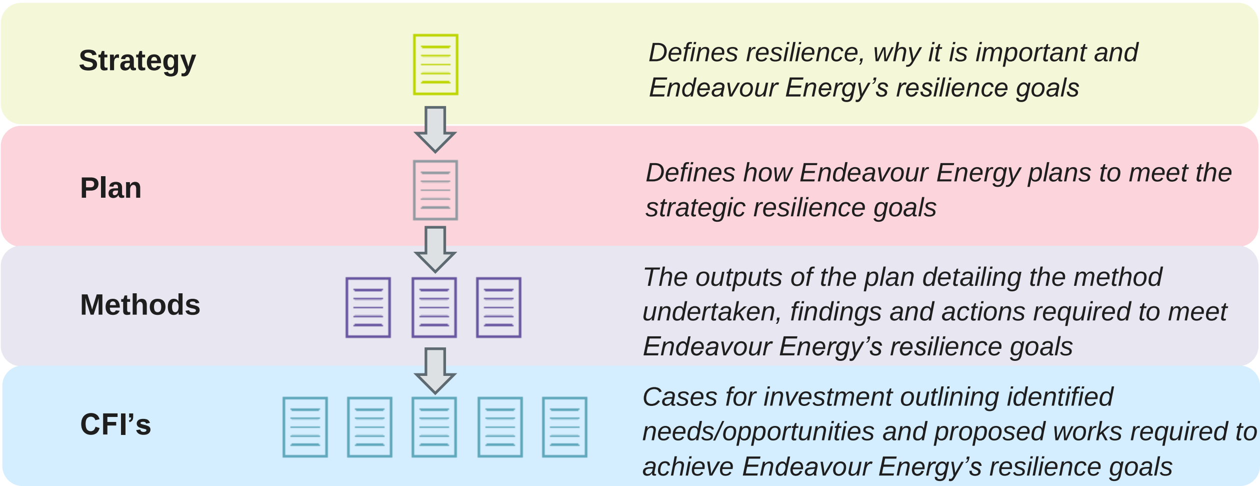
The purpose of this document is to seek endorsement of the case for investment (CFI) for managing the risks posed by aged high voltage (HV) distribution overhead conductors and improve the distribution networks resilience to the impacts of climate change.

To ensure the electrical network is more resilient to climate change, escalation factors accounting for change in future risk have been applied to Endeavour Energy's existing asset risk framework for assessment of HV distribution overhead conductors. The application of climate change escalation factors shifts forward the optimum timing of intervention for asset investments. The investments which are brought forward improve Endeavour Energy's network resilience to future climate conditions.

This case for investment (CFI) recommends proactive intervention for retirement of the identified overhead conductors to be replaced with covered conductor thick (CCT) during the FY23 – FY29 period.

This CFI, together with other network resilience CFI's, provide an overview of investments aimed towards achieving Endeavour Energy's resilience goals outlined in the "Resilience Strategy" and "Resilience Plan" [1] [2]. Figure 1 below illustrates where resilience CFI's are positioned in the structure of Endeavour Energy's network resilience documentation.

Figure 1 – Resilience documentation structure



3. Identified needs and/or opportunities

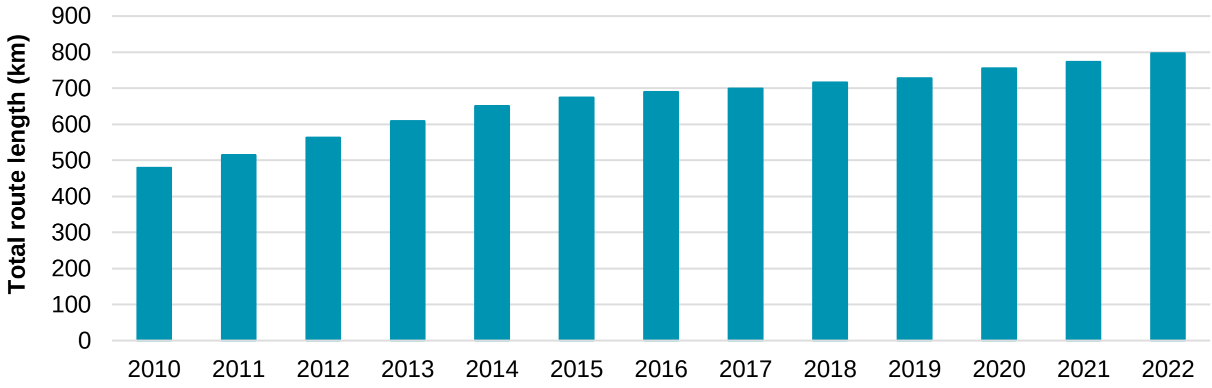
3.1 Background

Overhead conductors are critical components of the distribution network which provide a physical medium to safely transmit electricity between bulk supply points and customers. Endeavour Energy own and operate over 11,000 kilometres of high voltage distribution overhead conductor on the network across 76,000 unique linear assets.

Historically, the overhead conductor asset class has been managed through reactive programs which rely upon the identification of conditionally failed assets through routine 5.5 yearly overhead line inspections. Over recent years, an improved understanding of quantitative asset risk management has led to the development of programs which have proactively targeted conductors for replacement based on asset condition and risk cost of failure. These programs include *DS011 – High voltage steel mains replacement* (2014 – 2021) and *DS414 – Copper distribution mains replacement* (2015 - 2019) which have been carried out to manage risk posed by degraded steel mains and hard drawn copper conductors, and *DS422 – High voltage distribution bushfire mitigation* (2020 - 2023) targeting high bushfire risk areas suitable for augmentation to covered conductor thick (CCT) for management of bushfire ignition risk.

As a result of network growth, proactive and reactive programs, the amount of covered conductor installed on the overhead high voltage distribution network has increased by 66% since 2010, see Figure 2 below.

Figure 2 – Growth of covered conductor installed on Endeavour Energy's network



The increasing penetration of covered conductor over recent years has resulted in over 25% of high voltage conductors located within Endeavour Energy's highest bushfire risk areas to now be of a covered construction. Programs such as DS422 over recent years has reduced bushfire ignition risk and reliability risk on the distribution network. The increasing penetration of covered conductors establishes a more resilient electrical network which is less susceptible to interruptions caused by conductor clashing and vegetation contact from adverse weather.

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;

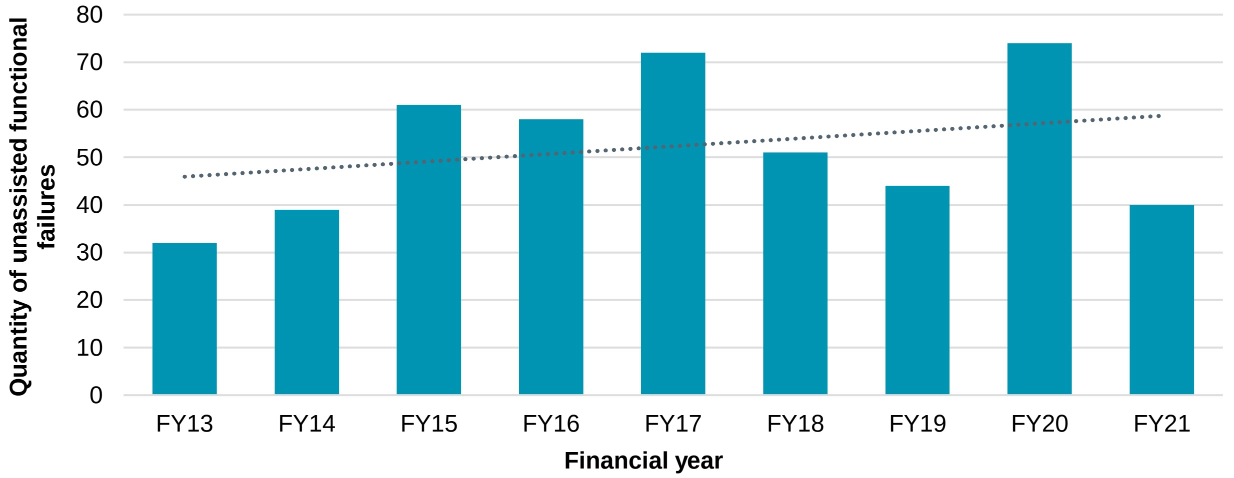
- Bushfire impacts: where failures lead to a phase to ground fault between the conductor/s and the ground or a grounded object, there is potential for arcing to ignite nearby combustible materials. Additionally, where a failure leads to a phase-to-phase fault, arcing between the conductor phases can 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 network and community assets 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.

Climate modelling commissioned by Endeavour Energy from Deloitte has indicated that across a range of future emission scenarios, localised risks across the network are changing as a result of climate change. The climate modelling has indicated that risks such as bushfire risk are forecast to increase due to a higher likelihood of bushfire favourable weather in future climatic conditions. The application of these modelled climate change impacts to the asset risk framework methodology is outlined in “Endeavour Energy Resilience Method – Integration into Investment Planning” and has been incorporated into this assessment through the incorporation of climate change escalation factors [3].

Endeavour Energy has existing maintenance procedures in place to manage the failure risks 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 3 below provides the number of historical functional failures each year. Refer Appendix B for further detail of the assessed failure consequences.

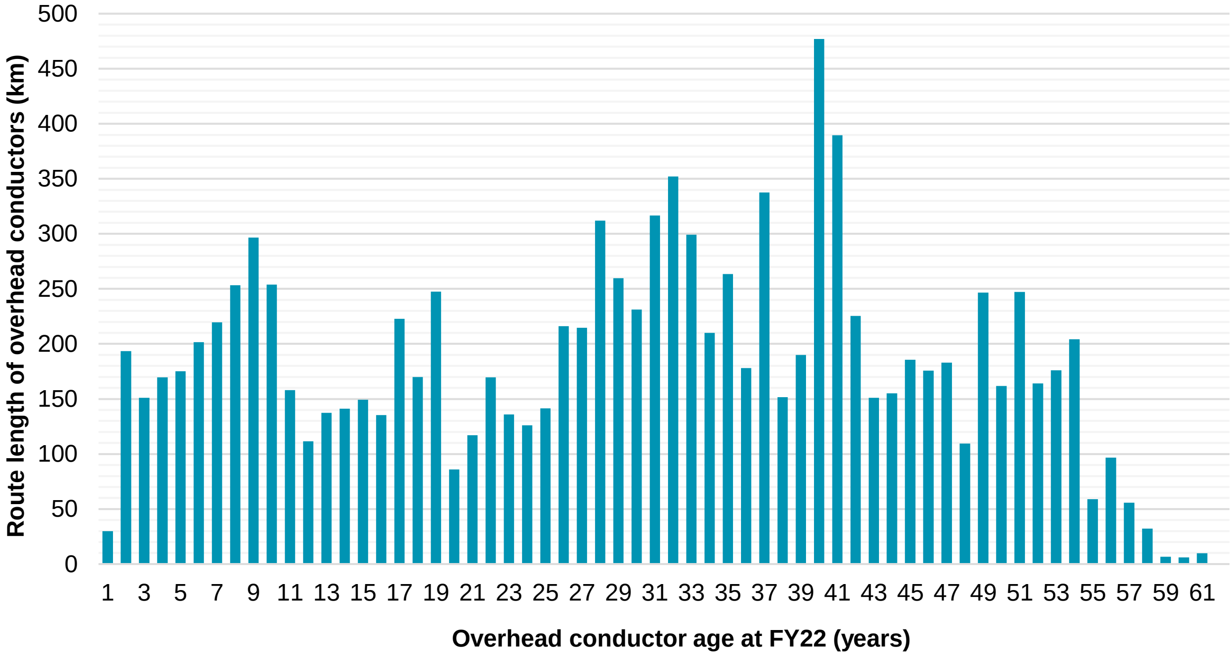
Figure 3 – Annual quantities of overhead conductor unassisted failures



3.3 Asset age profile

The age profile for high voltage distribution overhead conductor linear assets is shown in Figure 4.

Figure 4 – Age profile of high voltage distribution overhead conductor linear assets



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* [4]:

- 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 [4].

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 1 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 1 – BAU risk cost summary

Risk category	PV of residual risk ($M)	Risk proportion (%)
Safety	0.06	0.0
Reliability	27.20	3.5
Bushfire	740.34	96.4
Total	**767.60**	**100**

As noted in Table 1 above, the residual risk presented by the BAU case totals $767.60 million. The residual risk value presented by each segment of overhead conductor ranges from $932 dollars to $20.4 million dollars and averages $755,000 across the fleet of 1,550 linear assets assessed.

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

A range of options have been considered to address the risk presented by the overhead conductors being assessed as an alternative to network investment. These approaches are summarised in Table 2 below.

Table 2 – 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

Overhead conductors are a vital component of the network and provide a physical medium to distribute electricity from one place to another. Overhead conductors' function to carry load and fault currents without annealing or sagging below limits for conductor height clearances and must maintain continuity under these conditions.

There are no credible non-network solutions capable of replacing their functionality under the assumption that the feeder in which they service is still required. Upon functional or conditional failure of an overhead conductor, the future requirement of the feeder should be considered on a site-specific basis prior to undertaking replacement of the asset. This includes assessment of whether a stand-alone power system (SAPS) can provide a more economically beneficial outcome than continued upkeep of all existing network assets which make up an overhead feeder.

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 HV 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. This option assesses and compares the economic value of replacement with:

1. A like-for-like equivalent conductor; or
2. A covered conductor thick (CCT) alternative.

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

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 – Like-for-like overhead conductor replacement

This option identifies 611 overhead conductor linear assets totalling a route length of 159 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 $279.73 million and provides a benefit of $487.87 million compared to the counterfactual case. The PV of the cost of the option is $23.58 million and the NPV overall is $464.28 million.

Table 3 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 3 – Option 1 residual risk summary

Risk category	PV of residual risk ($M)	Risk proportion (%)
Safety	0.02	0.01
Reliability	9.91	3.5
Bushfire	269.80	96.4
Total	**279.73**	**100**

5.4.2 Option 2 – Augmentation to covered overhead conductor

This option identifies 855 overhead conductor linear assets totalling a route length of 212 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 $159.89 million and provides a benefit of $607.70 million compared to the counterfactual case. The PV of the cost of the option is $37.01 million and the NPV overall is $570.61 million.

Table 4 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 4 – Option 2 residual risk summary

Risk category	PV of residual risk ($M)	Risk proportion (%)
Safety	0.01	0.01
Reliability	5.67	3.5
Bushfire	154.22	96.4
Total	**159.89**	**100**

5.5 Evaluation summary

Table 5 below summarises the outcomes of the cost-benefit assessment for replacement options across Endeavour Energy's fleet of 76,057 high voltage distribution overhead conductor assets 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 5 – 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
BAU	Counter-factual	-	767.60	-	-	-	3	BAU – Does not capture benefits
1. Like-for-like overhead conductor replacement	Network	611	279.73	487.87	23.58	464.28	2	NPV positive and reduces risk but provides lower NPV
2. Augmentation to covered overhead conductor	Network	855	159.89	607.70	37.09	570.61	1	Preferred option

As outlined in Table 5, Option 2 is the preferred option as augmentation to covered conductor for the selected overhead conductor assets provides the highest NPV and therefore delivers the highest economic value.

The “Risk Model Framework” documentation outlines in detail the process used for determining the economic evaluation for any given asset (repairable or non-repairable) [5]. 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.

The “Endeavour Energy Resilience Method – Integration into Investment Planning” documentation outlines in detail the application of climate change escalation factors to the “Risk Model Framework” [3] [5].

5.6 Economic evaluation assumptions

There are a wide range of assumptions of risk, their likelihoods and consequences which support the cost benefit assessment outlined within this CFI. Refer to Appendix C for details of the economic evaluation 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 6.

Table 6 – 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 2) NPV is shown in Table 7 below and the resultant spread of replacement years to give the maximum NPV for each of the 855 overhead conductor linear assets identified for replacement under the preferred option is shown in Figure 5.

Table 7 – NPV of scenario analysis for the preferred option (Option 2)

Scenario	NPV of preferred option ($M)
Scenario 1 – Low benefits, high costs	338
Scenario 2 – Central risks and costs	570
Scenario 3 – High benefits, low costs	984
Average	**631**

Each scenario reduces the risks posed by the 855 overhead conductor linear assets with an average NPV of $631 million across the three scenarios analysed.

Figure 5 - Option 2: Optimum timing of intervention across the three sensitivity scenarios

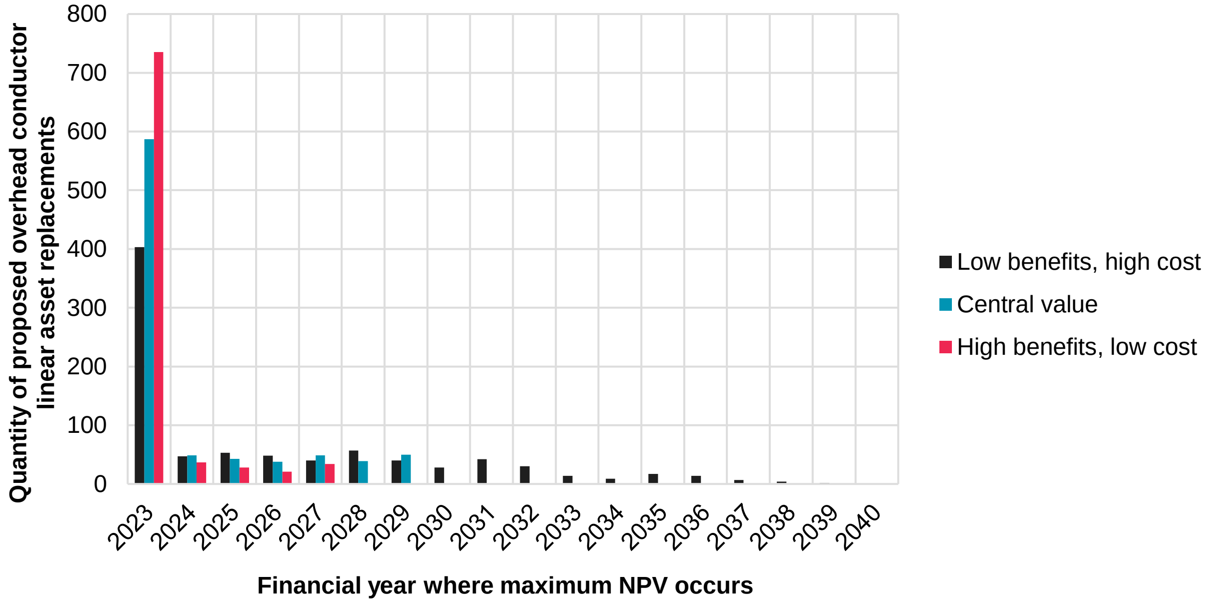


Figure 5 illustrates the optimal timing of each 855 recommended assets for replacements based on the year in which their NPV is maximum across each of the three tested scenarios.

All high benefit, low-cost replacement cases fall within FY23 to FY27, while the low benefit, high-cost cases are spread between FY23 and FY38 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 2.

5.8 Climate change escalation factor sensitivity analysis

A sensitivity assessment has been carried out on the climate change escalation factors used in the economic analysis in order to test the robustness of the evaluation.

Three scenarios of future emissions for the application of climate change escalation factors have been assessed:

- Scenario 1 - baseline with no application of climate change escalation factors;
- Scenario 2 - RCP4.5 escalation factors representing a moderate CO_2 emissions scenario; and
- Scenario 3 - RCP8.5 escalation factors representing a high CO_2 emissions scenario.

The impact on optimum timing of intervention for HV overhead conductor linear assets under these three climate change scenarios is shown in Figure 6.

Figure 6 – Option 2: Optimum timing of intervention across the three climate change scenarios

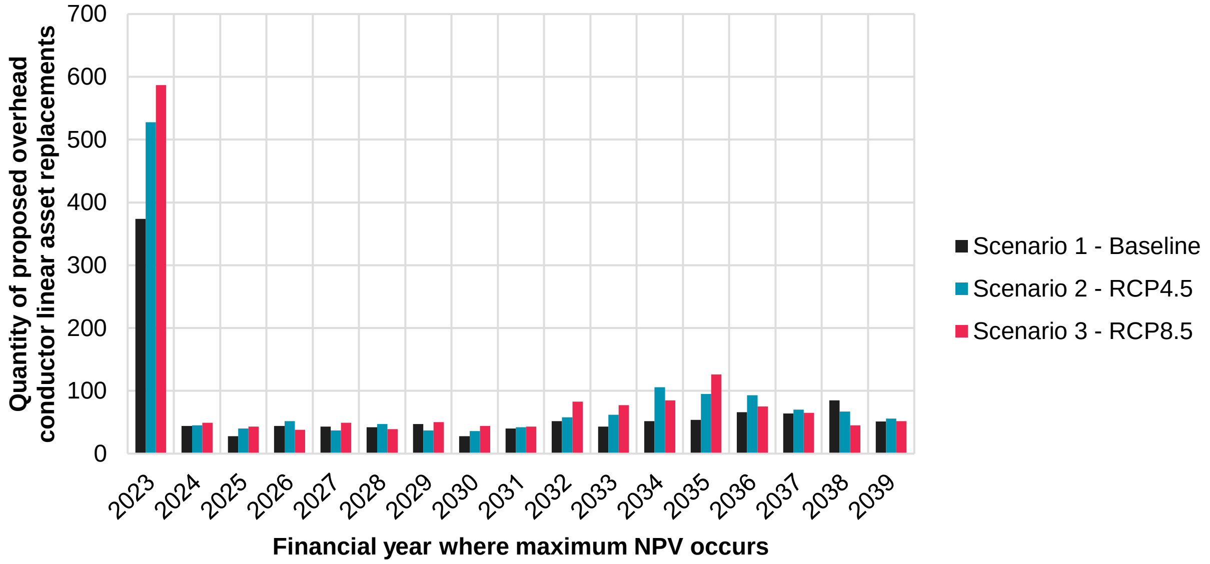


Figure 6 illustrates that the largest difference in proposed interventions across the tested climate scenarios is during the first eligible year of investment. Comparing the optimal intervention time of individual assets, investments are shifted 0 to 11 years forward between scenario 1 and scenario 3.

The climate change escalation factor sensitivity analysis indicates that the investments from Option 2 are shifted forward at most 11 years under a high emissions scenario when compared to the baseline asset risk framework assessment methodology for replacement expenditure. The comparable annual quantities of interventions proceeding the first eligible year of investment indicates that after the initial backlog of investment, annual expenditure across all three scenarios is proportionate.

6. Preferred option details

6.1 FY23 – FY29 scope and timing

The preferred option is Option 2, which includes replacement of 855 overhead conductor linear assets during the FY23 – FY29 period.

The overall cost of the proposed program is estimated to be $38.1 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 variations in individual site costs expected to even out across the proposed program.

6.2 Additional scope and timing

A further 332 overhead conductor linear assets totalling a route length of 81 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 332 investments total a further $14.7 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 8 below. All costs are in real FY23 terms.

Table 8 – Summary of investment for optimisation

Intervention type	Route length (km)	Quantity of interventions	Total costs ($M)
HV Overhead Conductor Augmentation (NPV Max FY23-FY24)	168	636	30.29
HV Overhead Conductor Augmentation (NPV Max FY25-FY29)	43	219	7.79
HV Overhead Conductor Augmentation (NPV Max FY30-FY34)	81	332	14.66
Total	**293**	**1,187**	**52.75**

This CFI has been prepared in parallel with the overhead conductor asset class CFI "Overhead Conductor Failure Risk Mitigation" [6]. As these two CFI's examine the same set of assets, a review of overlaps between proposed scopes has been conducted. The same asset, PoF and LoC data (excluding climate change escalation factors) have been used for both CFI's. Since the same assets are under review and the benefits associated with the proposed asset class CFI are lower than the benefits identified in this CFI, all overlaps of scope have been removed from the "Overhead Conductor Failure Risk Mitigation" CFI.

Refer to the "Overhead Conductor Failure Risk Mitigation" CFI for additional information regarding removal of scope due to overlap [6].

6.3.2 Reactive investment

No reactive investment proposed.

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 [7] [8].

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

7. Regulatory investment test

The project cost of the credible option(s) for each site falls below the threshold for application of the Regulatory Investment Test for Distribution (RIT-D) (currently $6.0 million) and therefore the RIT-D is not applicable to this project.

8. Recommendation

It is recommended that Option 2 for the proactive replacement of HV distribution overhead conductor linear assets with covered conductor thick (CCT) where the intervention timing indicates that maximum NPV is between FY23-FY34, be included in the PIP FY23-29 and to proceed to the investment portfolio optimisation stage.

9. Attachments

Appendix A – Details of recommended scope for optimisation

Appendix B – Risk assessment variables

10. References

[1] Endeavour Energy, “Endeavour Energy Resilience Strategy,” 2022.

[2] Endeavour Energy, “Endeavour Energy Resilience Plan,” 2022.

[3] Endeavour Energy, “Endeavour Energy Resilience Method - Integration into investment planning,” 2022.

[4] Endeavour Energy, “MMI 0002 Distribution Overhead Defect Handbook,” 2021.

[5] Endeavour Energy, “Risk Model Framework,” 2022.

[6] Endeavour Energy, “Overhead Conductor Failure Risk Mitigation Case for Investment FY23-29,” August 2022.

[7] Endeavour Energy, “MDI 0031 Overhead Line Design,” 2017.

[8] Endeavour Energy, “MCI 0005 Overhead construction standards manual,” 2017.

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

[10] Endeavour Energy, “MMI 0001 - Pole and line inspection and treatment procedures,” 2016.

[11] Endeavour Energy, “MMI 0012 - Overhead transmission line routine inspection,” 2019.

[12] Endeavour Energy, “MMI 0034 - Pre-summer bushfire inspections,” 2016.

[13] Endeavour Energy, “MMI 0028 - Thermovision of distribution and transmission lines,” 2014.

Appendix A – Details of recommended scope for optimisation

Scope with maximum NPV between FY23-FY34 can be found in the attached Microsoft 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	76,057 linear assets (11,244 km)	Number of high voltage distribution 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)
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	FIGLEAF – 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	Augmentation costs: HV CCT: $180,000/km Like-for-like replacement costs: 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

Parameter	Value	Description/justification	Source/assumptions
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 data 2012 -2021 Ellipse
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	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
	- 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 - 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	Public safety modelling EE Network Public Safety Likelihood.kml

Parameter	Value	Description/justification	Source/assumptions
		LoC: 0.0008% to 0.0273%	
	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 LoC: 0.0001% to 0.0204%	Public safety modelling EE Network Public Safety Likelihood.kml
	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 outage records.	OMS 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% Bare LV - 6% Bare TR - 20% CCT HV - 2%	Likelihood that a conductor failure will ignite a small fire:	Based on historical fire start data. Fire Database.xlsx
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. Disproportionate factor applied to public safety component of bushfire ignition risk CoF: 6	Bushfire ignition risk CoC modelling based on the Phoenix Fire Characteristic Simulations
Bushfire Escalation Factors	Bushfire escalation factors vary by geographical area: East – 163-170% Central – 168-180% West – 183-255% South – 182-228%	Increase in bushfire risk due to change in likelihood of bushfire favourable weather (increase in very high FFDI days).	Deloitte climate modelling for changes to bushfire weather under moderate (RCP4.5) to high (RCP8.5) CO2 emission scenarios

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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