UNDERGROUND CABLE FAILURE RISK MITIGATION

Case for investment FY23 – 29
(Pre-optimisation)

August 2022

Investment Title	**Condition based replacement of underground cable**
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Portfolio	Repex
CFI Date	30/06/2022
Pre RIT-D	☐
Final CFI (Pre-optimisation)	☒
Other	☐

Version control and endorsements

Version	Date	Comments
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1. Executive summary

1.1 Recommendation

This case for investment (CFI) recommends investment in the replacement of *underground cable linear assets* across the distribution network during the period of FY23 – FY29 to address the reliability and financial 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.

The total cost of the proposed works is estimated to be $0.4 million 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 $26.8 million is proposed for the replacement of underground cables that fail unexpectedly and in a non-repairable manner during the FY23 - FY29 period giving a total proposed investment of $27.2 million. This CFI does not include forecast expenditure for the fleet of 132kV Oil Filled cables, these assets will be covered in their own specific CFI.

1.2 Identified need

Endeavour Energy own 20,564 kilometres of underground cables (excluding customer services) in-service represented by 395,097 unique underground cable linear assets which operate at voltages ranging from 415 volts up to 132,000 volts. Failure of an underground cable 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;
- Financial impacts: due to the cost of repair procedures can incur large financial costs.;
- Safety impacts: where the failure of a low voltage neutral conductor in a cable occurs but the cable remains energised there are possible safety impacts. The principal risk in this situation is potential of shock to members of the public and workers; and
- No significant environmental, bushfire or regulatory compliance consequences have been experienced or are anticipated for future failures of underground cables.

1.3 Options analysis

There are no credible non-network solutions for replacing the functionality of an *underground cable linear asset* under the assumption that the feeder in which they service is still required.

For *underground cable linear assets* the only option available for addressing the failure risk of underground cables in a proactive planned manner which is considered to be credible is retirement followed by the replacement of the cable with a modern equivalent cable.

Table 1 below summarises the outcomes of the cost-benefit assessment for the replacement of Endeavour Energy's fleet of 395,097 underground cables compared to the counterfactual case. The summary shows the impact of investment in the replacement of underground cables 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	-	437.2	-	-	-	2	Excessive risk
1. Replace underground cable	Network	7	434.8	2.4	0.3	0.3	1	Preferred option

1.4 Recommended option

Recommended option is Option 1 for the replacement of 7 underground cables with a modern equivalent cable, subject to project optimisation.

The NPV of the proposed interventions is unique to each underground cable and varies from $12,355 to $169,607 with an average of $45,060 across the 7 assets proposed for intervention during the period. The total NPV of the proposed program is $0.3 million.

The benefit to cost ratio (BCR) for each underground cable site varies from 1.5 to 3.2 and averages 2.3 across the 7 underground cable interventions.

1.5 Budget

The total cost of the proactive replacement works is estimated to be $0.4 million in real FY23 terms.

The additional funding required for underground cables that are likely to fail in service is $26.8 million giving a total for the recommended funding of $27.2 million.

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2. Purpose

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

This case for investment (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 underground cables during the FY23 – FY29 period and provision of additional capital for the reactive replacement of underground cables 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

Underground cables are a vital component of the network and provide a physical medium to distribute electricity from one place to another. For Endeavour Energy's network, the distribution of electricity is typically between TransGrid bulk supply points and residential, commercial and industrial customers. Underground cables also function to carry load and fault current and maintain continuity under both normal and fault conditions.

Endeavour Energy own 20,564 kilometres of underground cables (excluding customer services) in-service represented by 395,097 unique underground cable linear assets. Each underground cable linear asset represents a unique segment of cable of varying length.

Currently, within Endeavour Energy's network there are 28 different types of underground cables in-service which vary in construction, insulation, conductor metal, quantity of cores and size. Furthermore, each of these kinds of cables can also be operating at low voltage, high voltage or transmission. This is summarised in Table 2 below.

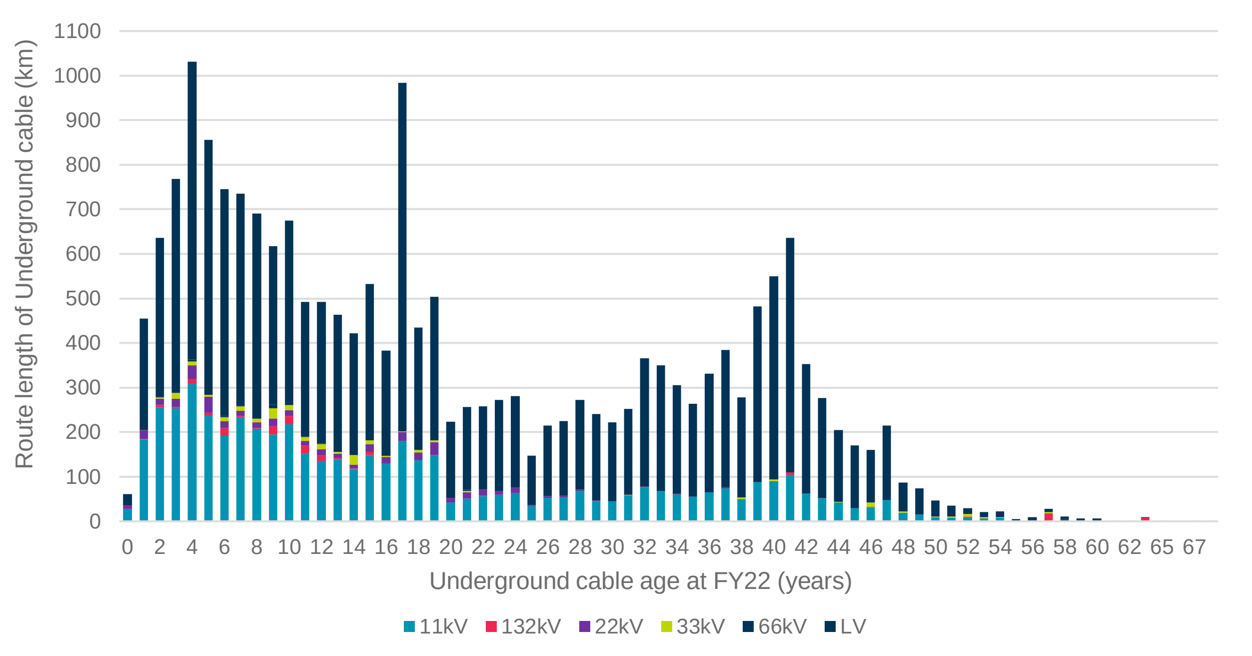
Table 2 - Underground cable linear assets summary

Voltage Classification	Quantity of asset types	Quantity of linear assets	Route length (km)
Low voltage distribution (LV) (upto 415V)	9	351,147	14,421
High voltage distribution (HV) (11kV – 22kV)	8	43,003	5,730
Transmission (TR) (33kV – 132kV)	11	947	414
Total	**28**	**395,097**	**20,564**

Historically, programs for the management of underground cables have been primarily reactive in identification of assets which require intervention. In recent years programs such as *DS006 – LV CONSAC cable replacement* (2003 - 2022), *DS014 – LV cable network renewal* (2016 - 2018), and *DS415 – LV mains replacement* (2014 - 2015) have been carried out to manage the risk posed by underground cables on the network. These programs all targeted specific asset types of underground cables which were experiencing poor performance.

The age profile for the underground cable asset class is shown in Figure 1 by operating voltage.

Figure 1 – Age profile by operating voltage for underground cable linear assets



3.2 Risks and identified need

Several different types of failure modes are observed in underground cables. A specific failure mode may be more prominent in a certain type of underground cable. The functional failure of an underground cable can include:

- Breakdown of the cable insulation leading to an electrical phase to phase and/or phase to earth fault. This type of failure mode is often due to poor cable condition from aging and long-term operating conditions (electrical overloading) or due to defects imparted into the insulation during the cable manufacturing processes.
- Degradation of the cable sheath due to environmental conditions in which the cable is installed or due to abrasion during installation. While cable sheath degradation does not immediately lead to a failure resulting in a loss of supply, it can often be associated as a catalyst for other cable failure modes to occur.
- Moisture ingress into a cable can lead to an electrical phase to phase and/or phase to earth fault where the cable insulation has been compromised. Moisture ingress also has the potential to cause corrosion to metals within the cable construction such as metallic sheaths, screens, armours and conductors.
- Excessive heating of the cable can cause degradation in the cable insulation and inner cable layers leading to premature failure. Heating can occur due to environmental factors, fault currents or cable overloading.

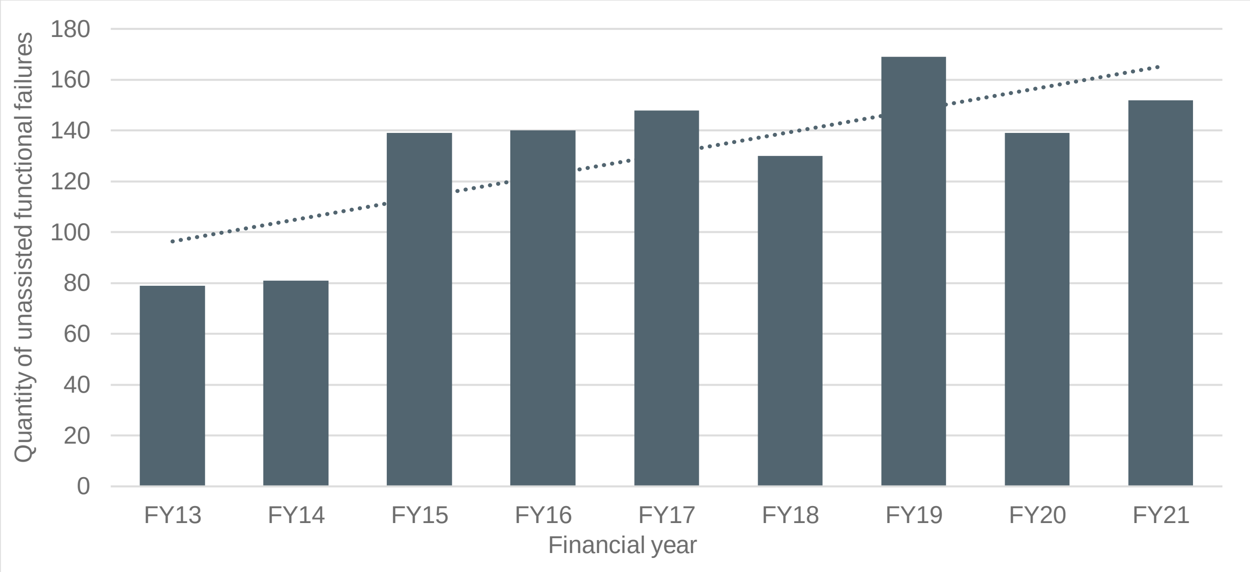
Undergrounds cables have historically performed in a reliable manner and the majority of the failure modes outlined above have occurred at locations of cable joints or terminations where the cable experiences the highest electrical stresses. From FY17 onwards Endeavour Energy has experienced on average 146 unassisted functional failures of underground cables 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;
- Financial impacts: due to the cost of repair procedures can incur large financial costs;
- Safety impacts: where the failure of a low voltage neutral conductor in a cable occurs but the cable remains energised there are possible safety impacts. The principal risk in this situation is potential of shock to members of the public and workers; and
- No significant environmental, bushfire or regulatory compliance consequences have been experienced or are anticipated for future failures of underground cables.

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

Figure 2 – Annual quantities of underground cable 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, underground cables 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 underground cable 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 underground cable 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 underground cables 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 underground cables 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 underground cables until they have failed followed by repair of the cable after failure, providing its service is still required. Nil proactive capital intervention is carried out.

The scope of works under the BAU include:

- Reactive repair after failure.

Currently, "failure" refers to the inability of an underground cable 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 cable or cable joint; or
- Failure of the underground cable to perform its rated duty.

Conditional failures occur when sections of cable are identified to be in a poor condition indicating a high likelihood of failure. Where maintenance standards have been developed which set out conditional failure thresholds, these will be used to assess conditional failure, otherwise cable conditional failure is assessed at an individual asset level based on the available condition information.

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 (%)
Reliability	341.5	78
Financial	95.7	22
Total	**437.2**	**100**

As noted in Table 3 above, the residual risk presented by the BAU case totals $437.2 million. The residual risk value presented by each segment of underground cable ranges from $0 to $0.74 million and averages $2,700 across the fleet of 395,097 linear assets.

The higher risk values are considered to be excessive and indicate the need for the higher risk segments of underground cable 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 underground cables. These approaches are summarised in Table 4 below.

Table 4 – Underground cable 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 underground cable. The ongoing management and maintenance of underground cables typically involves routine inspections for defects.	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 an unassisted failure occurring is generally independent of load. A minor reduction in the consequences of failure could be achieved by transferring load from any of the feeders in which underground cables are installed however, these options are very limited within the low voltage and high voltage distribution network. Underground cables provide a physical medium to distribute electricity from one place to another on the distribution and sub-transmission networks, there are no practicable non-network solutions for replacing the function they provide.	No technically feasible solution
Reactive repair and/or replacement of underground cables 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 cable is replaced post failure, the overall condition of the entire section of cable and future probability of failure remain relatively unchanged (as-good-as-old).	Technically feasible solution but does not always effectively mitigate risk of future failures
Staged replacement to maintain option value and reduce the consumer's long-term service cost	Replacement of underground cables.	Recommended approach for further consideration.

5.2 Non-network options

Underground cables are a vital component of the network and provide a physical medium to distribute electricity from one place to another. Underground cables function to carry load and fault currents below thermal cable limits 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 underground cable, the future requirement of the feeder should be considered on a site-specific basis prior to undertaking replacement of the linear asset.

Therefore, network options should be considered which include intervention to address the identified need.

5.3 Credible network options

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

Replacement of underground cable linear assets based on condition is considered a credible network option.

5.3.1 Underground cable replacement

Under this option, the intervention includes the complete replacement of underground cable linear assets in a planned proactive manner.

The per kilometre unit rates used for estimating the cost of replacement for underground cables vary with operating voltage, cable conductor material, size, and location. The unit rates which have been used for this assessment are outlined in Appendix B and includes:

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

The unit rates were provided by Endeavour Energy's Mains Design team and represent typical values based on past programs and ongoing experience of replacing similar type cables within Endeavour Energy's network.

5.4 Economic evaluation

5.4.1 Option 1 – Underground cable replacement

This option identifies 7 underground cable linear assets totalling a route length of 1.3 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 $434.8 million and provides a benefit of $2.4 million compared to the counterfactual case. The PV of the cost of the option is $0.3 million and the NPV overall is $0.3 million.

The NPV of the proposed interventions is unique to each underground cable and varies from $12,355 to $169,607 with an average of $45,060 across the 7 assets proposed for intervention during the period.

The benefit to cost ratio (BCR) for each underground cable site varies from 1.5 to 3.2 and averages 2.3 across the 7 underground cable interventions.

Table 5 below provides a summary of the residual risk presented by this option. Refer Appendix A for details of the underground cable 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 (%)
Reliability	340.7	78
Financial	94.1	22
Total	**434.8**	**100**

5.5 Evaluation summary

Table 6 below summarises the outcomes of the cost-benefit assessment for underground cable replacement options for Endeavour Energy's fleet of 395,097 linear assets (excluding XLPE cables) compared to the BAU case. The summary shows only the impact of investment in underground cables 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	-	437.2	-	-	-	2	Excessive risk
Replace underground cable	Network	7	434.8	2.4	0.3	0.3	1	Preferred option

As shown in Table 6, underground cable 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 Scenario assessment

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)

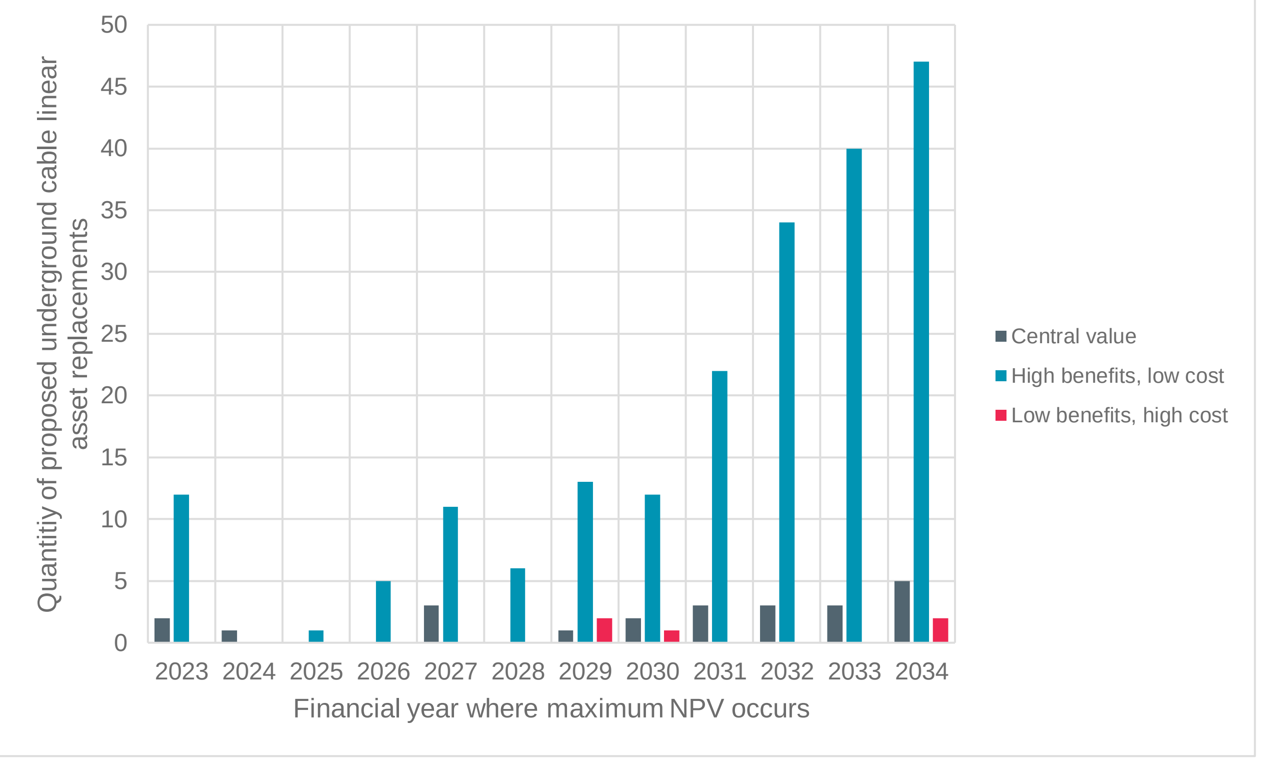
The impact on the preferred option (Option 1) NPV is shown in Table 8 below and the resultant spread of replacement years to give the maximum NPV for each of the 18 underground cable linear assets identified for replacement under the preferred option is shown in Figure 3.

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

Scenario	NPV of preferred option ($M)
Scenario 1 – Low benefits, high costs	0.02
Scenario 2 – Central risks and costs	0.3
Scenario 3 – High benefits, low costs	2.4
Average	**0.9**

Each scenario reduces the risks posed by the 7 underground cable linear assets with an average NPV of $0.9 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 (over the FY23 and Fy29 period) that the assets maximum NPV occurred. In this assessment, sensitivity lies around the Weibull end-of-life element. This assessment has been able to rely on historical underground cable failure data over the FY12-FY21 period to assist in determining the Weibull parameters.

Figure 3 illustrates the optimal timing of each 7 recommended assets for replacement 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 FY34, while the low benefit, high-cost cases are spread between FY29 and FY34.

Figure 3 above also shows that across the three sensitivity scenarios, the timing of the maximum NPV of the recommended 7 replacements are initially skewed towards FY23 out suggesting an appropriate level of investment for Option 1, which is the earliest year that the works can now be practically carried.

6. Preferred option details

6.1 FY23 – FY29 scope and timing

The preferred option is Option 1, which includes replacement of 7 underground cable linear assets during FY23 – FY29.

The overall cost of the proposed program is estimated to be $0.4 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 underground cables 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 16 underground cable linear assets totalling a route length of 0.9 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 16 investments total a further $0.3 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 underground cable replacement costs vary between asset type and location.

All costs are in real FY23 terms.

Table 9 – Summary of investment for optimisation

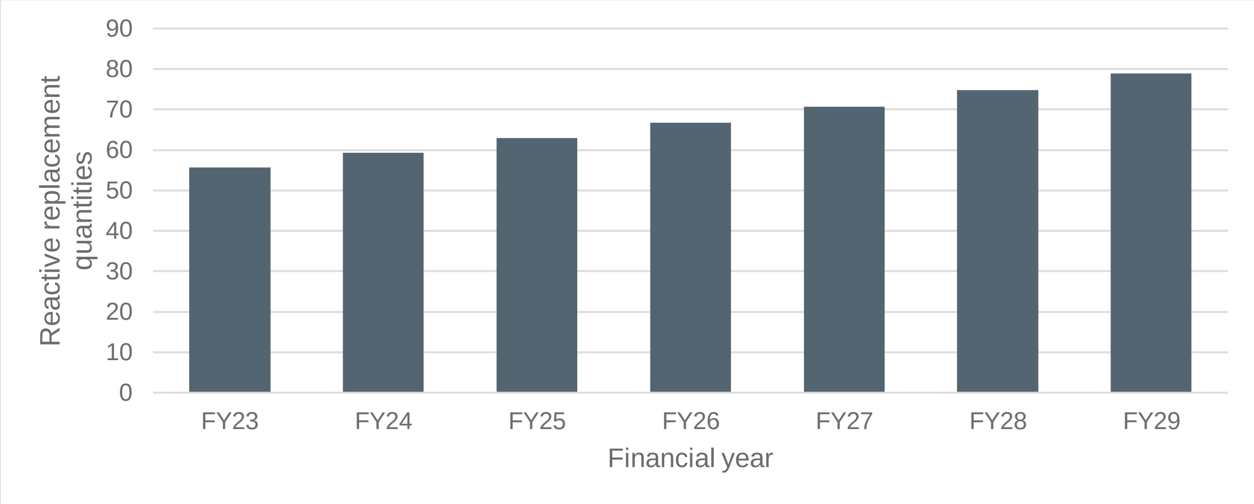
Intervention type	Route length (m)	Quantity of interventions	Total costs ($000's)
LV Underground Cable Replacement (NPV Max FY23-FY24)	30	1	23.9
HV Underground Cable Replacement (NPV Max FY23-FY24)	70	2	20
Subtotal FY23-FY24	***100***	***3***	***43.9***
HV Underground Cable Replacement (NPV Max FY25-FY29)	1,210	4	333
Subtotal FY25-FY29	***1,280***	***4***	***333***
HV Underground Cable Replacement (NPV Max FY30-FY34)	940	16	317.9
Subtotal FY30-FY34	***940***	***16***	***317.9***
Total	**2,320**	**23**	**694.8**

6.3.2 Reactive investment

Reactive modelling for the FY23 -FY29 period has forecast a further 469 underground cable linear assets to reach a state of conditional failure or functional failure requiring capital investment for rectification. It is to be noted that the underground cable 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 interventions requiring capital expenditure which likely to be required for the replacement of failed underground cable linear assets between FY23 and FY29.

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 underground cables to give an annual forecast of reactive funding requirements. To accommodate this eventuality, it is proposed that additional funding of $26.8 million (in real$ FY23 terms) be made available for reactive replacement of underground cable 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)	115	6.5
Regulatory control period (FY25-FY29)	354	20.3
Total	**469**	**26.8**

6.4 Project scope of works

6.4.1 Underground cable replacement

The proposed scope of works includes replacement of the selected underground cables in accordance with Endeavour Energy design and construction standards MDI 0028 and MCI 0006 [1] [2].

Due to inaccuracies in cable type and cable commissioning date within Endeavour Energy's GIS database, proposed scope which is identified to be in an acceptable service condition for the foreseeable future (10 years) is to be raised with the Asset Performance team for further investigation prior to retirement.

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 underground cable 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 $26.8 million (in real $ FY23 terms) within the FY23-FY29 period for the reactive replacement of Underground cables 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, "MDI 0028 - Underground distribution network design," 2017.

[2] Endeavour Energy, "MCI 0006 - Underground distribution construction standards manual," 2016.

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

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

Appendix A – Details of recommended scope for optimisation

Scope with maximum NPV between FY23-FY34, shown in order of descending BCR, then descending NPV

G3E_FID	SAP Functional Location	SAP UUID	Asset Type	Operating Voltage	feeder	conductor code	In-Service Date	Asset Length (km)	Maximum NPV Value	BCR	Maximum NPV window	Replacement Cost
50152956	CSHV00316877	6B98E67A-A66B-4BC8-8CFA-83E9851FF2DB	11kV Cable (PLYSWS) Multi Core / 11kV Underground Cable (PLYSWS) Multi Core	11kV	HS1132	U10	19680101	0.049	$ 31,954	3.22	FY23-FY24	$14,399
50152957	CSHV00316878	588FE7E4-2182-438C-86DE-4E6733D60E38	11kV Cable (PLYSWS) Multi Core / 11kV Underground Cable (PLYSWS) Multi Core	11kV	HS1132	U10	19680101	0.019	$ 12,355	3.17	FY23-FY24	$5,621
50177024	CSHV00821431	3295C4BB-4AAB-4B46-9037-4FD3B661D58C	11kV Cable (PLYSWS) Multi Core / 11kV Underground Cable (PLYSWS) Multi Core	11kV	CS1247	U18	19710101	0.148	$ 44,395	2.38	FY25-FY29	$29,572
50210793	CSHV00426926	784D48FB-BDC9-4600-8CE6-988786E1937A	11kV Cable (PLYSWS) Multi Core / 11kV Underground Cable (PLYSWS) Multi Core	11kV	S735	U17	19820101	0.128	$ 30,420	2.32	FY30-FY34	$25,620
50217416	CSHV00742535	DF850B3F-3FE6-487A-8AF9-CBA62E298B78	11kV Cable (PLYSWS) Multi Core / 11kV Underground Cable (PLYSWS) Multi Core	11kV	A048	U17	19780101	0.083	$ 21,597	2.29	FY30-FY34	$16,564
50400244	CSHV00565864	FEF817AC-0EA2-49F8-8C26-753795140F16	11kV Cable (Unknown) Unknown / 11kV Underground Cable (Unknown) Unknown	11kV	MVG2	U99	19770801	0.067	$ 22,749	2.25	FY25-FY29	$16,617
50274677	CSHV00799050	E689E4F7-AD1F-4755-9B93-42D45A8D9576	11kV Cable (PLYSWS) Multi Core / 11kV Underground Cable (PLYSWS) Multi Core	11kV	A048	U17	19790227	0.203	$ 49,697	2.24	FY30-FY34	$40,662
50221978	CSHV00109738	296208E5-971E-4CA2-B921-D2488D0E7D34	11kV Cable (PLYSWS) Multi Core / 11kV Underground Cable (PLYSWS) Multi Core	11kV	27454	U12	19750320	0.040	$ 10,220	2.20	FY30-FY34	$8,082
50157590	CSHV00791580	3AF2CC6F-47C1-4A8B-ABF1-684D67B5F675	11kV Cable (PLYSWS) Single Core / 11kV Underground Cable (PLYSWS) Single Core	11kV	WM1212	U45	19760331	0.001	$ 203	2.16	FY30-FY34	$177
50397928	CSHV00384942	7726E266-0384-41F8-9382-26592BB6D076	11kV Cable (Unknown) Unknown / 11kV Underground Cable (Unknown) Unknown	11kV	MVG2	U99	19820101	0.034	$ 8,494	1.97	FY30-FY34	$8,390
50204091	CSHV00574286	CBF3B966-A1FB-460E-8D9D-CA56E978AACF	11kV Cable (PLYSWS) Multi Core / 11kV Underground Cable (PLYSWS) Multi Core	11kV	S788	U12	19810902	0.078	$ 13,702	1.91	FY30-FY34	$15,658
50204095	CSHV00574289	432DA362-DC15-44DD-A0EE-51761F262C2C	11kV Cable (PLYSWS) Multi Core / 11kV Underground Cable (PLYSWS) Multi Core	11kV	S788	U12	19810101	0.049	$ 8,599	1.91	FY30-FY34	$9,850
50204092	CSHV00574287	52ED764D-B99A-476C-8DA7-72AA72AB3630	11kV Cable (PLYSWS) Multi Core / 11kV Underground Cable (PLYSWS) Multi Core	11kV	S788	U12	19810902	0.008	$ 1,347	1.89	FY30-FY34	$1,570
50215915	CSHV00738642	8A9E1351-E268-4683-9F76-7BFECE264A56	11kV Cable (PLYSWS) Multi Core / 11kV Underground Cable (PLYSWS) Multi Core	11kV	CX1206	U17	19650101	0.080	$ 15,324	1.83	FY25-FY29	$16,056
50429912	CSLV00170429	EE901663-67FA-4F83-8E8C-4083A6176C8A	LV Cable (RUBBER) Single Core / LV Underground Cable (RUBBER) Single Core	LV	SWE2	T41	19651201	0.032	$ 19,037	1.80	FY23-FY24	$23,944
50215914	CSHV00738641	D9DD8E69-1AB9-4D18-AD29-0A86D3A509F3	11kV Cable (PLYSWS) Multi Core / 11kV Underground Cable (PLYSWS) Multi Core	11kV	CX1206	U17	19730101	0.069	$ 8,016	1.46	FY30-FY34	$13,720
50304261	CSHV00087922	8652F7B5-9DA3-4872-A2C7-567DDAE2E58E	11kV Cable (PLYSWS) Multi Core / 11kV Underground Cable (PLYSWS) Multi Core	11kV	PK1236	U5	19620617	0.918	$ 169,607	1.45	FY25-FY29	$270,727
50305130	CSHV00088476	2D9CBAAB-B4CF-44BC-AD38-7C2C17E2596F	11kV Cable (PLYSWS) Multi Core / 11kV Underground Cable (PLYSWS) Multi Core	11kV	DP1236	U14	19700701	0.041	$ 13,742	1.30	FY30-FY34	$31,319
50426002	CSHV00167598	95096DF2-AA70-4CAA-82CA-6B0AF7E789AD	11kV Cable (Unknown) Unknown / 11kV Underground Cable (Unknown) Unknown	11kV	BWB2	U99	19531001	0.036	$ 7,569	1.09	FY30-FY34	$25,813
50246888	CSHV00461977	716792AE-3074-444E-81C8-E0E10288D853	11kV Cable (PLYSWS) Multi Core / 11kV Underground Cable (PLYSWS) Multi Core	11kV	PH1297	U18	19550526	0.058	$ 11,490	1.04	FY30-FY34	$39,463
50426001	CSHV00167597	50CF2CBA-DF3C-4E82-8F15-870E23BD4E91	11kV Cable (Unknown) Unknown / 11kV Underground Cable (Unknown) Unknown	11kV	BWB2	U99	19530101	0.014	$ 2,609	1.02	FY30-FY34	$10,497
50162849	CSHV00799703	1D792FD0-B120-42E3-A622-9CAE6E3328F7	11kV Cable (PLYSWS) Multi Core / 11kV Underground Cable (PLYSWS) Multi Core	11kV	WP1271	U25	19590101	0.072	$ 14,108	1.01	FY30-FY34	$48,998
50324142	CSHV00320772	11EAC99A-7BB3-44CD-8375-589793C2AA4E	11kV Cable (PLYSWS) Multi Core / 11kV Underground Cable (PLYSWS) Multi Core	11kV	PH1297	U17	19550526	0.031	$ 5,868	1.00	FY30-FY34	$21,488

Appendix B – Summary of key risk assessment variables and assumptions

General variables and assumptions

Parameter	Value	Description/justification	Source/assumptions
Population	395,097 linear assets (20,564 km)	Number of underground cable linear assets in service in Endeavour Energy's (EE) network	GIS database. GIS_FID = 126, reticulation = UG
Annual conditional failures - leading to capital replacement works (excl OPEX repairs)	56	Defective equipment as raised in Ellipse under standard job numbers for cable repair works.	Ellipse defect workorder records LA reactive expenditure v3.fmw FME workflow
Annual functional failures	146	A functional failure is considered to be an unassisted failure of the cable, causing reliability, and/or financial 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 for underground cables are excluded from the condition-based assessment as there is no material impact on the assessment outcome	Ellipse workorders
Planned intervention costs – replacement of underground cable	LV Rural: $200,000/km LV Urban: $752,000/km HV Al Urban: $685,000/km HV Cu Urban: $768,000/km HV Unkn Urban: $726,500/km HV Al Rural: $200,000/km HV Cu Rural: $295,000/km HV Unkn Rural: $247,500/km 33kV 630mm road: $1,561,300/km 33kV 630mm non-road: $1,149,300/km 33kV 1200mm road: $1,890,600/km 33kV 1200mm non-road: $1,478,600/km 33kV Unkn road: $1,725,950/km 33kV Unkn non-road: $1,313,950/km 66kV 630mm road: $1,705,900/km 66kV 630mm non-road: $1,293,900/km 132kV 630mm road: $1,924,900/km 132kV 630mm non-road: $1,512,900/km 132kV 1200mm road: $2,234,200/km 132kV 1200mm non-road: $1,822,200/km 132kV Unkn road: $2,079,550/km 132kV Unkn non-road: $1,667,550/km	Replacement of existing underground cables across urban and rural locations for distribution and within or outside road carriage ways for transmission. Note: All new cable types are assumed to be XLPE.	This estimate is based on design estimates including: - Project Management - Design - Materials - Labour and plant - Traffic management

Parameter	Value	Description/justification	Source/assumptions
Failure modes	Cable fault	The main failure mode for underground cables is a cable fault that leads to a phase to earth and/or phase to phase fault. There are several failure modes which can result in a cable fault as outlined in Section 3.2. Cable faults typically lead to a loss of supply and results in financial impacts due to the cost of repair.	OMS / ADMS data 2012 -2021 Ellipse
Asset age	Varies for each underground cable linear asset	Calendar age based on the in-service date compared to the year of assessment (2022) Where in-service date of the underground cable is not available, the in-service date is assigned the most common adjoined UGOH pole, DSUB or adjacent cables in-service date.	Ellipse nameplate data GIS Job place date SAP installation date Spatial analysis

Weibull failure probability parameters

Parameter	Value	Description/justification	Source/assumptions
α (Alpha)	- LV Cable (CONSAC) Multi Core - 43.4 - LV Cable (PLYSWS) Multi Core - 50.8 - LV Cable (PLYSWS) Single Core - 60 - LV Cable (PVC) Multi Core - 67.4 - LV Cable (PVC) Single Core - 69.1 - LV Cable (RUBBER) Single Core - 34.1 - LV Cable (XLPE) Multi Core - 57.6 - LV Cable (XLPE) Single Core - 44 - LV Cable (Unknown) Unknown - 123.9 - 11kV Cable (PAPER) Multi Core - 60 - 11kV Cable (PLYSWS) Multi Core - 57.9 - 11kV Cable (PLYSWS) Single Core - 60 - 11kV Cable (XLPE) Multi Core - 48 - 11kV Cable (XLPE) Single Core - 54.2 - 11kV Cable (PVC) Multi Core - 60 - 11kV Cable (Unknown) Unknown - 60 - 22kV Cable (XLPE) Multi Core - 42.9 - 33kV Cable (XLPE) Single Core - 67.7 - 33kV Cable (GAS) Multi Core - 60 - 33kV Cable (HSL) Multi Core - 60 - 33kV Cable (OIL) Multi Core - 60 - 33kV Cable (PAPER) Multi Core - 60 - 33kV Cable (PAPER) Single Core - 60 - 33kV Cable (Unknown) Unknown - 60 - 66kV Cable (XLPE) Single Core - 60 - 132kV Cable (XLPE) Single Core - 68.4 - 132kV Cable (OIL) Single Core - 90 - 132kV Cable (Unknown) Unknown - 60 - LV Cable (Generic) - 61.6 - 11kV Cable (Generic) - 51.6 - 22kV Cable (Generic) - 42.9 - 33kV Cable (Generic) - 72.6 - 66kV Cable (Generic) - 78.1 - 132kV Cable (Generic) - 107.6	The "scale" parameter used for calculating probability of failure. Note: XLPE distribution PoF parameters require additional assessment during future analysis and have been excluded from this CFI.	Estimated to correlate predicted quantity of annual unassisted functional failures with the actual recorded quantity of annual failure rates being experienced.
β (Beta)	- LV Cable (CONSAC) Multi Core - 3.6 - LV Cable (PLYSWS) Multi Core - 3.6 - LV Cable (PLYSWS) Single Core - 3.6 - LV Cable (PVC) Multi Core - 3.6 - LV Cable (PVC) Single Core - 3.6 - LV Cable (RUBBER) Single Core - 3.6 - LV Cable (XLPE) Multi Core - 3.6 - LV Cable (XLPE) Single Core - 3.6	The "shape" parameter used for calculating probability of failure function. Note: XLPE distribution PoF parameters require additional assessment during future analysis and have been excluded from this CFI.	The generalised wear-out function shape for a normal distribution is 3.6. Weibull Curve generator_5.xlsm

Parameter	Value	Description/justification	Source/assumptions
	- LV Cable (Unknown) Unknown - 3.6 - 11kV Cable (PAPER) Multi Core - 3.6 - 11kV Cable (PLYSWS) Multi Core - 3.6 - 11kV Cable (PLYSWS) Single Core - 3.6 - 11kV Cable (XLPE) Multi Core - 3.6 - 11kV Cable (XLPE) Single Core - 3.6 - 11kV Cable (PVC) Multi Core - 3.6 - 11kV Cable (Unknown) Unknown - 3.6 - 22kV Cable (XLPE) Multi Core - 3.6 - 33kV Cable (XLPE) Single Core - 3.6 - 33kV Cable (GAS) Multi Core - 3.6 - 33kV Cable (HSL) Multi Core - 3.6 - 33kV Cable (OIL) Multi Core - 3.6 - 33kV Cable (PAPER) Multi Core - 3.6 - 33kV Cable (PAPER) Single Core - 3.6 - 33kV Cable (Unknown) Unknown - 3.6 - 66kV Cable (XLPE) Single Core - 3.6 - 132kV Cable (XLPE) Single Core - 3.6 - 132kV Cable (OIL) Single Core – 6.5 - 132kV Cable (Unknown) Unknown - 3.6 - LV Cable (Generic) - 3.6 - 11kV Cable (Generic) - 3.6 - 22kV Cable (Generic) - 3.6 - 33kV Cable (Generic) - 3.6 - 66kV Cable (Generic) - 3.6 - 132kV Cable (Generic) - 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
N/a			

Financial risk inputs

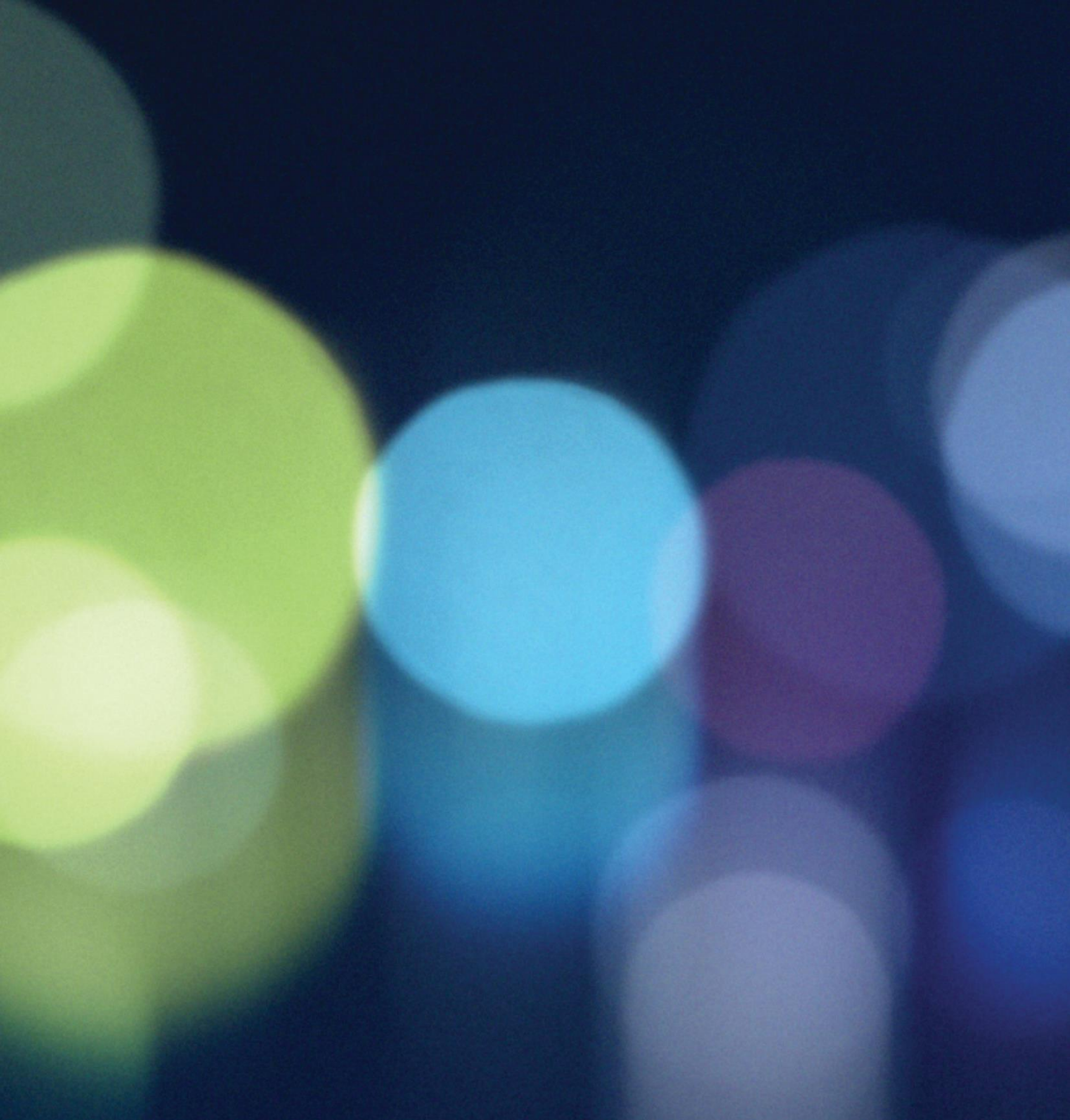
Parameter	Value	Description/justification	Source/assumptions
Financial CoC (repair cost)	- LV Urban - $12,047 - LV Rural - $9,727 - 11kV & 22kV Urban - $19,370 - 11kV & 22kV Rural - $17,047 - 33kV & 66kV Road - $77,861 - 33kV & 66kV Non-Road - $25,343 - 132kV Road - $211,990 - 132kV Non-Road - $43,652 - 132kV Oil Filled Cable - $601,650	Cable fault repair of existing underground cables across urban and rural locations for distribution and within or outside road carriage ways for transmission.	Low voltage and distribution cable fault repair costs provided from mains design team based on design estimates and subject matter expert previous repair costs. Transmission cable fault repair costs based on past actuals from Ellipse workorders. Oil filled cable fault repair costs based on contractor quotation.

Bushfire 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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