Attachment 5.11

Quantitative risk evaluation - selected replacement projects

January 2015

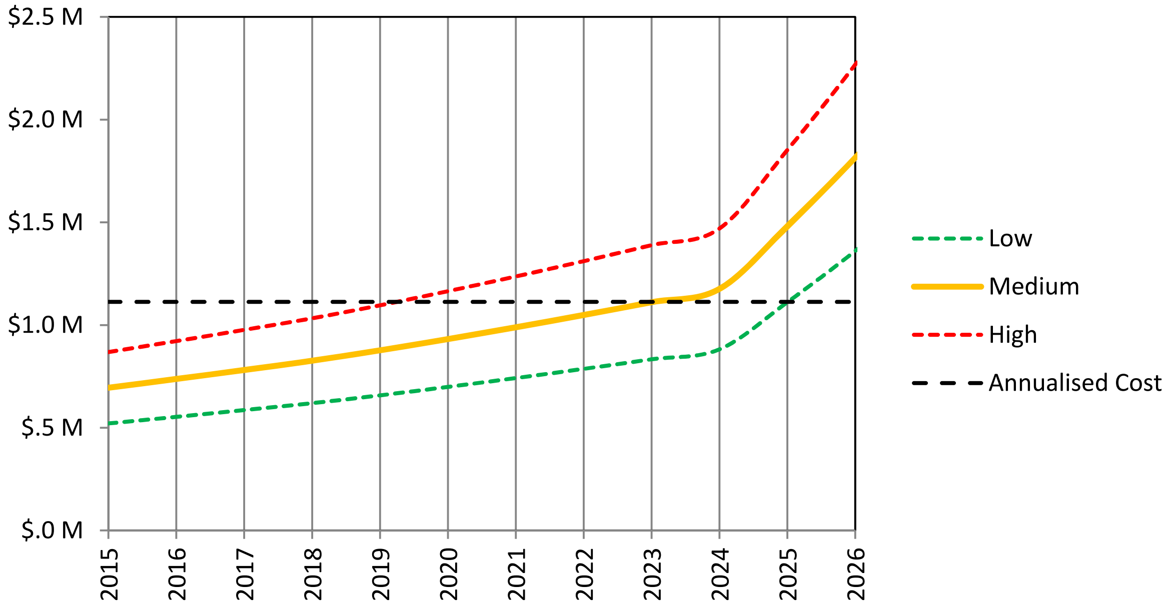
Ausgrid revised regulatory proposal attachment

Executive Summary

Ausgrid has undertaken a quantitative risk evaluation of selected replacement projects in order to identify areas where it may be possible to defer replacement costs. Projects selected for evaluation were major replacement projects that had significant proposed expenditure in the 2015-19 regulatory control period. These projects lend themselves to quantitative risk evaluation because each project addresses unique risks and Ausgrid has good data availability to support the evaluation of larger, more valuable assets.

The quantitative risk evaluation methodology determines the risk cost associated with the failure of assets that are approaching end-of-life, and compares it to the annualised cost of replacing those assets. The risk cost is determined by simulating failures of those assets, using failure rates and consequences that are based on historical failures for that asset type. Based on this approach, the optimal time to replace the asset is before the risk cost exceeds the annualised replacement cost.

An example of the results of this analysis is provided in the figure below. In this example, the optimal time for replacement lies between 2019 and 2025.



Results of quantitative risk evaluation for switchboards at Blakehurst zone substation

Of the thirty projects evaluated using this methodology, six projects were identified where there was a potential to defer the replacement of these assets.

Contents

1 Introduction

Ausgrid has undertaken a quantitative risk evaluation of selected replacement projects in order to refine its capex proposal for the 2015 – 19 regulatory control period. The objectives of this study are to determine the economic timing of selected replacement projects proposed to commence within the 2015 – 2019 regulatory control period and to identify areas where potential exists to defer the replacement of assets. Ausgrid has recently developed a methodology based on the following:

- Quantified risk consequence assessment consistent with Ausgrid's board approved risk management policy
- Quantified calculation of failure likelihood utilising actual failure data
- Recent estimates of the Value of Customer Reliability (VCR)
- Monte Carlo simulation to calculate probabilistic network risks
- Analysis of recent failures that resulted in a range of failure scenarios

The projects that have been selected for evaluation using this methodology are major projects designed to eliminate significant risks. These projects lend themselves to quantitative risk evaluation because each project addresses unique risks and Ausgrid has good data availability to support the evaluation for larger, more valuable assets. The projects considered fall into two broad categories – 11kV switchgear/switchboards, and subtransmisison cables. In some cases we have also assessed the combined risk where a project addresses multiple replacement needs.

Asset replacement projects are generally implemented to eliminate the risk of failure as the asset wears out. The risk of asset failure typically increases as the asset approaches it's end of life, as shown in the wear out stage of the curve shown in Figure 1 (commonly called the 'bathtub' or 'basin' asset life curve). Ausgrid's failure data has revealed that there is a good correlation between asset age and condition for 11kV switchgear, switchboards and subtransmisison cables.

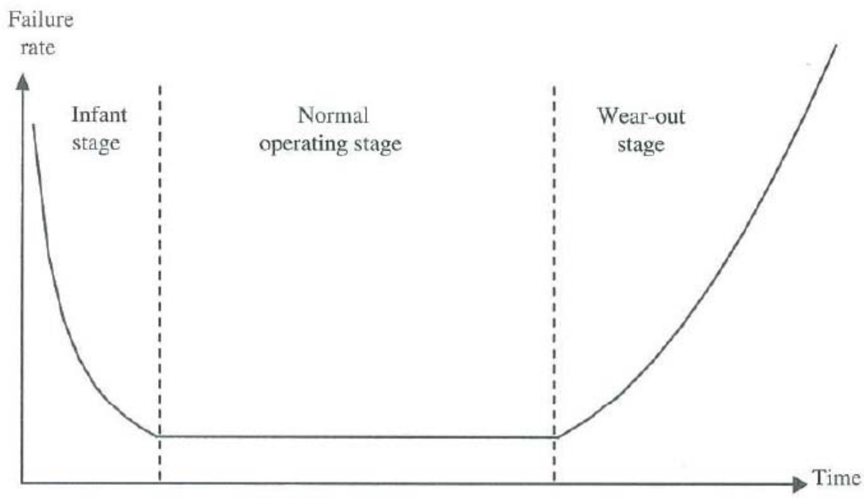


Figure 1: Basin curve of an asset's life[1]

The methodology is underpinned by the evaluation of "monetised baseline risk". This evaluation combines consequence assessments with calculated failure likelihoods to represent a quantified risk cost associated with not replacing an aged asset for a given year. The monetised baseline risk generally increases each year as the likelihood of failure increases with asset age. The economic timing is determined to be the year before the monetised baseline risk exceeds the annualised project cost. Sensitivity analysis is carried out in order to determine a range for the appropriate economic timing.

As a result of the quantitative risk evaluation, six projects have been identified for deferral.

The methodology is discussed in Section 2, projects evaluated are listed in Section 3 and the results are presented in Section 4.

[1] ***Wenyuan Li,*** *Risk Assessment of Power Systems, Wiley and Sons, Vancouver, 2014 (pg 18)*

2 Methodology

The steps followed in the quantitative risk evaluation methodology are illustrated by Figure 2. Each step is described in detail in the following sections.

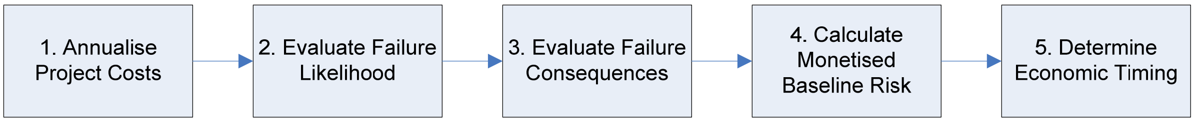


Figure 2: Quantitative risk evaluation methodology

2.1 Project Costs

In order to effectively compare project costs and benefits, the cost of each project is converted to an annualised cost that represents the cost per year of owning and operating an asset over its entire lifespan. The discount rate (*r*), asset lifespan (*n*) and initial project cost (*$Y*) are provided as inputs to the equation below to determine annualised cost ($\$A_n$)[2]. $Y is based on the least cost option that satisfactorily eliminates the risk associated with aged asset failures.

$$\$A_n = \frac{r}{1 - e^{-rn}} \$Y$$

2.2 Failure Likelihood

The failure likelihood is defined as the probability of an asset failing within a twelve month period and is denoted as P_f. The method for evaluating P_f differs for non-repairable and repairable failure, and is outlined in Sections 2.2.1 and 2.2.2 respectively.

If a failure has a number of failure scenarios, P_f is weighted for each failure scenario by a weighting factor denoted as *α*. e.g. an 11kV circuit breaker has two failure scenarios, an isolated failure, or a propagating explosive failure. Failure scenario weighting factors are assigned by considering historical failures for that asset type. (refer to Figure 5).

2.2.1 Non-repairable Failure

For the purposes of this analysis, failures of circuit breakers and switchboards are assumed to be non-repairable since typically the asset is no longer functional following a failure (and hence is replaced or removed from service). The following method is used to determine failure likelihood in the quantitative risk evaluation for 11kV circuit breakers and switchboards. This method utilises Weibull analysis to derive a probability distribution function for the asset's age at time of failure[3]. This function is denoted as *f(t)*, where *t* is expressed in years. The time to failure for the assets is set to the point of conditional failure (i.e. where the asset first shows signs of wearing out). In the case of switchgear, this is when insulation test results have exceeded a defined limitation. Assets that have not been identified as conditional failures are treated as suspended counts (i.e. they are included in the analysis and act to reduce the calculated P_f).

This data is used to develop the Weibull parameters using the Isograph Availability Workbench™ software. The parameters are estimated using the least squares method of parameter estimation. The process is carried out for both 11kV circuit breakers and 11kV switchboards. The resultant Weibull parameters are given in Table 1.

Table 1: Weibull parameters

Asset	Shape	Scale
11kV Circuit Breakers	8.098	64.58
11kV Switchboards	4.189	62.51

A typical probability distribution function *f(t)* is shown below in Figure 3 (shape = 8, scale = 65).

[2] *Monies are* expressed in 2014-15 real dollars

[3] The methodology for deriving *f(t)* is set out in Ausgrid's Maintenance Requirements Analysis Manual (MRAM) ASM-STG-10005

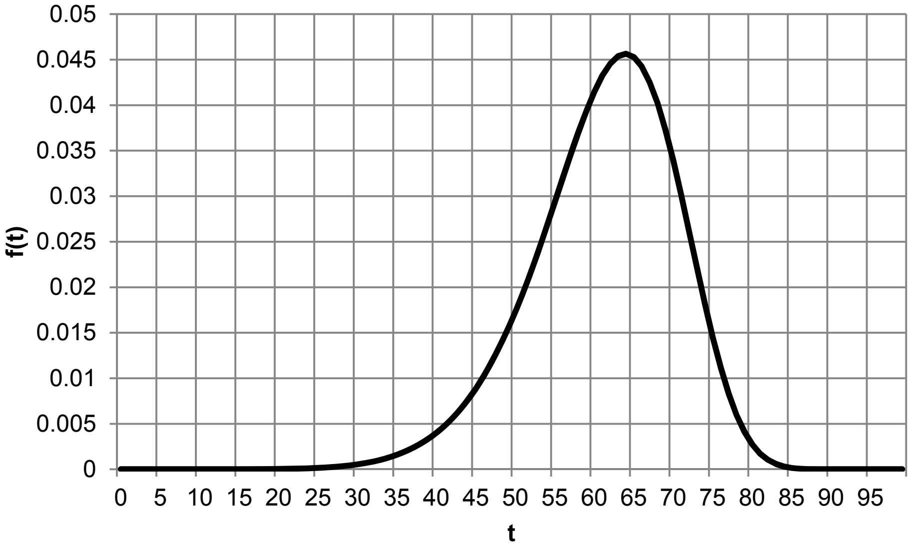


Figure 3: Probability distribution function for the asset's age at time of failure

The probability distribution function represents the failure intensity for an age *t*. The concept of conditional probability is applied to evaluate the likelihood of failure. The probability of a non-repairable failure of an asset occurring within the next year after having survived for *t* years is be calculated by the following equation[4]:

$$P_f = \frac{\int_t^{t+1} f(t)dt}{\int_t^{\infty} f(t)dt}$$

Figure 4 shows P_f when the above equation is applied to the probability distribution function *f(t)* shown in Figure 3. P_f is used in the evaluation of monetised baseline risk.

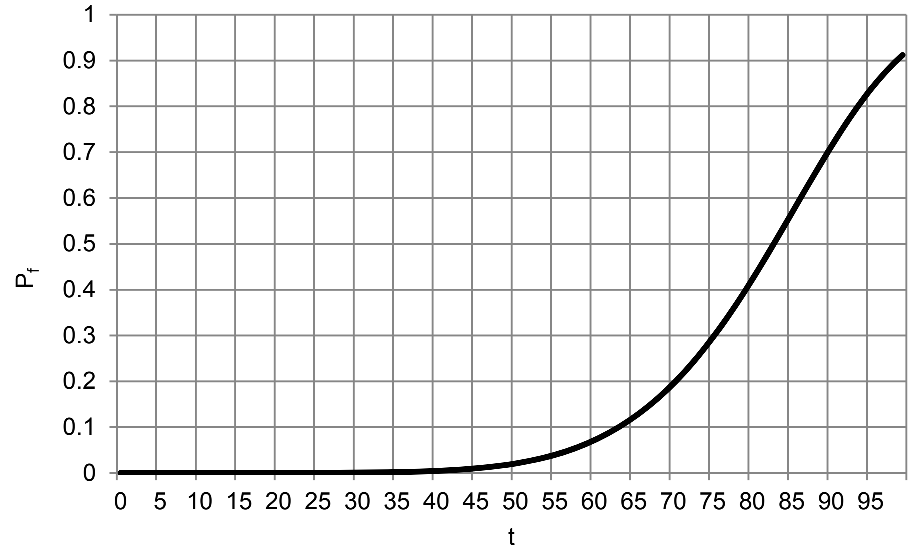


Figure 4: Probability of a non-repairable failure between age t and t+1, after surviving t years

2.2.2 Repairable Failures

Failures of underground cables are assumed to be repairable because failed portions of the cable can typically be repaired and returned to service. The Crow-AMSAA model is used to determine failure likelihood in the quantitative risk evaluation for 33kV and 132kV cables. The failure likelihood was evaluated for the following cable types:

- Self-Contained Fluid Filled (SCFF) or oil filled cable
- Gas Pressure cable

[4] ***Wenyuan Li,*** *Risk Assessment of Power Systems, Wiley and Sons, Vancouver, 2014 (pg 20)*

- Solid / HSL cable, and
- XLPE cable.

The Crow-AMSAA model can be used to evaluate failure likelihood for repairable systems. As a result it can be used to model a cable segment (of particular type, e.g. Oil) that has failed and has been repaired multiple times over its lifetime. The Crow-AMSAA model is also capable of handling a mixture of failure modes.

An analysis is undertaken of failure data of each cable type (i.e. Oil, Gas, HSL and XLPE) to ascertain the age of the cable type at failure. A log-log plot of cumulative failures (per km) versus cumulative time (i.e. age in years) is produced and a line of best fit determined. The resulting log-log plot is linear and the line of best fit can be described by the following equation:

$$n(t) = \lambda t^{\eta}$$

where:

n(t) is the cumulative number of failures (per km).

t is the cumulative time (i.e. age of the cable at failure, in years).

η is a measure of the failure rate.

λ is a scale a parameter.

Table 2 shows the modelled Cow-AMSAA parameters for each cable type.

Table 2: Crow-AMSAA parameters for subtransmission cables

Asset	**λ**	**η**
Gas Pressure Cable	0.0059	1.2950
SCFF Cable	0.0015	1.5605
Solid / HSL Cable	0.0059	1.2814
XLPE Cable	0.0075	1.0000

Assuming the failure intensity can be approximated by the Weibull failure rate function over a given test interval ([0, t]) the probability of failure within a one year period for each cable type is given by the following equation:

$$P_f = \lambda \eta t^{\eta-1}$$

The probability of failure is then be determined by using the above formula and incrementing the age (i.e. 't') of the cable and multiplying by the length of that cable type in the feeder circuit.

2.3 Failure Consequence

Failure consequences are categorised in accordance with Ausgrid's Risk Management Board Policy (GV0000-Y0014). Consequences that relate to safety, network, finance, compliance, reputation and environment are evaluated.

Safety, compliance, reputation and environment consequences are evaluated using the consequence assessment table provided below (GV0000-Y0014). The cost for insignificant, minor, moderate, major and severe consequences are calculated by taking the geometric mean of the financial consequence range. A conditional probability factor (denoted as *β*) is applied to the consequence cost to arrive at a probability weighted consequence cost. The conditional probability factor accounts for the fact that only a portion of failures will result in the assessed consequence.

Table 3: Consequence assessment table

	Insignificant	**Minor**	**Moderate**	**Major**	**Severe**
Safety	Low level injury/symptoms requiring first aid only	Non-permanent injuries/work related illnesses requiring medical treatment	Significant non-permanent injuries/ work related illnesses requiring emergency surgery or hospitalisation for more than 7 days	Permanent injuries/ work related illnesses to one or more persons	One or more fatalities Significant permanent injuries/ work related illnesses to one or more persons
Compliance	Indication of interest from Regulator No fines incurred but administration costs may be payable No litigation	Warning/ notifications from Regulator Minor financial penalties Short term duration litigation	Medium financial penalties Medium duration litigation	High financial penalties Lengthy litigation	Significant financial penalties Potential jail term for individuals Extensive litigation Loss of Operational Licence
Reputation	Public concern restricted to local complaints or intra-industry knowledge / awareness	Attention from media and or heightened concern from local community / external stakeholders Criticism from multiple sources for one or two days	Adverse state media/public/stakeholders attention sustained over 1-2 weeks	Significant adverse national media/public/stakeholders attention sustained over 1-2 weeks Loss of confidence by State government minister Directive to amend practice received from regulators	Significant adverse national media/public/stakeholders outcry Sufficient outcry to cause irreparable damage to brand Ministerial enquiry / Royal Commission
Environment	Limited localised damage to minimal area of low significance	Minor impact on biological or physical environment or heritage item over a limited area Little or no need for remediation	Moderate damage over a large area or affecting ecosystem, or heritage item Moderate remediation is required	Serious widespread, long term damage to ecosystem or heritage item Significant rectification is required	Very serious long term, wide spread impairment of ecosystem or heritage item
Financial	\$100k – 500k	\$500k – 10M	\$10M – 50M	\$50M – 100M	\$100M – 500M
Consequence Cost	\$224k	\$2.24M	\$22.4M	\$70.7M	\$223M

Financial consequences are evaluated by considering actual or estimated repair and replacement costs for each failure scenario. A conditional probability is also applied to the financial consequence to account for the fact that some failures may only require repair to part of the asset (rather than its complete replacement).

Network consequences are evaluated by estimating the Value of Customer Reliability (VCR) and unserved energy for each scenario. VCR estimates are based on AEMO's "Value of Customer Reliability Review Final Report, September 2014". To derive VCRs for each zone substation, the aggregate residential and business VCRs are weighted by the percentage energy consumption within each category. The network consequence cost is calculated by taking the product of unserved energy and VCR. No conditional probability factor is applied to network consequences because these consequences are realised for all failures. The calculation of unserved energy associated with failure of aged assets is discussed in Appendix A. Note that if an outage time exceeds 2 weeks, a mobile generation cost of \$19.6/kWh is used in place of VCR.

2.4 Monetised Baseline Risk

The monetised baseline risk (*\$R*) for each asset is calculated with the below equation. The calculation is further illustrated in Figure 5. The monetised baseline risk is calculated for each year in the forecast period.

$$\$R = P_f\left(\alpha_1 \sum_{i=1}^{n} \beta_{1i} \,.\, \$C_i + \alpha_2 \sum_{j=1}^{n} \beta_{2j} \,.\, \$C_j\right)$$

The monetised baseline risk may consist of summated risks for multiple assets. E.g. a zone substation may contain ten aged 11kV circuit breakers and two aged 11kV switchboards.

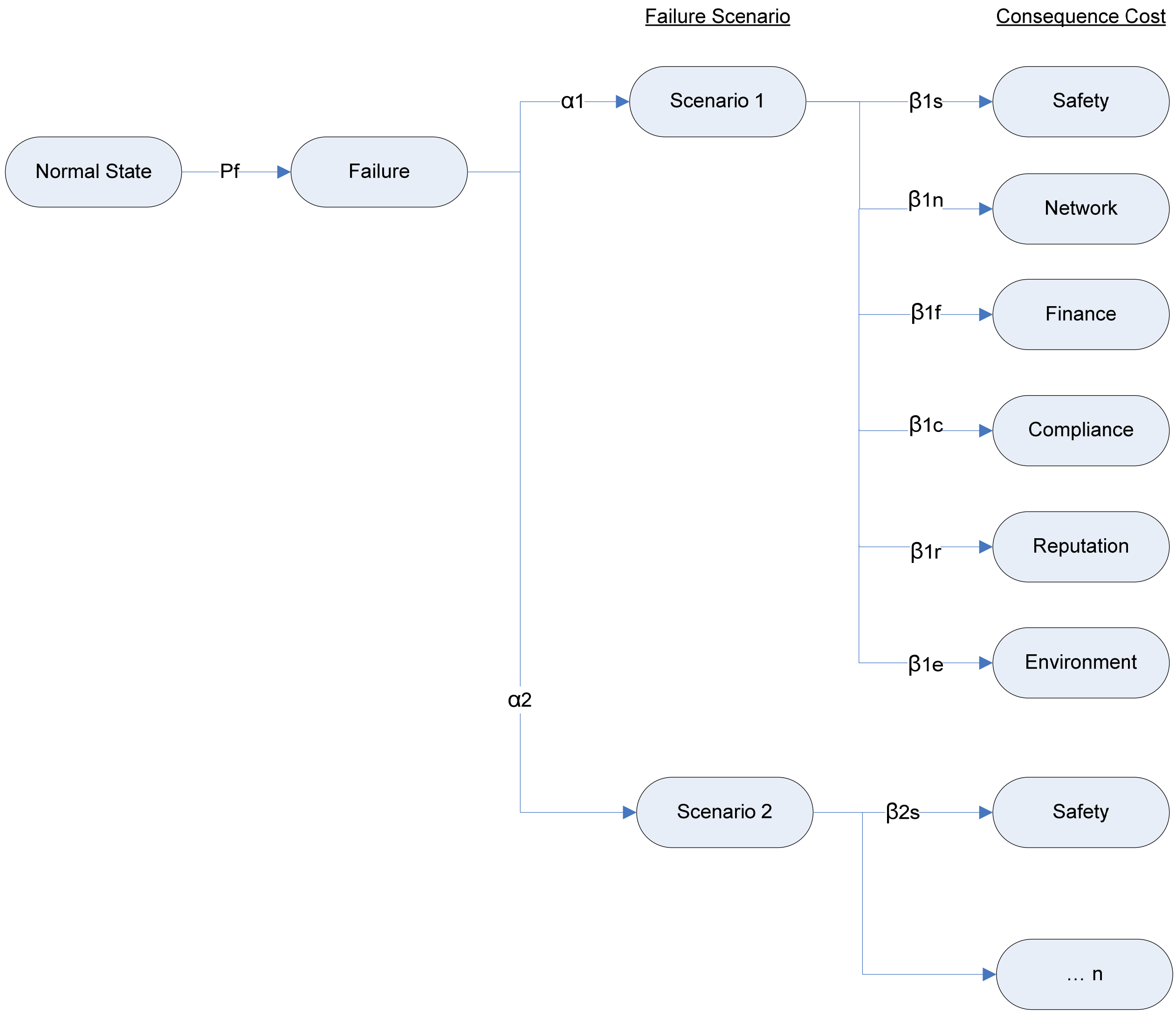


Figure 5: Calculation of monetised risk

2.5 Economic Timing

The annualised project cost is compared to the total monetised baseline risk in order to determine an early, preferred and late economic project timing. The preferred timing is determined by selecting the year before $\$A_n$ exceeds the total monetised baseline risk. The early timing is determined by selecting the year before $\$A_n$ exceeds 125% of the total monetised baseline risk. The late timing is determined by selecting the year before $\$A_n$ exceeds 75% of the total monetised baseline risk. The selection of economic timing is illustrated in Figure 6.

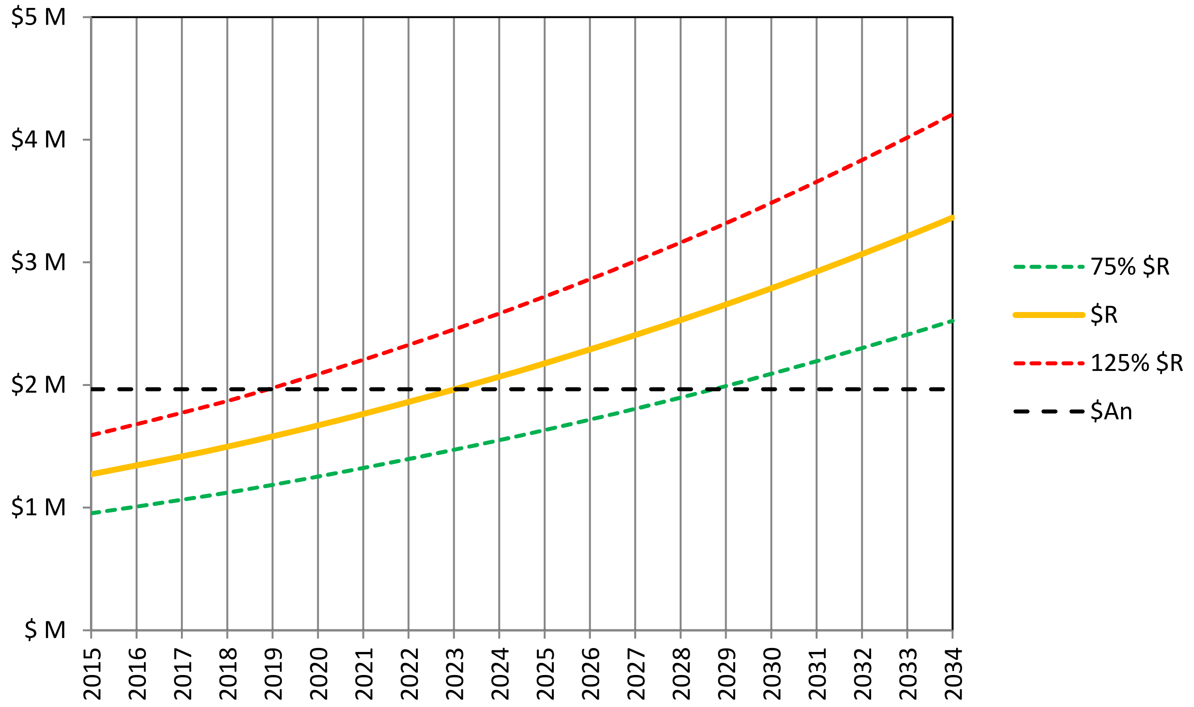


Figure 6: Selection of economic timing

3 Selected Projects

Projects selected for quantitative risk evaluation had significant proposed expenditure in the 2015-19 regulatory control period. Projects that have obtained board approval were excluded.

3.1 11kV Switchboards

Ausgrid has proposed a number of projects designed to eliminate the risk associated with aged 11kV switchboards and their associated circuit breakers. The projects selected for evaluation are listed in Table 4. The switchboards include both compound and air insulated boards.

Table 4: Selected 11kV switchboard projects

Zone Substation	Board insulation	Make	Expenditure ($k)	Planned completion date	Associated Project
Enfield	Compound	Westinghouse HQ	27,487	Jun-17	ARA_04.3A.0007
Matraville	Compound	Westinghouse HQ	23,326	Dec-18	ARA_03.1B.0016
Dulwich Hill	Compound	Westinghouse HQ	21,866	Dec-17	ARA_04.3A.0019
Lidcombe	Compound	Westinghouse HQ	21,311	Sep-18	ARA_04.4.C.0009
Surry Hills	Compound	Reyrolle 2C6T / 2B5T	18,004	Dec-15	ARA_03.1C.0004
Leightonfield	Compound	Email HQ	17,955	Dec-19	ARA_04.3A.0005
Punchbowl	Compound	Westinghouse HQ	17,525	Dec-18	ARA_04.3B.0011
Arncliffe	Compound	Westinghouse HQ	14,587	Dec-18	ARA_04.1.0010
Botany	Compound	Westinghouse HQ	12,715	Dec-18	ARA_03.1B.0003
Nelson Bay	Air	OLX2	12,272	Mar-17	ARA_01.0025
Denman	Air	South Wales	10,077	Jun-19	ARA_08.2.0012
Mitchel Line	Air	OLX3	9,948	Jun-18	ARA_08.2.0038A
Edgeworth	Air	OLX2	9,868	Nov-17	ARA_07.3.0013A
Terrey Hills	Air	OLX3	8,892	Sep-17	ARA_05.4.0035A
Lisarow	Air	OLX3	8,892	Oct-16	ARA_06.1.0006
Mascot	Compound	Westinghouse HQ	8,049	Dec-20	ARA_03.1B.0020
Mona Vale	Air	OLX	7,864	Sep-16	ARA_05.4.0034A
Branxton	Air	OLX1	7,569	Nov-15	ARA_08.1.0012
Singleton	Air	Email S15	7,378	Jul-16	ARA_08.1.0014
Umina	Air	OLX3	1,453	Sep-16	ARA_06.1.0031A
Clovelly	Air	Email A	930	Dec-17	ARA_03.1C.0014
Stockton	Compound	Westinghouse HQ	143	Jun-21	ARA_07.8.0013
Greenacre Park	Compound	Email HQ	27,968	Dec-17	ARA_04.3A.0014
Blakehurst	Compound	Westinghouse HQ	15,564	Dec-19	ARA_04.1.0007
Blackwattle Bay	Compound	Westinghouse HQ	9,551	Dec-18	ARA_04.5.0005

3.2 Subtransmission Cables

Ausgrid has proposed a number of projects designed to eliminate the risk associated with aged subtransmission cables. The projects selected for evaluation are listed in Table 5. The cables include HSL, gas and SCFF.

Table 5: Selected subtransmission cable projects

Description	Cable Type	Expenditure ($k)	Planned completion date	Associated Project
Auburn & Lidcombe Zn 33kV Feeder Replacement	HSL/Gas	31,478	Jun-17	ARA_04.4.C.0008
Dulwich Hill 33kV Feeder Replacement	Gas	29,346	Dec-17	ARA_04.3A.0021
Graving Dock 33kV Feeder Replacement	HSL/Gas	4,906	Dec-17	ARA_03.1A.0020
Mascot 33kV Feeders Replacement (Alexandria - Mascot)	HSL	14,176	Dec-18	ARA_03.1B.0017
Paddington 33kV Feeders Replacement	Gas	9,555	Dec-17	ARA_03.1A.0017
132kV Feeders 92FA/B and 90XA/B Replacement	SCFF	32,965	Sep-16	ARA_01.1.0024
132kV Feeders 92JA/B and 92GA/B Replacement	SCFF	27,563	Sep-19	ARA_01.1.0027
Darlinghurst 33kV Feeders	Gas	6,257	Dec-18	ARA_03.1A.0005
Sydney Airport 33kV Feeder Replacement (Alexandria STS)	HSL	22,659	Dec-18	ARA_03.1B.0029A
132kV Feeders 260/2 & 261/2 Replacement (Clovelly-Kingsford)	SCFF	20,939	Dec-18	ARA_03.1C.0022
Strathfield South 132kV connections	Gas	4,719	Jun-17	ARA_04.3A.0001
Kotara ZS refurbishment and 33kV Feeder 767 replacement	SCFF	7,193	Dec-18	ARA_07.1.0016
33kV Feeder 760 & 766 Replacement	SCFF	6,613	Dec-16/Jun-15	ARA_07.5.0001

3.3 Combined Projects

Ausgrid has proposed a number of projects that offer an integrated solution to multiple aged asset issues. The monetised baseline risk is summated and compared to the total cost of the integrated solution in order to determine the economic timing. These projects are listed in Table 6.

Table 6: Combined projects

Description	Expenditure ($k)	Planned completion date	Associated Project
Strathfield South 132/11kV ZS and decomm Enfield 33/11kV ZS	27,487	Jun-17	ARA_04.3A.0007
Strathfield South 132kV connections	4,719	Jun-17	ARA_04.3A.0001
Combined feeder + Switchgear (Enfield) - Strathfield South zone	32,206	Jun-17	
Dulwich Hill 33kV Zone + Decom	21,866	Dec-17	ARA_04.3A.0019
Dulwich Hill 33kV Feeder Replacement	29,346	Dec-17	ARA_04.3A.0021
Combined feeder + Switchgear (Dulwich Hill - New Dulwich Hill zone	51,212	Dec-17	
New Alexandria STS (SJ-00091, SJ-00172, SJ-00175)	37,554		ARA_03.1A.0028A
Mascot 33kV Feeders Replacement (Alexandria - Mascot)	14,176	Dec-18	ARA_03.1B.0017
Sydney Airport 33kV Feeder Replacement (Alexandria STS)	22,659	Dec-18	ARA_03.1B.0029A
Combined	74,389		
Lidcombe Zn Refurbishment	21,311	Sep-18	ARA_04.4.C.0009
Auburn & Lidcombe Zn 33kV Feeder Replacement	31,478	Jun-17	ARA_04.4.C.0008
Combined	52,789		

4 Results

The resultant economic timing for the selected projects is provided in this section. The project specific assumptions are provided contained within each individual project model and can be provided if required.

4.1 11kV Switchboards

The results of the quantitative risk evaluation have indicated that the majority of Ausgrid's proposed 11kV switchboard projects offer immediate benefits that exceed annualised project costs in the first year of the forecast period. It is recommended that the projects with a late economic timing of 2015 are implemented as soon as possible. This is reflective of the fact that many of these assets have exceeded their standard life and have reached the wear-out stage. The Nelson Bay, Terrey Hills and Blakehurst results indicated that the associated projects could be deferred due to a low monetised baseline risk. Nelson Bay and Terrey Hills zone substations both contain air insulated 11kV switchboards with good transfer capacity to adjacent zone substations and a lower likelihood of failure when compared to other switchboards. The aged 11kV circuit breakers at Blakehurst have already been replaced by modern vacuum circuit breakers, resulting in a lower monetised baseline risk. The 11kV switchboard assumptions and detailed results are provided in Appendix B1.

Table 7: 11kV switchboard results

Zone Substation	Expenditure ($k)	Planned completion date	Associated Project	Early	Preferred	Late
Matraville	23,326	Dec-18	ARA_03.1B.0016	2015	2015	2015
Surry Hills	18,004	Dec-15	ARA_03.1C.0004	2015	2015	2015
Leightonfield	17,955	Dec-19	ARA_04.3A.0005	2015	2015	2015
Punchbowl	17,525	Dec-18	ARA_04.3B.0011	2015	2015	2015
Arncliffe	14,587	Dec-18	ARA_04.1.0010	2015	2015	2015
Botany	12,715	Dec-18	ARA_03.1B.0003	2015	2015	2015
Nelson Bay	12,272	Mar-17	ARA_01.0025	2024	2024	2024
Denman	10,077	Jun-19	ARA_08.2.0012	2015	2015	2015
Mitchel Line	9,948	Jun-18	ARA_08.2.0038A	2015	2015	2017
Edgeworth	9,868	Nov-17	ARA_07.3.0013A	2015	2015	2015
Terrey Hills	8,892	Sep-17	ARA_05.4.0035A	2029	2031	2034
Lisarow	8,892	Oct-16	ARA_06.1.0006	2030	2033	2034
Mascot	8,049	Dec-20	ARA_03.1B.0020	2015	2015	2015
Mona Vale	7,864	Sep-16	ARA_05.4.0034A	2015	2015	2015
Branxton	7,569	Nov-15	ARA_08.1.0012	2015	2015	2015
Singleton	7,378	Jul-16	ARA_08.1.0014	2015	2015	2015
Umina	1,453	Sep-16	ARA_06.1.0031A	2015	2015	2015
Clovelly	930	Dec-17	ARA_03.1C.0014	2015	2015	2015
Stockton	143	Jun-21	ARA_07.8.0013	2015	2015	2015
Greenacre Park	27,968	Dec-17	ARA_04.3A.0014	2015	2015	2015
Blakehurst	15,564	Dec-19	ARA_04.1.0007	2019	2023	2025
Blackwattle Bay	9,551	Dec-18	ARA_04.5.0005	2015	2015	2015

4.2 Subtransmission Cables

In general, the failure likelihood for repairable failures does not increase as quickly as non-repairable failures. Therefore, the range of economic timings is generally wider for repairable aged assets. The results indicate that the Paddington and Darlinghurst 33kV feeder replacement projects could potentially be deferred. Paddington and Darlinghurst zone substations are supplied by 3 and 4 feeders respectively, thus resulting in a low likelihood of unserved energy and hence a low network consequence cost. Similarly, the 260/2 and 261/2 132kV feeder replacement project could also potentially be deferred because Clovelly can be supplied via feeder 262 in the event of a coincident failure of feeders 260/2 and 261/2. The subtransmission cable assumptions and detailed results are provided in Appendix B2.

Table 8: Subtransmission cable results

Description	Expenditure ($k)	Planned completion date	Associated Project	Early	Preferred	Late
Graving Dock 33kV Feeder Replacement	4,906	Dec-17	ARA_03.1A.0020	2015	2023	2034
Paddington 33kV Feeders Replacement	9,555	Dec-17	ARA_03.1A.0017	2034	2034	2034
132kV Feeders 92FA/B and 90XA/B Replacement	32,965	Sep-16	ARA_01.1.0024	2017	2027	2034
132kV Feeders 92JA/B and 92GA/B Replacement	27,563	Sep-19	ARA_01.1.0027	2017	2027	2034
Darlinghurst 33kV Feeders	6,257	Dec-18	ARA_03.1A.0005	2034	2034	2034
132kV Feeders 260/2 & 261/2 Replacement (Clovelly-Kingsford)	20,939	Dec-18	ARA_03.1C.0022	2034	2034	2034
Kotara ZS refurbishment and 33kV Feeder 767 replacement	7,193	Dec-18	ARA_07.1.0016	2015	2015	2028
33kV Feeder 760 & 766 Replacement	6,613	Dec-16/Jun-15	ARA_07.5.0001	2015	2015	2015

4.3 Combined Projects

The results of the quantitative risk evaluation indicate that all projects listed below should proceed as planned within the 2015 – 19 period. The combined project assumptions and detailed results are provided in Appendix B3.

Table 9: Combined projects results

Description	Expenditure ($k)	Planned completion date	Associated Project
Strathfield South 132/11kV ZS and decomm Enfield 33/11kV ZS	27,487	Jun-17	ARA_04.3A.0007
Strathfield South 132kV connections	4,719	Jun-17	ARA_04.3A.0001
Combined feeder + Switchgear (Enfield) - Strathfield South zone	32,206	Jun-17	
	Early	**Preferred**	**Late**
	2015	2018	2025

Dulwich Hill 33kV Zone + Decom	21,866	Dec-17	ARA_04.3A.0019
Dulwich Hill 33kV Feeder Replacement	29,346	Dec-17	ARA_04.3A.0021
Combined feeder + Switchgear (Dulwich Hill - New Dulwich Hill zone	51,212	Dec-17	
	Early	**Preferred**	**Late**
	2015	2017	2022

New Alexandria STS (SJ-00091, SJ-00172, SJ-00175)	37,554		ARA_03.1A.0028A
Mascot 33kV Feeders Replacement (Alexandria - Mascot)	14,176	Dec-18	ARA_03.1B.0017
Sydney Airport 33kV Feeder Replacement (Alexandria STS)	22,659	Dec-18	ARA_03.1B.0029A
Combined	74,389		
	Early	**Preferred**	**Late**
	2015	2019	2023

Lidcombe Zn Refurbishment	21,311	Sep-18	ARA_04.4.C.0009
Auburn & Lidcombe Zn 33kV Feeder Replacement	31,478	Jun-17	ARA_04.4.C.0008
Combined	52,789		
	Early	**Preferred**	**Late**
	2015	2015	2015

Appendix A: Unserved Energy Modelling

In this study, the unserved energy is calculated by applying a range of Monte Carlo models. Monte Carlo methods are a broad class of computational algorithms that rely on repeated random sampling to obtain numerical results. Typically in Monte Carlo analysis, simulations are run many times over in order to obtain the probability distribution of outputs for a given set of variable inputs. These methods are often used to solve mathematical problems when it is difficult or impossible to obtain a closed form expression or not feasible to apply a deterministic algorithm.

Monte Carlo methods vary but tend to follow a particular pattern from start to finish. Firstly a domain of possible inputs needs to be defined. Then a set of correlated inputs is randomly selected from a probability distribution over the domain.

Once the series of inputs have been calculated, deterministic calculations over the series of inputs are performed. From these deterministic calculations, the required data should be calculated and probability distribution functions are calculated from this data.

11kV Switchboards

This analysis utilises Monte Carlo simulations to produce an average unserved energy estimate if an 11kV circuit breaker or switchboard fails. This methodology includes the impact of potential 11kV load transfers to adjacent zone substations.

Calculate the mean Unserved Energy (USE) as follows:

1. Obtain a three year Cleansed Load Profile (CLP) (total zone substation amps 1/10/2011 – 30/9/2014)[5].
2. Obtain the twenty five year forecast summer and winter peak demand[6].
3. Record the annual summer and winter peak loads in the CLP.
4. Calculate the ratio of the forecast peak demand to actual seasonal peaks for all twenty five years. This will result in six ratios for each forecast year.
5. Calculate the Load Adjustment Factor (LAF) for each forecast year by taking the average of the six ratios.
6. Generate a forecast CLP for each forecast year by applying the LAFs to the original CLP.
7. Obtain the Load Transfer Capacity (LTC) representing the maximum demand that can be transferred to adjacent zone substation[7].
8. Diversify the LTC by the ratio between the forecast peak demand in 2014/15 and the total 11kV load used in the original LTC study.
9. Assuming that LTC is inversely proportional to load growth, calculate a diversified LTC for each forecast year.
10. Generate a load transfer profile by multiplying the CLP by the diversified LTC for each forecast year.
11. Randomly choose 100 outage times within the three year period.
12. Calculate the unserved energy for a given Mean Time to Repair (MTTR) and percentage load interrupted. The percentage load interrupted is dependent on the failure scenario and specific for each case study. The unserved energy calculation is illustrated in Figure 7.

[5] CLPs are obtained by removing zero points and abnormal switching from measured SCADA loads.

[6] The peak demand forecast includes Broad Based Demand Management (BBDM) and a 55% scaling factor for 11kV spot loads.

[7] LTC sourced from *Distribution Zone Substations – Load Transfer Capabilities, Ausgrid, December 2013*

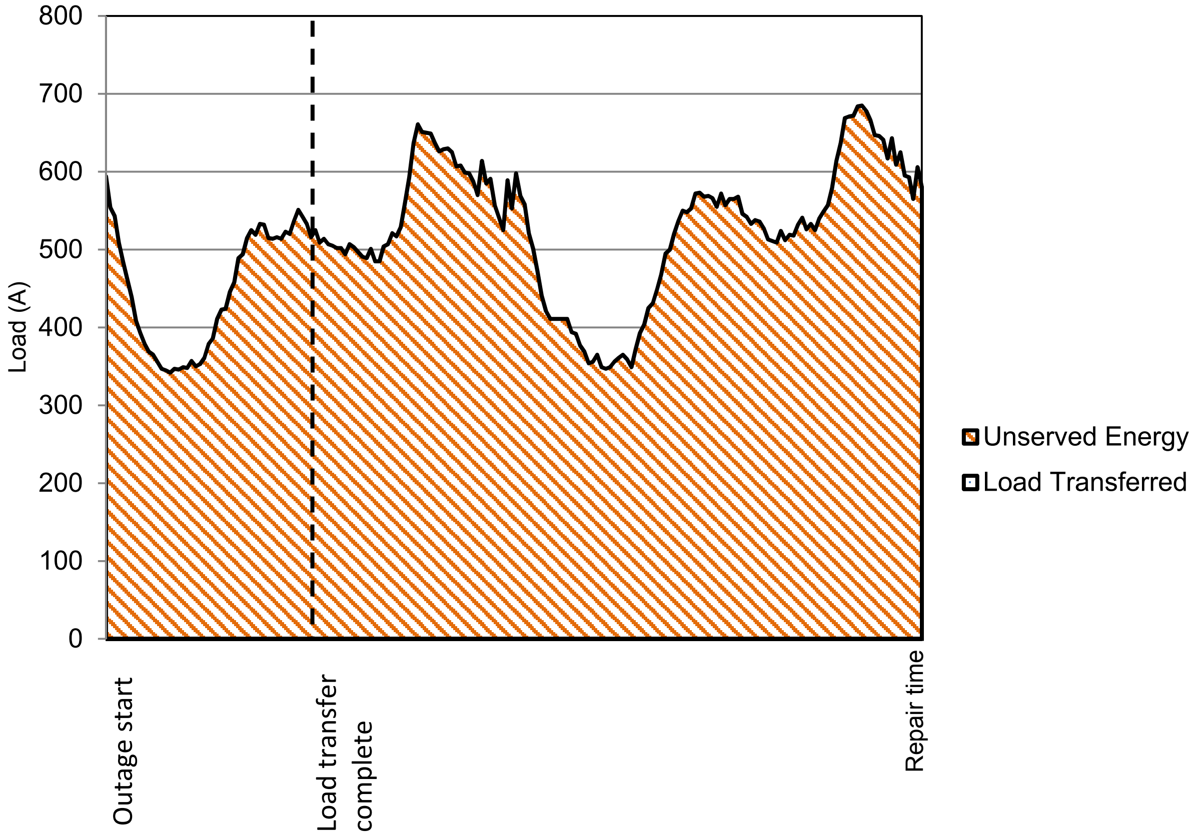


Figure 7: Calculation of unserved energy

Subtransmission Cables

Meshed Subtransmission Cables

This analysis utilises Monte Carlo simulations to produce a Probability Distribution of the loading on a network feeder element. The Total Unserved Energy is then calculated based on the thermal ratings of the network elements involved. Expected Unserved Energy is then calculated based on the Total Unserved Energy and the calculated unavailability for the network elements.

The probabilistic analysis uses Monte Carlo Simulations to provide a quantitative probabilistic assessment of the network elements being analysed. There are a number of quantities that are evaluated during this step:

Total Unserved Energy
The Total Unserved Energy is the cumulative summation of all load at risk for the network elements involved. This quantity is calculated as the area beneath the cumulative distribution function of the load where the thermal limit is exceeded.

Expected Unserved Energy
The Expected Unserved Energy (EUE) is derived from the Total Unserved Energy taking into consideration the likelihood of the event occurring and the time for which it will occur. The failure likelihood *Pf* multiplied by the MTTR as a portion of the total time duration is the Unavailability (U). The EUE is calculated for each year using the equation:

$$EUE = U \times Total\ Unserved\ Energy$$

Radialised Subtransmission Cables

A simplified method of calculating Expected Unserved Energy (EUE) on network feeder elements is used for radialised feeders in order to reduce unnecessary complexity. In a meshed feeder network, it is important to perform powerflow analysis for a wide range of load scenarios as flows on one network branch will significantly impact the flows on other network branches due to voltage changes at network buses. This is not the case for radialised feeders. EUE for radialised feeders can be calculated using a more simplified analysis.

Method:

1. Obtain the past three years of historical load data for the network elements involved.
2. Generate four typical daily load cycles for a year. This represents summer (high and low) and winter (high and low) load cycles.
3. Scale up each load cycle to obtain future load cycles based on the POE50% forecast.
4. Calculate the unserved energy that cannot be supplied following a single fault or multiple faults on the network elements, taking into account 11kV load transfers to surrounding zones.
5. Failure rate and repair time data are obtained for each feeder.
6. Failure rate (FR) for each forecast year is calculated as per Section 2.2.2
7. Unavailability of each feeder is calculated using failure likelihood *Pf* and mean time to repair (MTTR).

$$U = \frac{Pf \times MTTR}{8760}$$

8. Unavailability of two feeders outage is calculated as below.

$$U_{1\&2} = Pf_{feeder\ 1} \times U_{feeder\ 2} + Pf_{feeder\ 2} \times U_{feeder\ 1}$$

9. Expected Unserved Energy (EUE) for each year is calculated using the formula

$$EUE = Unavailability\ (U) \times Total\ Unserved\ Energy$$

Appendix B1: 11kV Switchboards - Assumptions and Results

Matraville 11kV Switchgear

Circuit breakers commissioned (Average): 1963

Switchboards commissioned: 1960

Number of aged circuit breakers: 18

Number of aged switchboards: 4

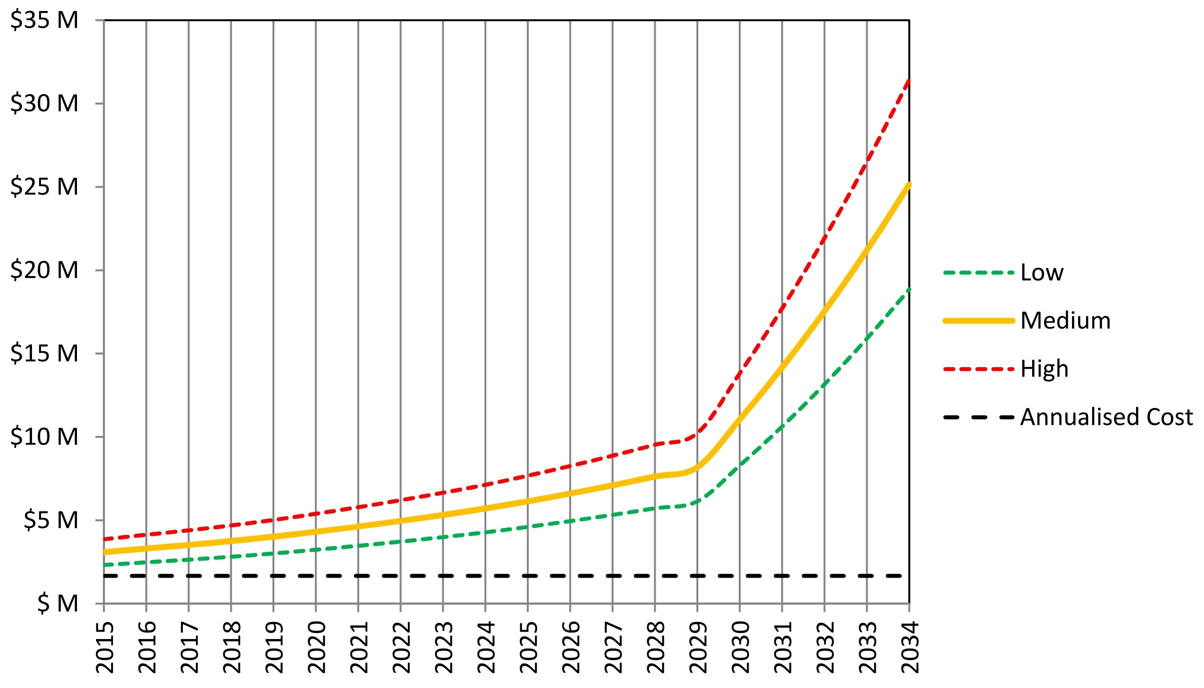
VCR: $39.52/kWh

Load transfer capacity: 719 Amps

Probability weighted consequence costs (β_j x $\$C_j$)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Isolated CB Failure	99%	$31,000	$707,107	$11,180	$22,361	$11,180
Propagating CB Failure	1%	$11,662,768	$707,107	$ 111,803	$ 223,607	$223,607
Board Failure	100%	$11,662,768	$707,107	$111,803	$223,607	$223,607
Board Fire	0%	$23,325,536	$11,180,340	$11,180,340	$11,180,340	$2,236,068

Monetised Baseline Risk



Surry Hills 11kV Switchboards

Circuit breakers commissioned (Average): 1958

Switchboards commissioned: 1958

Number of aged circuit breakers: 19

Number of aged switchboards: 3

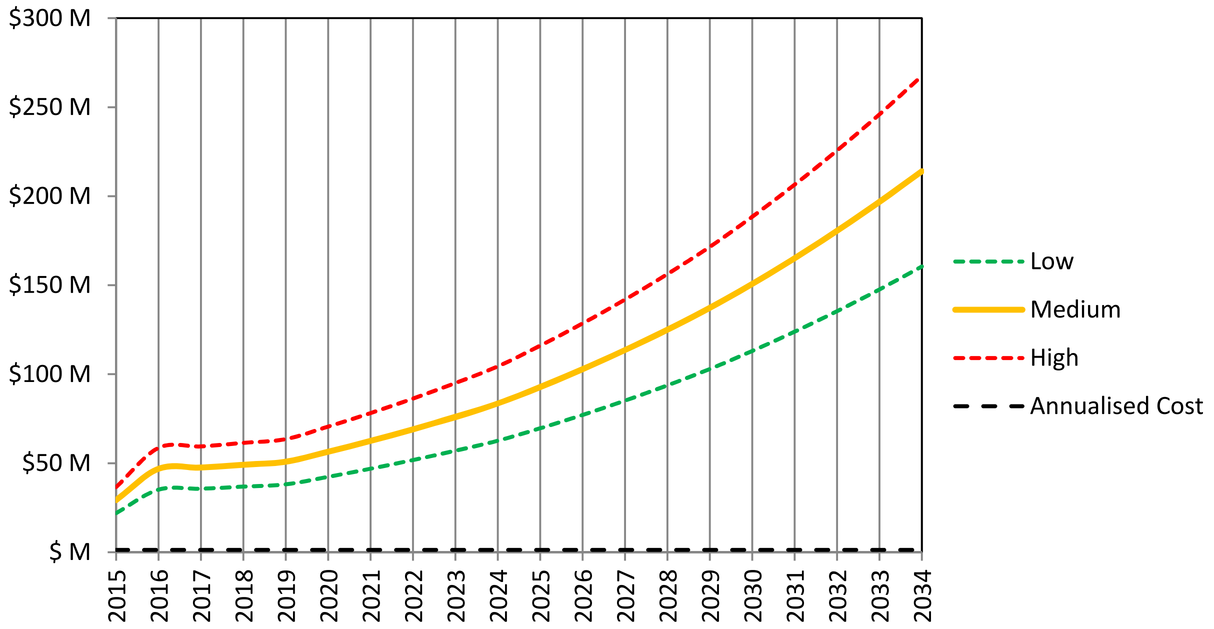
VCR: $41.7/kWh

Load transfer capacity: 756 Amps

Probability weighted consequence costs (β_j x $$C_j$)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Isolated CB Failure	99%	$ 31,000	$ 707,107	$ 11,180	$ 22,361	$ 11,180
Propagating CB Failure	1%	$ 9,002,098	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Failure	100%	$ 9,002,098	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Fire	0%	$ 18,004,196	$11,180,340	$11,180,340	$ 11,180,340	$ 2,236,068

Monetised Baseline Risk



Leightonfield 11kV Switchboards

Circuit breakers commissioned (Average): 1962

Switchboards commissioned: 1962

Number of aged circuit breakers: 4

Number of aged switchboards: 2

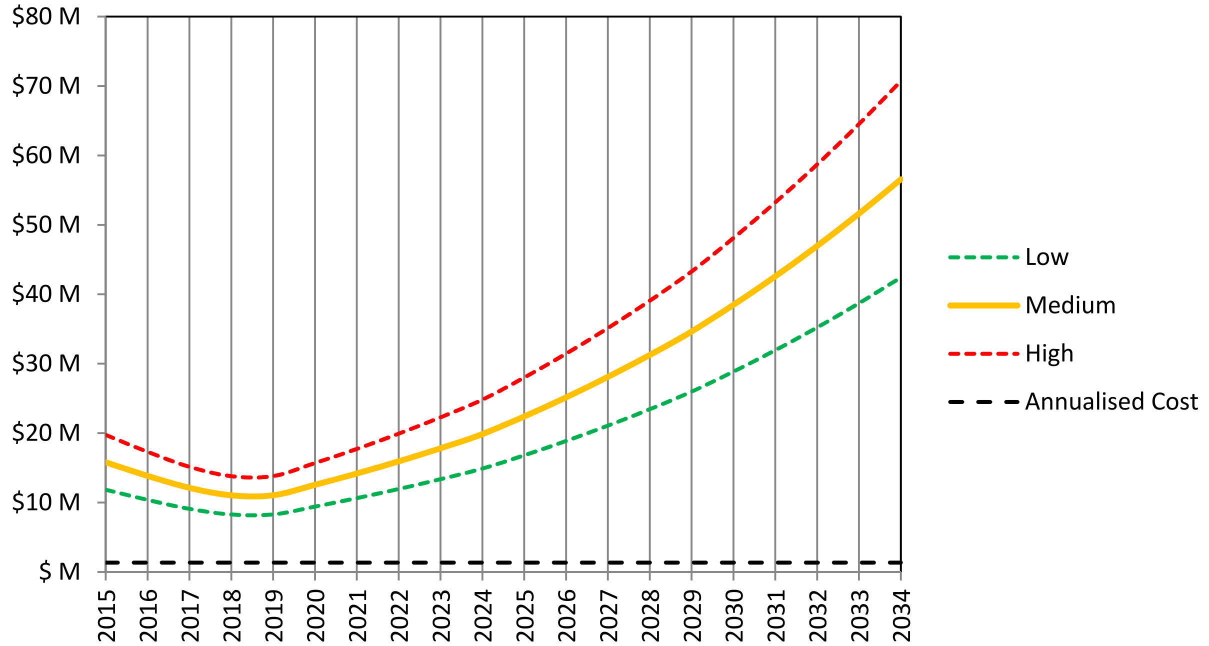
VCR: $39.79/kWh

Load transfer capacity: 466 Amps

Probability weighted consequence costs (β_j x $\$C_j$)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Isolated CB Failure	99%	$ 31,000	$ 707,107	$ 11,180	$ 22,361	$ 11,180
Propagating CB Failure	1%	$ 9,456,569	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Failure	100%	$ 9,456,569	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Fire	0%	$ 18,913,138	$ 11,180,340	$ 11,180,340	$11,180,340	$ 2,236,068

Monetised Baseline Risk



Punchbowl 11kV Switchboards

Circuit breakers commissioned (Average): 1967

Switchboards commissioned: 1967

Number of aged circuit breakers: 28

Number of aged switchboards: 4

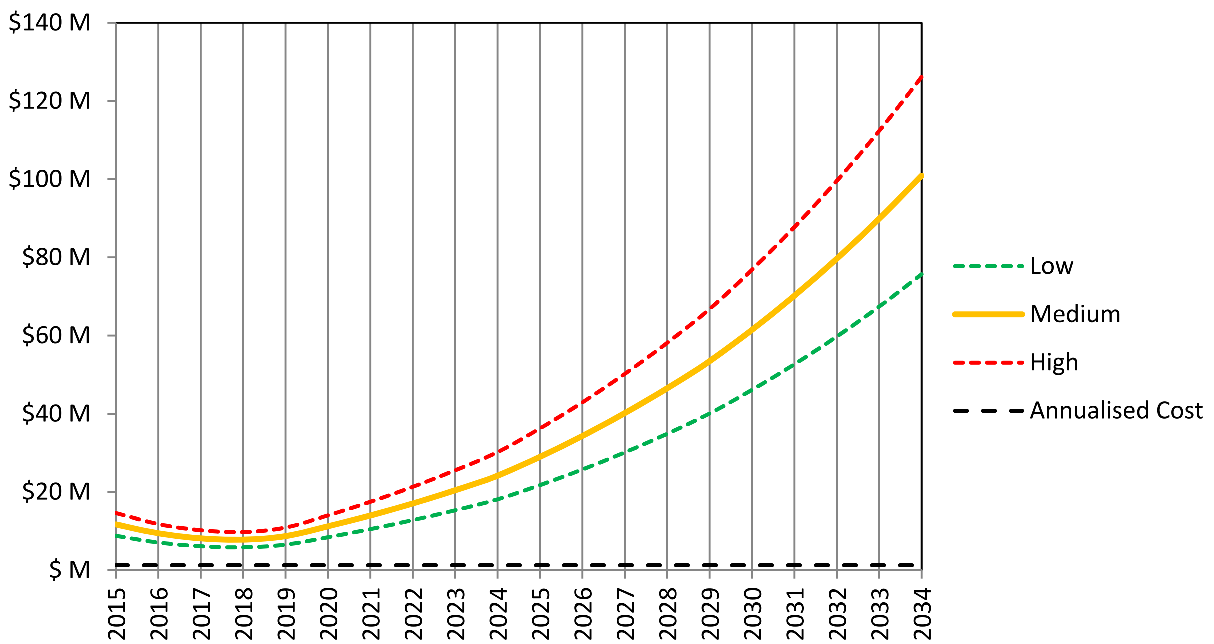
VCR: $35.19/kWh

Load transfer capacity: 782 Amps

<u>Probability weighted consequence costs (β_j x $\$C_j$)</u>

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Isolated CB Failure	99%	$ 31,000	$ 707,107	$ 11,180	$ 22,361	$ 11,180
Propagating CB Failure	1%	$ 8,762,670	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Failure	100%	$ 8,762,670	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Fire	0%	$ 17,525,339	$ 11,180,340	$ 11,180,340	$11,180,340	$ 2,236,068

Monetised Baseline Risk



Arncliffe 11kV Switchboards

Circuit breakers commissioned (Average): 1960

Switchboards commissioned: 1960

Number of aged circuit breakers: 0

Number of aged switchboards: 2

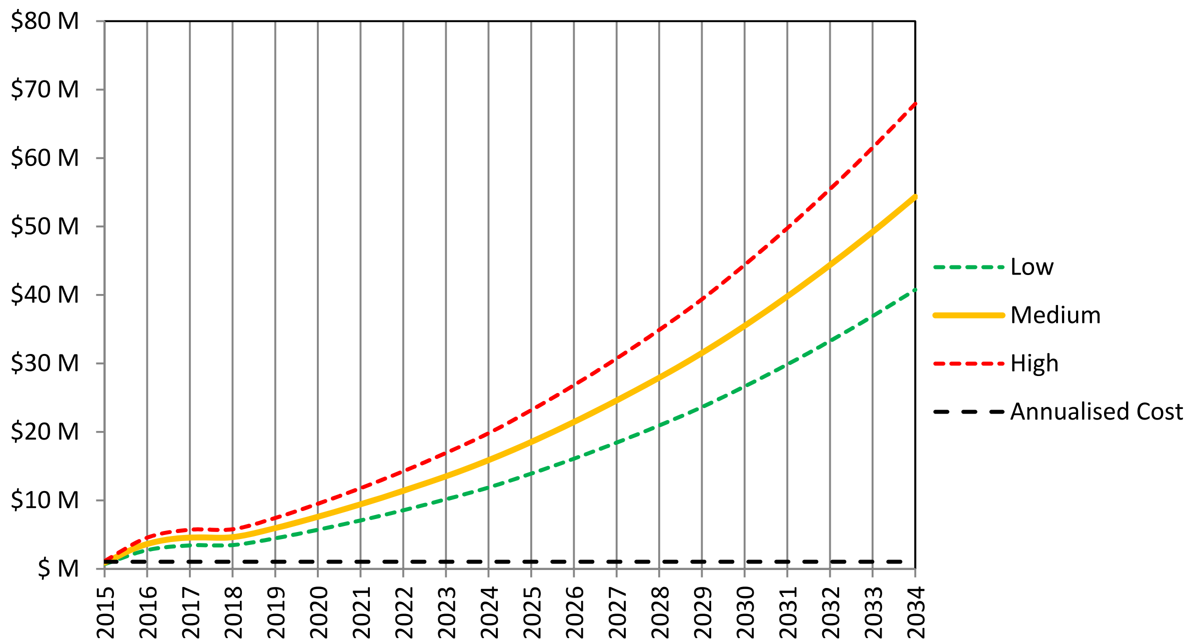
VCR: $35.84/kWh

Load transfer capacity: 659 Amps

Probability weighted consequence costs (β_i x $\$C_i$)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Isolated CB Failure	99%	$ 31,000	$ 707,107	$ 11,180	$ 22,361	$ 11,180
Propagating CB Failure	1%	$ 7,293,639	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Failure	100%	$ 7,293,639	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Fire	0%	$ 14,587,277	$ 11,180,340	$ 11,180,340	$11,180,340	$ 2,236,068

Monetised Baseline Risk



Botany 11kV Switchboards

Circuit breakers commissioned (Average): 1951

Switchboards commissioned: 1951

Number of aged circuit breakers: 8

Number of aged switchboards: 3

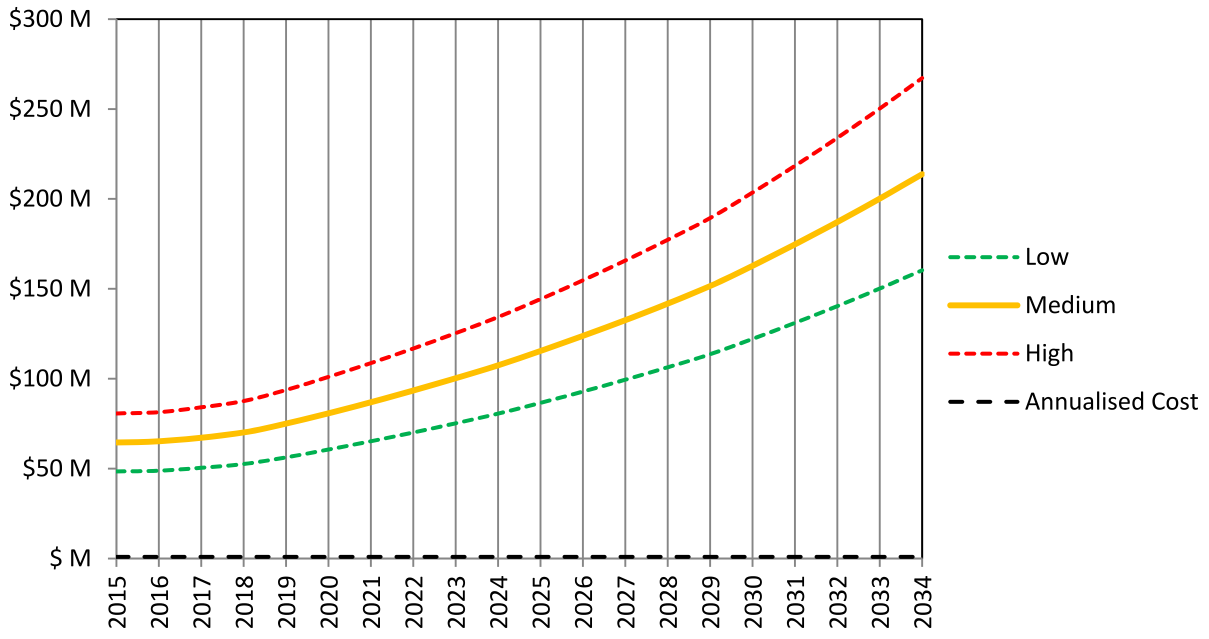
VCR: $41.25/kWh

Load transfer capacity: 234 Amps

Probability weighted consequence costs (β_i x C_i)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Isolated CB Failure	99%	$ 31,000	$ 707,107	$ 11,180	$ 22,361	$ 11,180
Propagating CB Failure	1%	$ 6,357,721	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Failure	100%	$ 6,357,721	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Fire	0%	$ 12,715,442	$ 11,180,340	$ 11,180,340	$11,180,340	$ 2,236,068

Monetised Baseline Risk



Nelson Bay 11kV Switchboards

Circuit breakers commissioned (Average): 1974

Switchboards commissioned: 1974

Number of aged circuit breakers: 9

Number of aged switchboards: 2

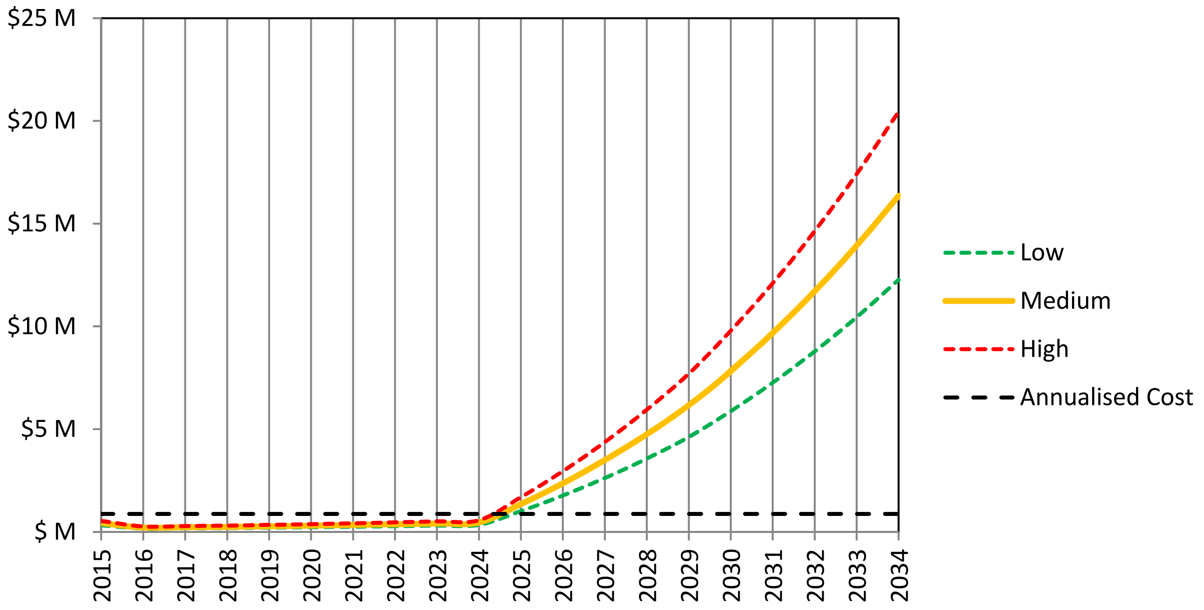
VCR: $36.38/kWh

Load transfer capacity: 978 Amps

Probability weighted consequence costs (β_i x C_i)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Isolated CB Failure	99%	$ 31,000	$ 707,107	$ 11,180	$ 22,361	$ 11,180
Propagating CB Failure	1%	$ 1,227,236	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Failure	100%	$ 1,227,236	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Fire	0%	$ 12,272,359	$ 11,180,340	$ 11,180,340	$11,180,340	$ 2,236,068

Monetised Baseline Risk



Denman 11kV Switchboards

Circuit breakers commissioned (Average): 1985

Switchboards commissioned: 1985

Number of aged circuit breakers: 7

Number of aged switchboards: 1

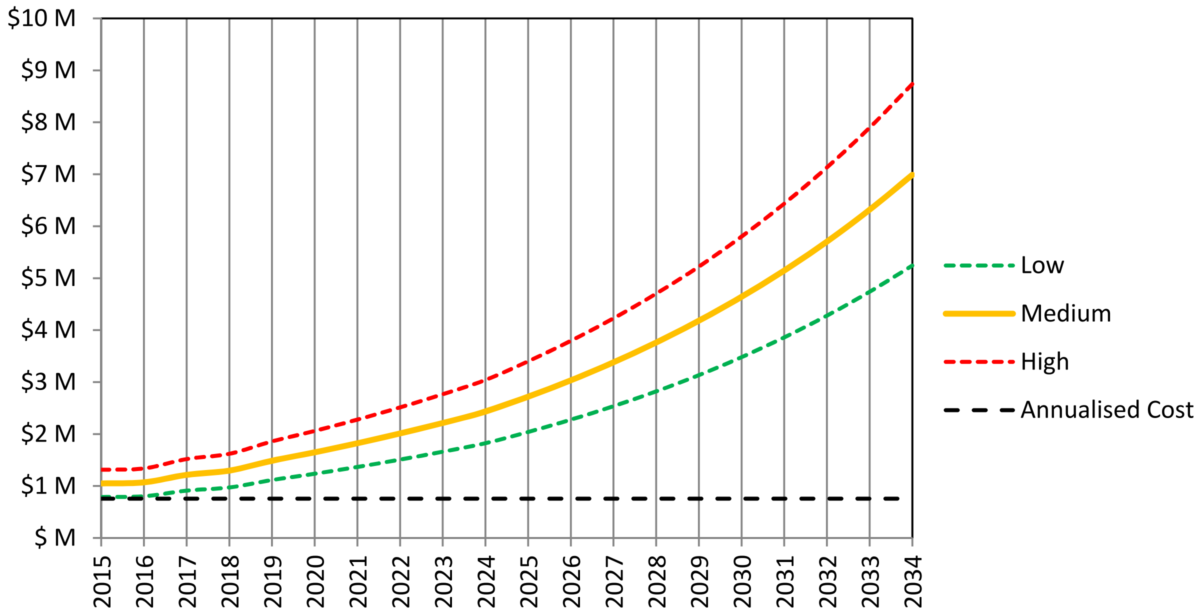
VCR: $39.23/kWh

Load transfer capacity: 78 Amps

Probability weighted consequence costs (β_j x $\$C_j$)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Isolated CB Failure	99%	$ 31,000	$ 707,107	$ 11,180	$ 22,361	$ 11,180
Propagating CB Failure	1%	$ 1,058,782	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Failure	100%	$ 1,058,782	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Fire	0%	$ 10,587,815	$ 11,180,340	$ 11,180,340	$11,180,340	$ 2,236,068

Monetised Baseline Risk



Mitchell Line 11kV Switchboards

Circuit breakers commissioned (Average): 1984

Switchboards commissioned: 1984

Number of aged circuit breakers: 11

Number of aged switchboards: 1

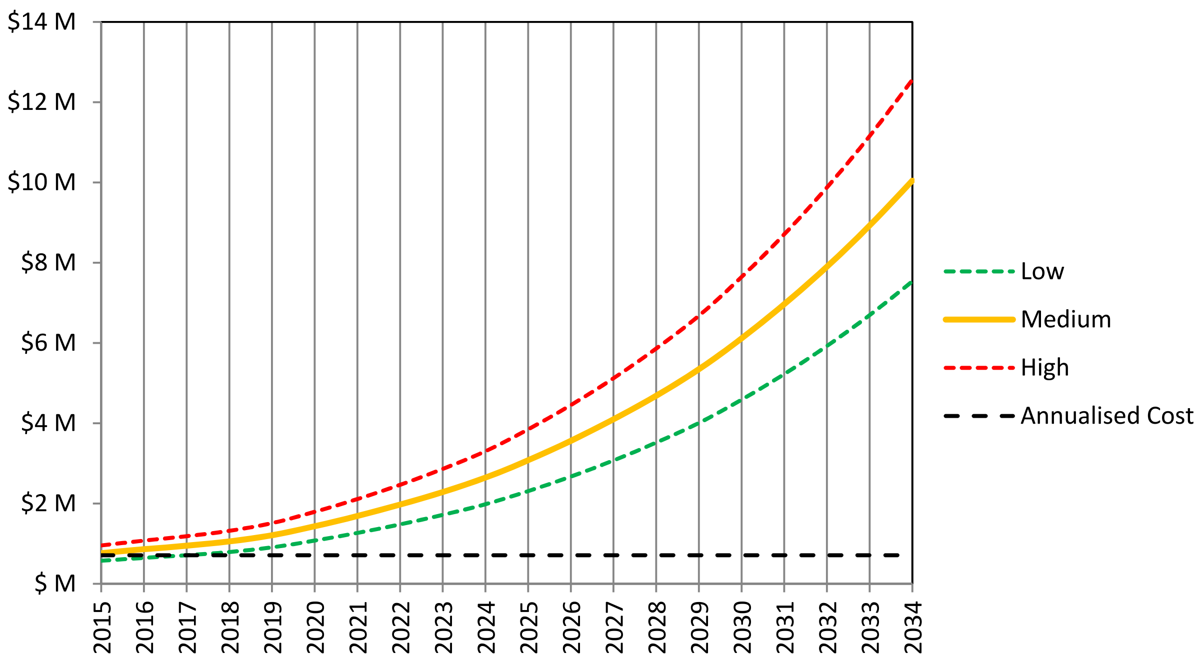
VCR: $39.06/kWh

Load transfer capacity: 662 Amps

Probability weighted consequence costs (β_i x $\$C_i$)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Isolated CB Failure	99%	$ 31,000	$ 707,107	$ 11,180	$ 22,361	$ 11,180
Propagating CB Failure	1%	$ 994,811	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Failure	100%	$ 994,811	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Fire	0%	$ 9,948,108	$ 11,180,340	$ 11,180,340	$11,180,340	$ 2,236,068

Monetised Baseline Risk



Edgeworth 11kV Switchboards

Circuit breakers commissioned (Average): 2006

Switchboards commissioned: 1960

Number of aged circuit breakers: 0

Number of aged switchboards: 1

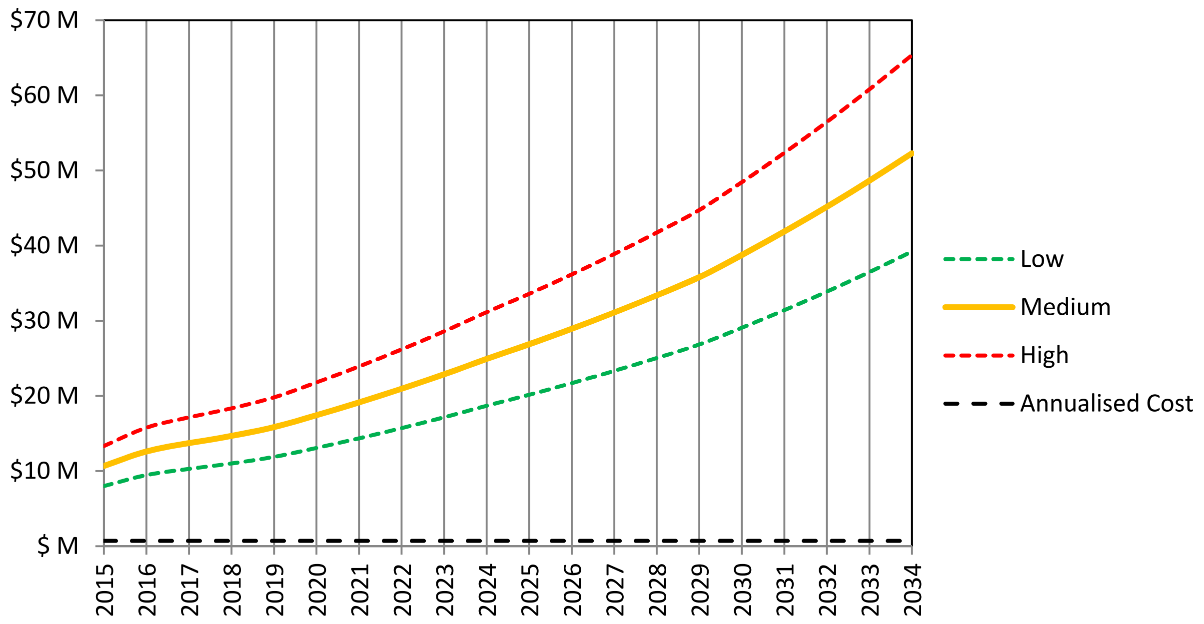
VCR: $33.69/kWh

Load transfer capacity: 696 Amps

Probability weighted consequence costs (β_j x $\$C_j$)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Isolated CB Failure	99%	$ 31,000	$ 707,107	$ 11,180	$ 22,361	$ 11,180
Propagating CB Failure	1%	$ 986,803	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Failure	100%	$ 986,803	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Fire	0%	$ 9,868,032	$ 11,180,340	$ 11,180,340	$11,180,340	$ 2,236,068

Monetised Baseline Risk



Terrey Hills 11kV Switchboards

Circuit breakers commissioned (Average): 1978

Switchboards commissioned: 1978

Number of aged circuit breakers: 9

Number of aged switchboards: 3

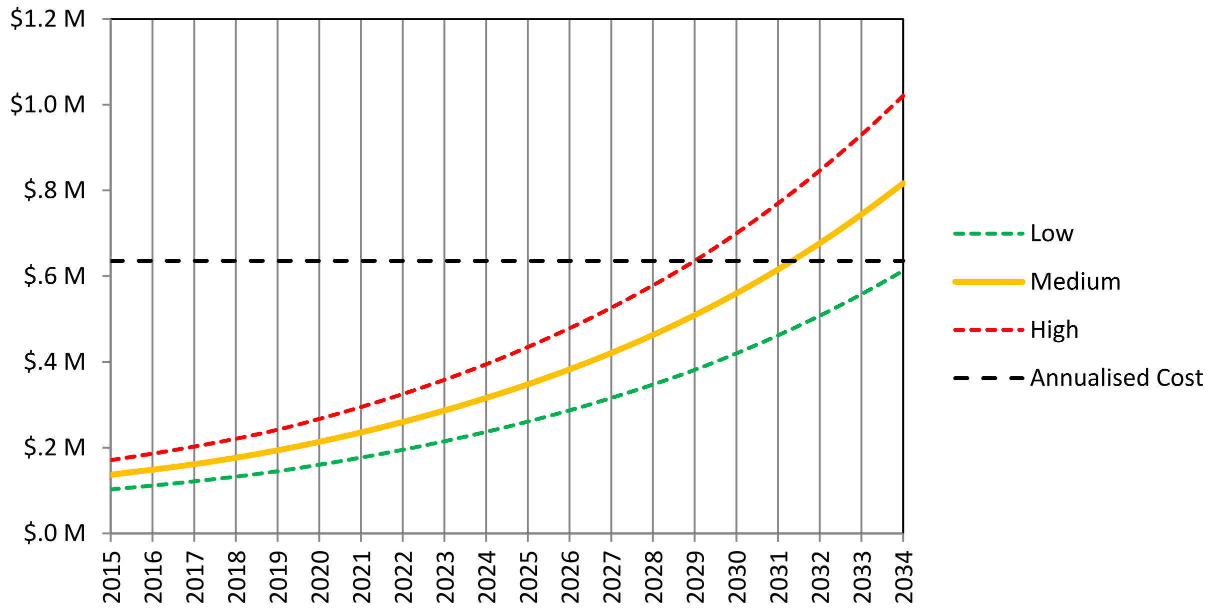
VCR: $41.41/kWh

Load transfer capacity: 380 Amps

Probability weighted consequence costs (β_i x $\$C_i$)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Isolated CB Failure	99%	$ 31,000	$ 707,107	$ 11,180	$ 22,361	$ 11,180
Propagating CB Failure	1%	$ 889,183	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Failure	100%	$ 889,183	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Fire	0%	$ 8,891,833	$ 11,180,340	$ 11,180,340	$11,180,340	$ 2,236,068

Monetised Baseline Risk



Lisarow 11kV Switchboards

Circuit breakers commissioned (Average): 1977

Switchboards commissioned: 1977

Number of aged circuit breakers: 9

Number of aged switchboards: 2

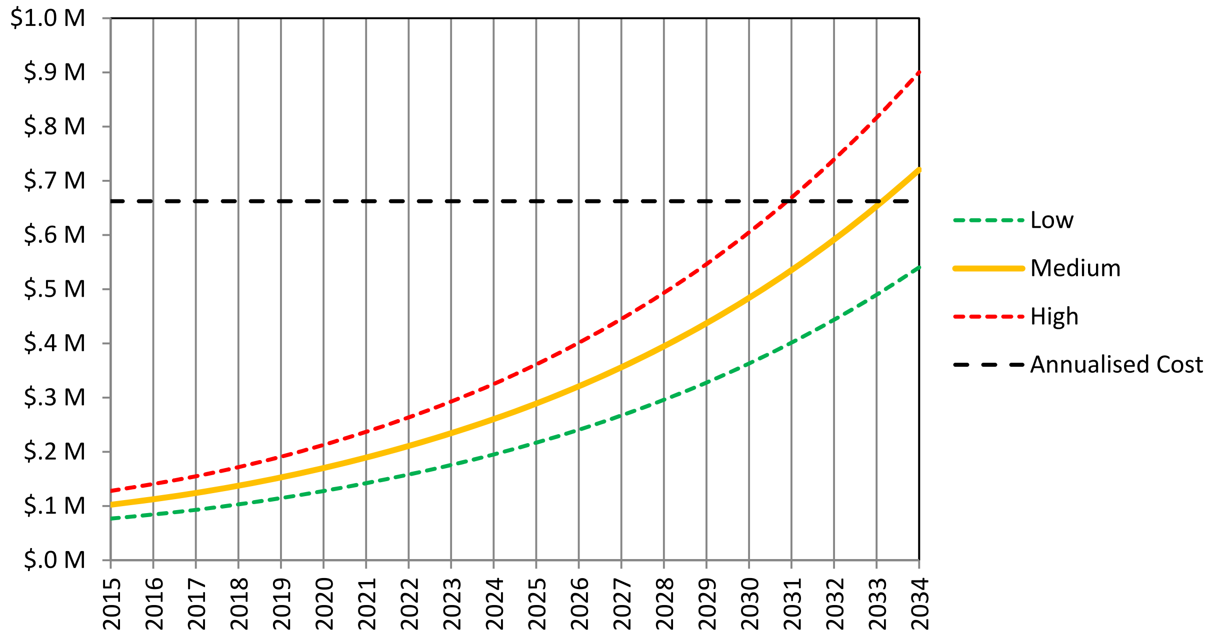
VCR: $35.84/kWh

Load transfer capacity: 1052 Amps

Probability weighted consequence costs (β_i x $\$C_i$)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Isolated CB Failure	99%	$ 31,000	$ 707,107	$ 11,180	$ 22,361	$ 11,180
Propagating CB Failure	1%	$ 889,180	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Failure	100%	$ 889,180	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Fire	0%	$ 8,891,803	$ 11,180,340	$ 11,180,340	$11,180,340	$ 2,236,068

Monetised Baseline Risk



Mascot 11kV Switchboards

Circuit breakers commissioned (Average): 1946

Switchboards commissioned: 1946

Number of aged circuit breakers: 21

Number of aged switchboards: 5

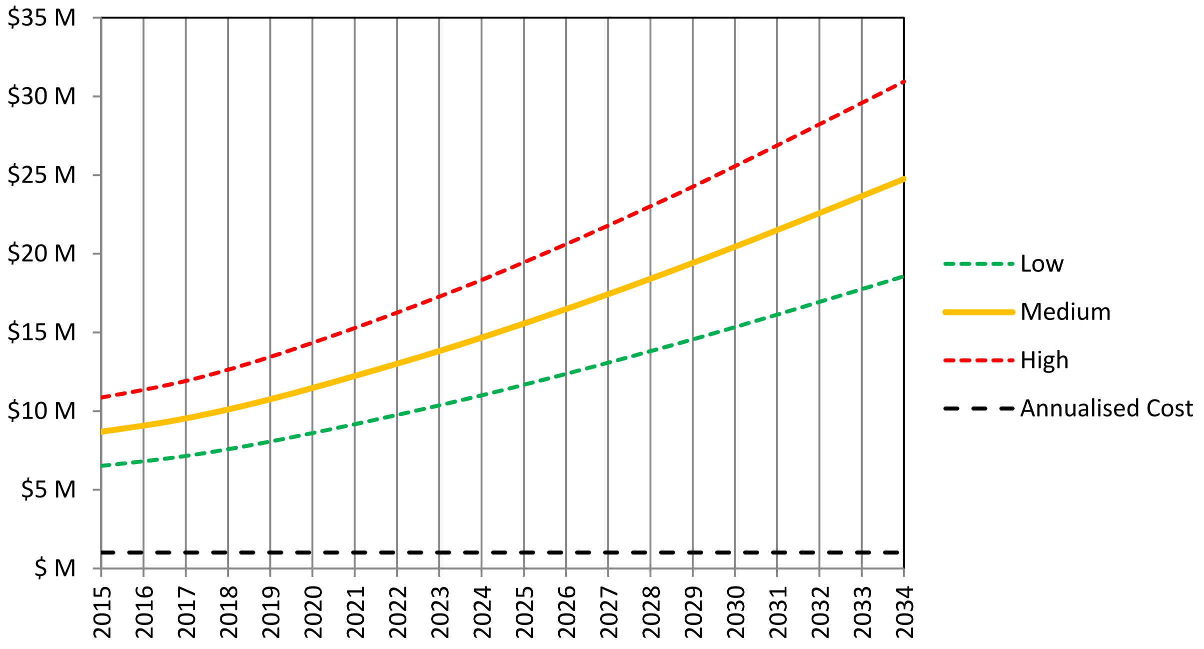
VCR: $42.68/kWh

Load transfer capacity: 899 Amps

Probability weighted consequence costs (β_j x $\$C_j$)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Isolated CB Failure	99%	$ 31,000	$ 707,107	$ 11,180	$ 22,361	$ 11,180
Propagating CB Failure	1%	$ 7,088,217	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Failure	100%	$ 7,088,217	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Fire	0%	$ 14,176,434	$ 11,180,340	$ 11,180,340	$11,180,340	$ 2,236,068

Monetised Baseline Risk



Mona Vale 11kV Switchboards

Circuit breakers commissioned (Average): 1976

Switchboards commissioned: 1976

Number of aged circuit breakers: 8

Number of aged switchboards: 1

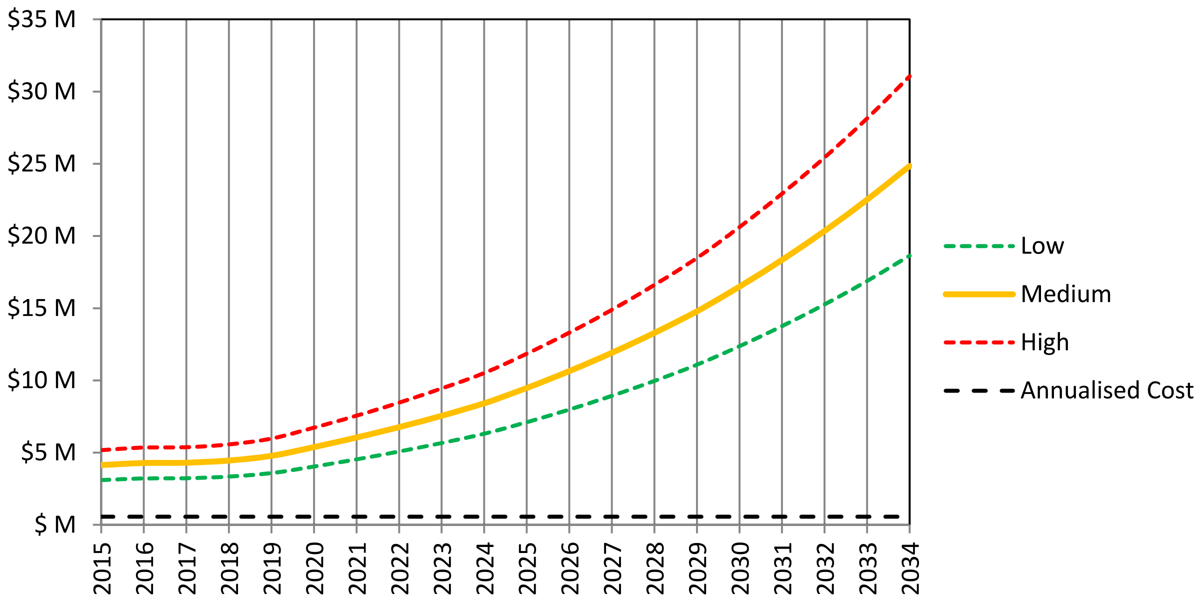
VCR: $35.36/kWh

Load transfer capacity: 688 Amps

Probability weighted consequence costs (β_j x $\$C_j$)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Isolated CB Failure	99%	$ 31,000	$ 707,107	$ 11,180	$ 22,361	$ 11,180
Propagating CB Failure	1%	$ 786,389	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Failure	100%	$ 786,389	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Fire	0%	$ 7,863,885	$ 11,180,340	$ 11,180,340	$11,180,340	$ 2,236,068

Monetised Baseline Risk



Branxton 11kV Switchboards

Circuit breakers commissioned (Average): 1960

Switchboards commissioned: 1960

Number of aged circuit breakers: 5

Number of aged switchboards: 1

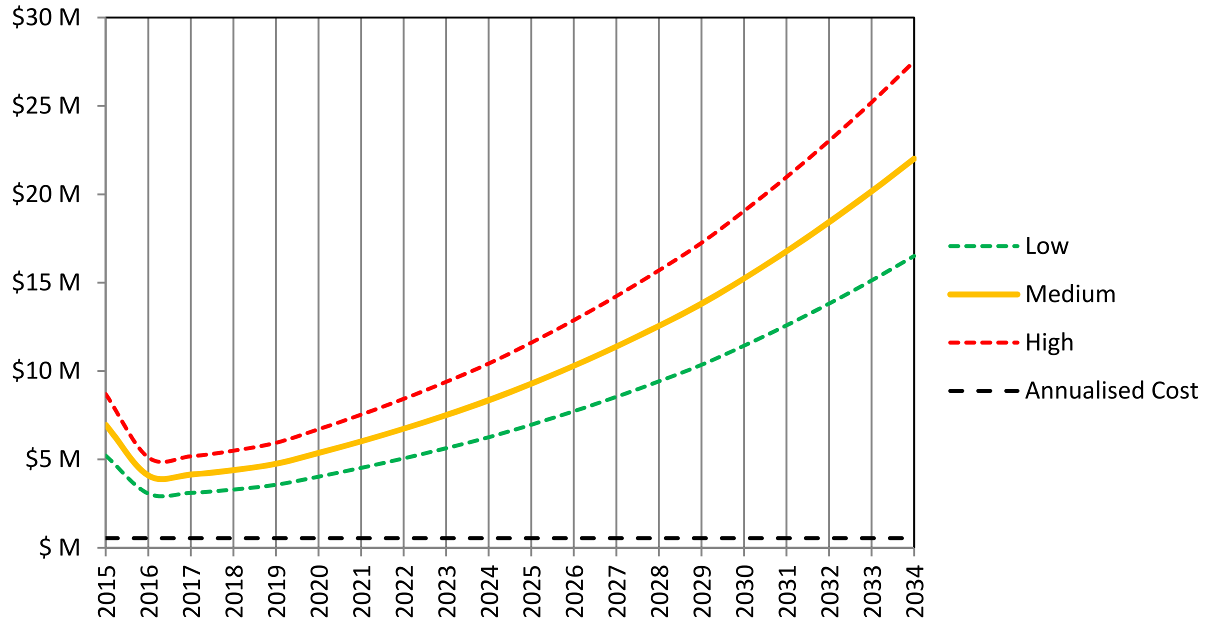
VCR: $32.45/kWh

Load transfer capacity: 344 Amps

Probability weighted consequence costs (β_i x $$C_i$)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Isolated CB Failure	99%	$ 31,000	$ 707,107	$ 11,180	$ 22,361	$ 11,180
Propagating CB Failure	1%	$ 756,921	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Failure	100%	$ 756,921	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Fire	0%	$ 7,569,207	$ 11,180,340	$ 11,180,340	$11,180,340	$ 2,236,068

Monetised Baseline Risk



Singleton 11kV Switchboards

Circuit breakers commissioned (Average): 1974

Switchboards commissioned: 1974

Number of aged circuit breakers: 7

Number of aged switchboards: 1

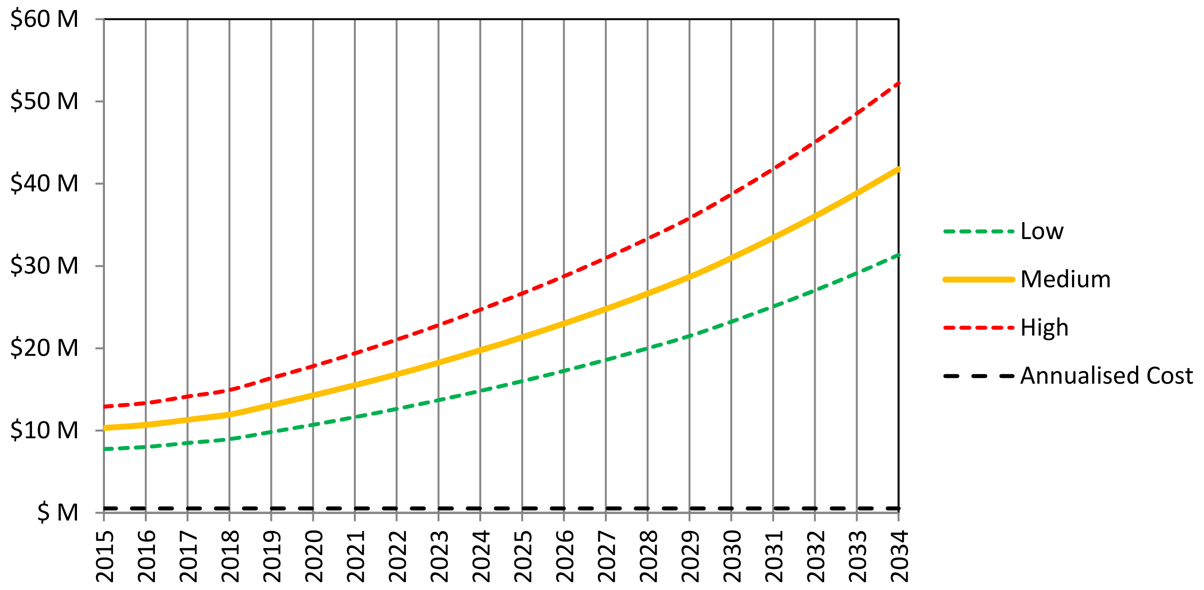
VCR: $39.95/kWh

Load transfer capacity: 238 Amps

Probability weighted consequence costs (β_j x $$C_j$)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Isolated CB Failure	99%	$ 31,000	$ 707,107	$ 11,180	$ 22,361	$ 11,180
Propagating CB Failure	1%	$ 737,804	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Failure	100%	$ 737,804	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Fire	0%	$ 7,378,038	$ 11,180,340	$ 11,180,340	$11,180,340	$ 2,236,068

Monetised Baseline Risk



Umina 11kV Switchboards

Circuit breakers commissioned (Average): 1979

Switchboards commissioned: 1979

Number of aged circuit breakers: 7

Number of aged switchboards: 2

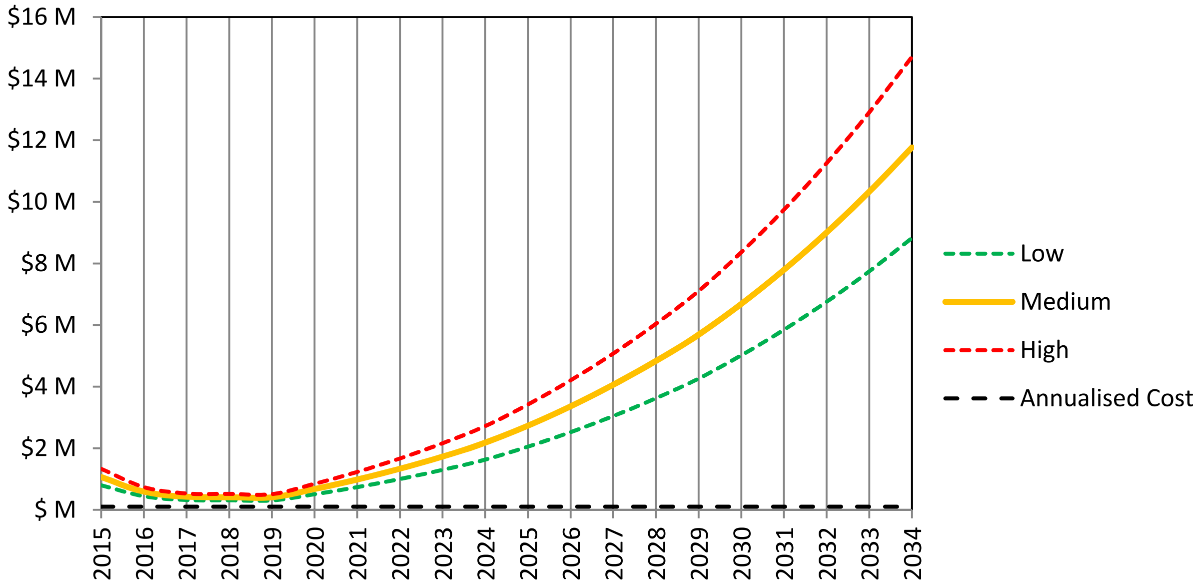
VCR: $31.62/kWh

Load transfer capacity: 556 Amps

Probability weighted consequence costs (β_i x $$C_i$)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Isolated CB Failure	99%	$ 31,000	$ 707,107	$ 11,180	$ 22,361	$ 11,180
Propagating CB Failure	1%	$ 145,274	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Failure	100%	$ 145,274	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Fire	0%	$ 1,452,745	$ 11,180,340	$ 11,180,340	$11,180,340	$ 2,236,068

Monetised Baseline Risk



Clovelly 11kV Switchboards

Circuit breakers commissioned (Average): 1970

Switchboards commissioned: 1970

Number of aged circuit breakers: 2

Number of aged switchboards: 1

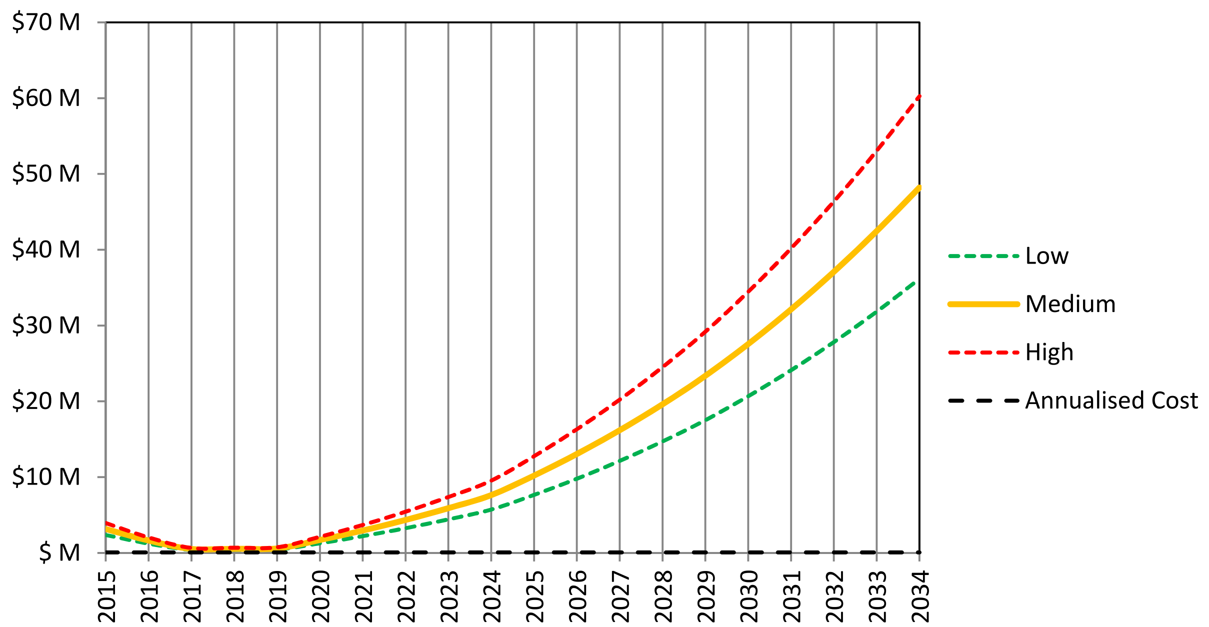
VCR: $36.15/kWh

Load transfer capacity: 2480 Amps

Probability weighted consequence costs (β_j x $\$C_j$)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Isolated CB Failure	99%	$ 31,000	$ 707,107	$ 11,180	$ 22,361	$ 11,180
Propagating CB Failure	1%	$ 93,033	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Failure	100%	$ 93,033	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Fire	0%	$ 930,328	$ 11,180,340	$ 11,180,340	$11,180,340	$ 2,236,068

Monetised Baseline Risk



Stockton 11kV Switchboards

Circuit breakers commissioned (Average): 1967

Switchboards commissioned: 1967

Number of aged circuit breakers: 0

Number of aged switchboards: 2

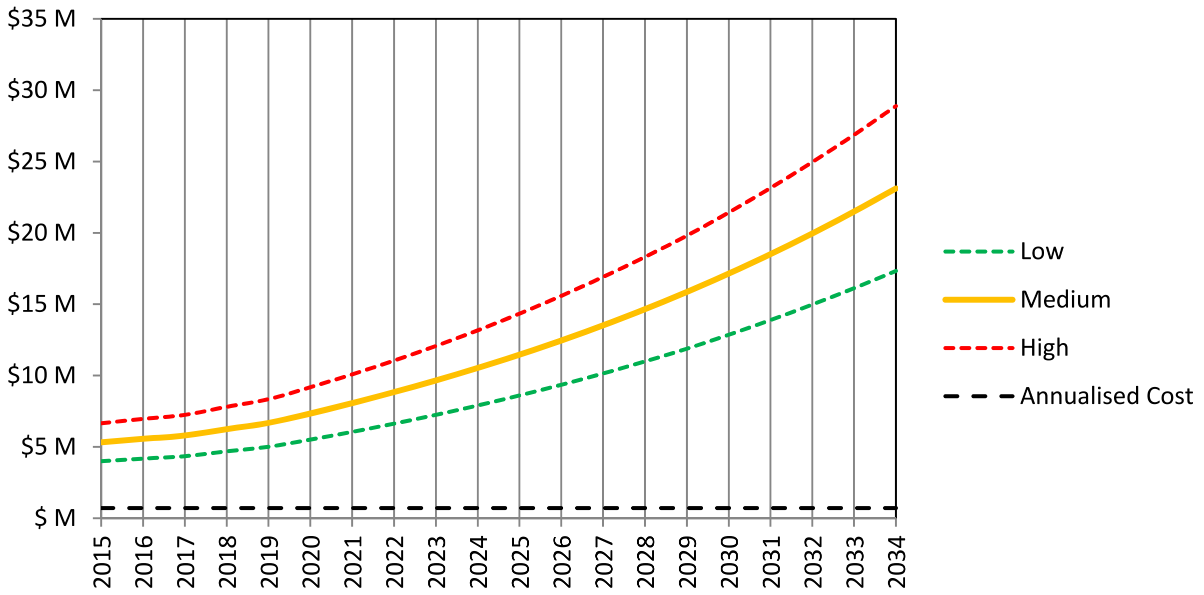
VCR: $34.94/kWh

Load transfer capacity: 44 Amps

Probability weighted consequence costs (β_i x $$C_i$)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Isolated CB Failure	99%	$ 31,000	$ 707,107	$ 11,180	$ 22,361	$ 11,180
Propagating CB Failure	1%	$ 4,985,372	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Failure	100%	$ 4,985,372	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Fire	0%	$ 9,970,745	$ 11,180,340	$ 11,180,340	$11,180,340	$ 2,236,068

Monetised Baseline Risk



Greenacre Park 11kV Switchboards

Circuit breakers commissioned (Average): 1970

Switchboards commissioned: 1970

Number of aged circuit breakers: 25

Number of aged switchboards: 1

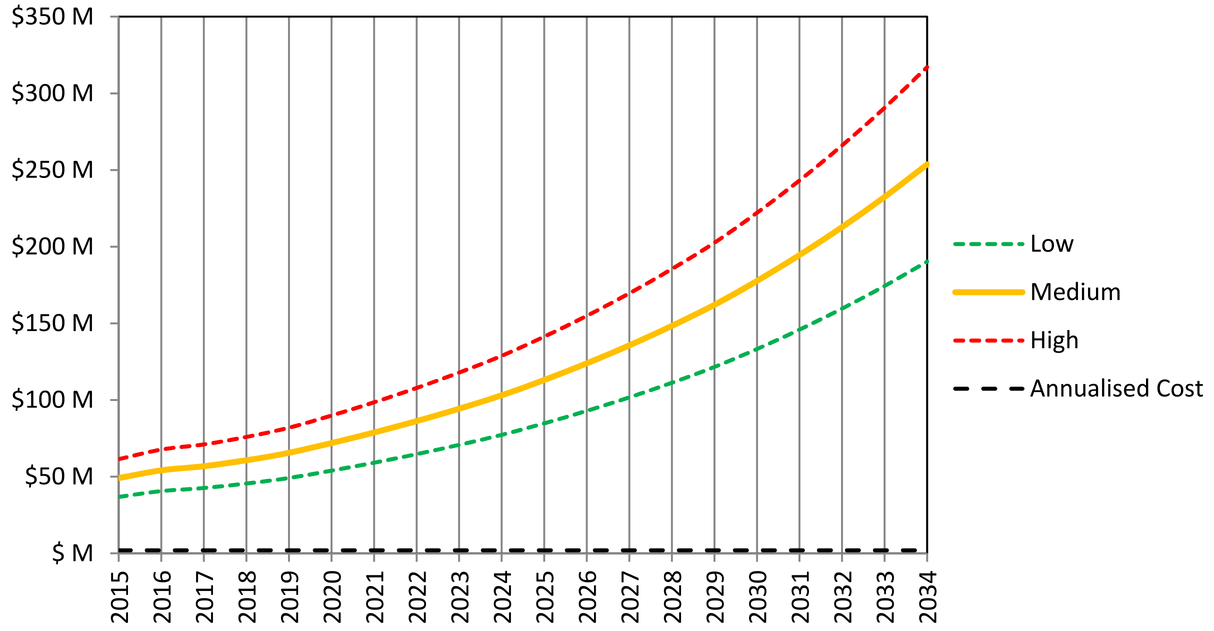
VCR: $40.6/kWh

Load transfer capacity: 1219 Amps

Probability weighted consequence costs (β_i x $\$C_i$)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Isolated CB Failure	99%	$ 31,000	$ 707,107	$ 11,180	$ 22,361	$ 11,180
Propagating CB Failure	1%	$ 13,984,227	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Failure	100%	$ 13,984,227	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Fire	0%	$ 27,968,454	$ 11,180,340	$ 11,180,340	$11,180,340	$ 2,236,068

Monetised Baseline Risk



Blakehurst 11kV Switchboards

Circuit breakers commissioned (Average): 1964

Switchboards commissioned: 1964

Number of aged circuit breakers: 0

Number of aged switchboards: 2

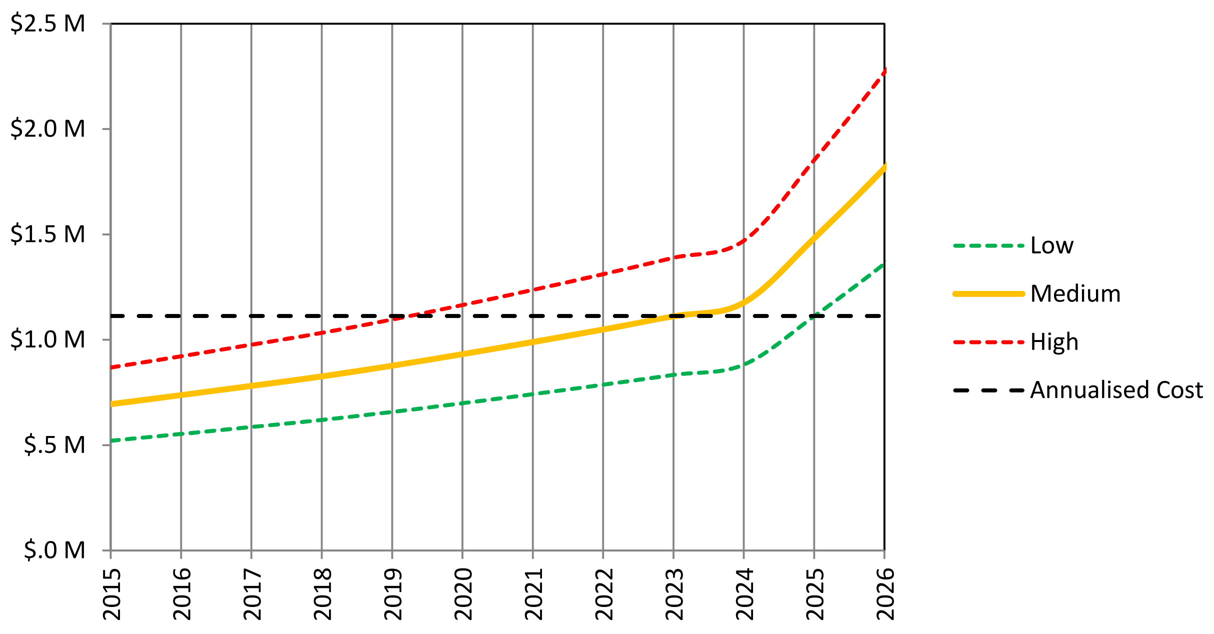
VCR: $33.23/kWh

Load transfer capacity: 855 Amps

Probability weighted consequence costs (β_i x C_i)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Isolated CB Failure	99%	$ 31,000	$ 707,107	$ 11,180	$ 22,361	$ 11,180
Propagating CB Failure	1%	$ 7,782,435	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Failure	100%	$ 7,782,435	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Fire	0%	$ 15,564,869	$ 11,180,340	$ 11,180,340	$11,180,340	$ 2,236,068

Monetised Baseline Risk



Blackwattle Bay 5kV Switchboards

Circuit breakers commissioned (Average): 1951

Switchboards commissioned: 1951

Number of aged circuit breakers: 29

Number of aged switchboards: 3

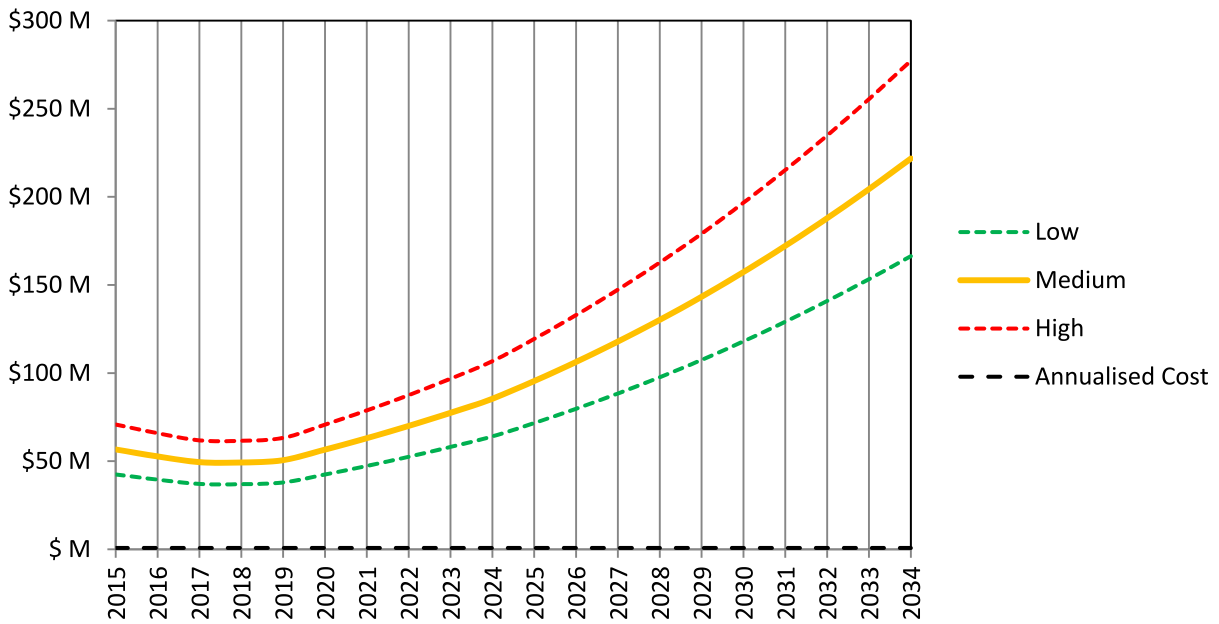
VCR: $40.98/kWh

Load transfer capacity: 234 Amps

Probability weighted consequence costs (β_i x $$C_i$)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Isolated CB Failure	99%	$ 31,000	$ 707,107	$ 11,180	$ 22,361	$ 11,180
Propagating CB Failure	1%	$ 5,026,215	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Failure	100%	$ 5,026,215	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Fire	0%	$ 10,052,430	$ 11,180,340	$ 11,180,340	$ 11,180,340	$ 2,236,068

Monetised Baseline Risk



Appendix B2: Subtransmission Cables - Assumptions and Results

Graving Dock 33kV Feeders Replacement

Feeder 377 Age (Average): 68 years

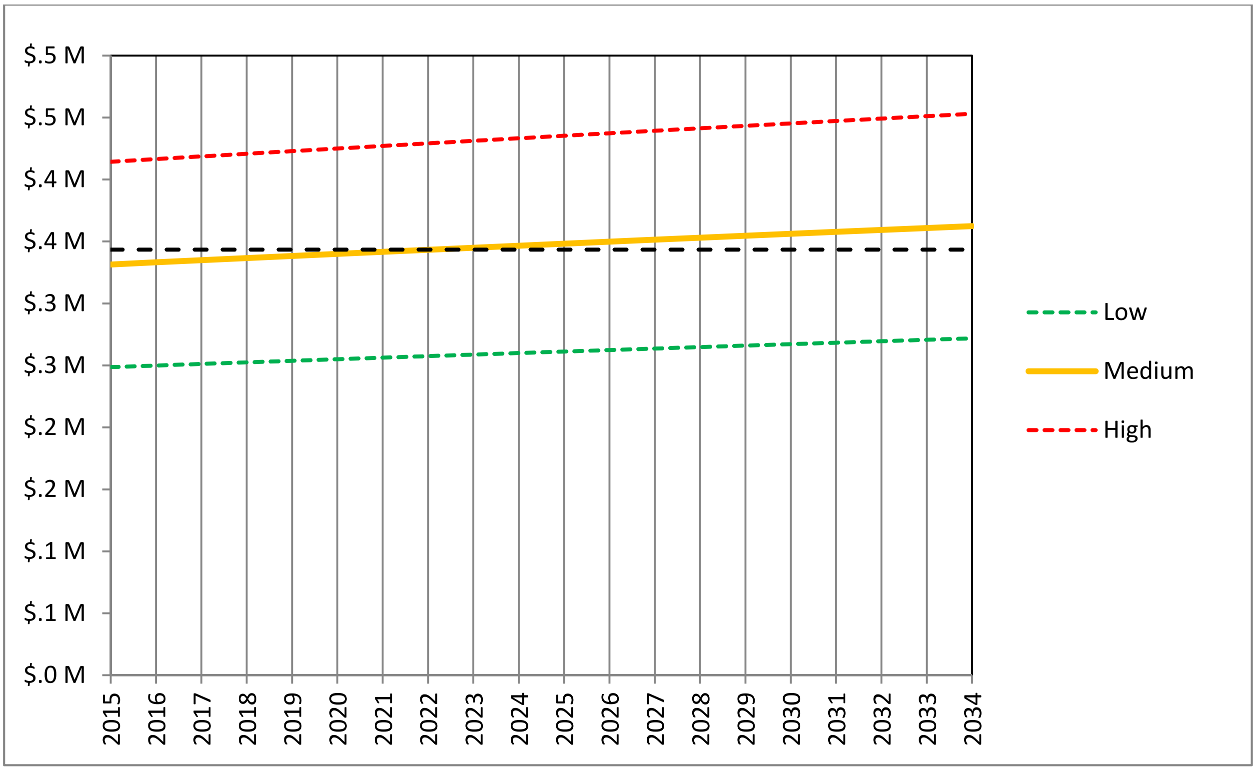
Feeder 378 Age (Average): 84 years

VCR: $44.06/kWh

Probability weighted consequence costs (β_j x $$C_j$)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Cable joint failure	80%	$ 71,250	$ 22,361	$ 2,236	$ 2,236	$ 2,236
Insulation failure (localised)	19%	$ 71,250	$ 22,361	$ 2,236	$ 2,236	$ 2,236
Insulation failure (widespread)	1%	$ 4,906,000	$ 707,107	$ 7,071,068	$ 11,180,340	$ 2,236,068
Serving failure (N/A)	0%	$ -	$ -	$ -	$ -	$ -
Gas leaks (maintenance)	0%	$ 7,321	$ 2,236	$ 2,236	$ 2,236	$ 2,236
> 2 feeders	0%	$ -	$ -	$ -	$ 35,355,339	$ -

Monetised Baseline Risk



Paddington 33kV Feeders Replacement

Feeder 380 Age (Average): 48 years

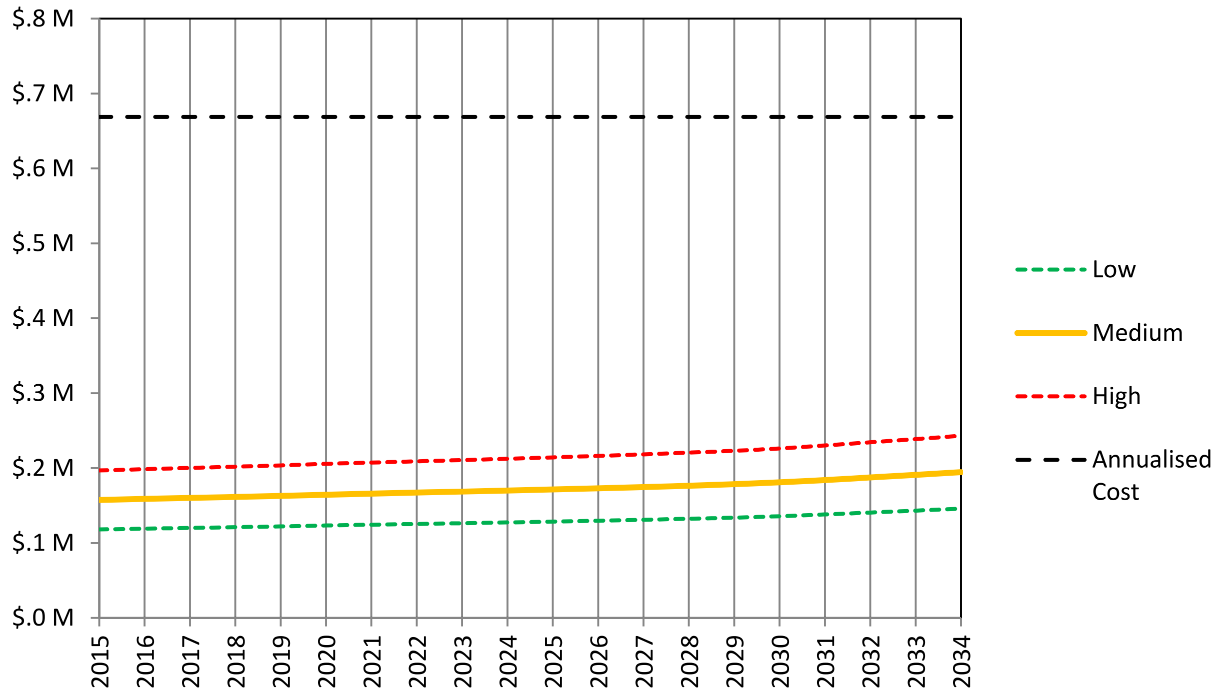
Feeder 381 Age (Average): 48 years

VCR: $26.53/kWh

Probability weighted consequence costs (β_j x $\$C_j$)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Cable joint failure	75%	$ 142,500	$ 22,361	$ 2,236	$ 2,236	$ 2,236
Insulation failure (localised)	19%	$ 142,500	$ 22,361	$ 2,236	$ 2,236	$ 2,236
Insulation failure (widespread)	1%	$ 9,555,000	$ 707,107	$ 7,071,068	$ 11,180,340	$ 2,236,068
Serving failure (N/A)	0%	$ -	$ -	$ -	$ -	$ -
Gas leaks	0%	$ 10,547	$ 2,236	$ 2,236	$ 2,236	$ 2,236
> 2 feeders	0%	$ -	$ -	$ -	$ 35,355,339	$ -

Monetised Baseline Risk



132kV Feeders 92FA/B & 90XA/B Replacement and 132kV Feeders 92JA/B & 92GA/B Replacement Top Ryde and Meadowbank

Feeder 92FA Age (Average): 42 years

Feeder 92FB Age (Average): 42 years

Feeder 92GA Age (Average): 42 years

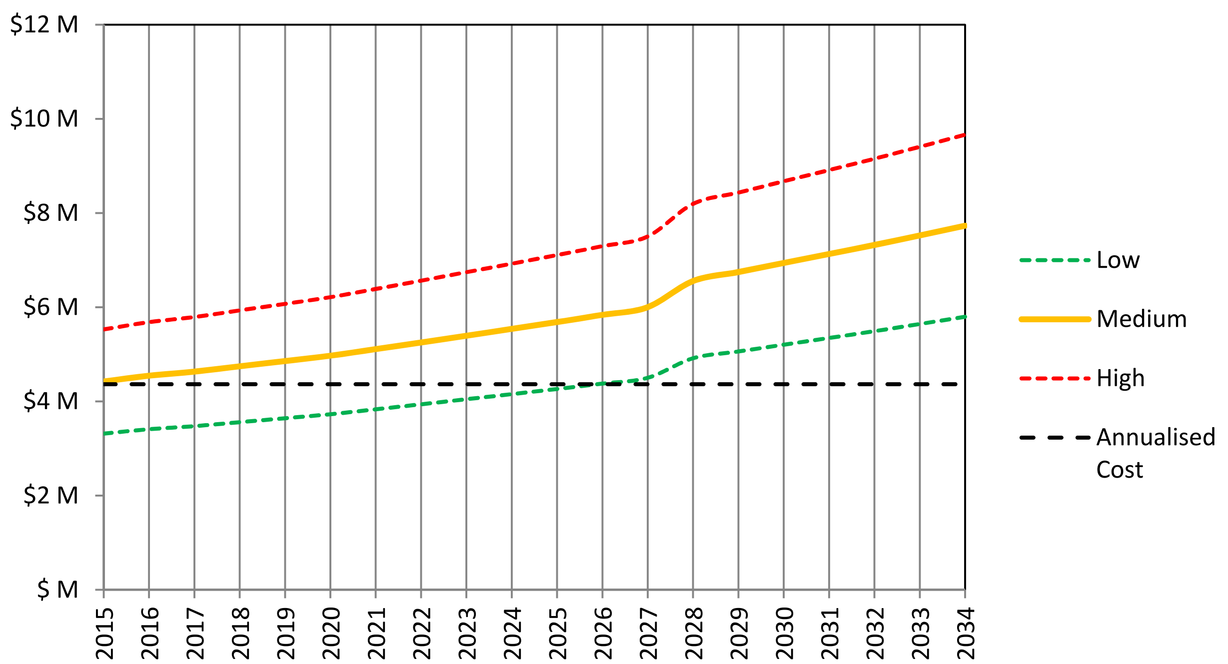
Feeder 92GB Age (Average): 42 years

VCR: $38.88/kWh

Probability weighted consequence costs (β_i x $\$C_i$)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Cable joint failure	80%	$ 142,500	$ 22,361	$ 2,236	$ 2,236	$ 2,236
Insulation failure (localised)	19%	$ 142,500	$ 22,361	$ 2,236	$ 2,236	$ 2,236
Insulation failure (widespread)	1%	$ 62,360,970	$ 707,107	$ 7,071,068	$ 11,180,340	$ 2,236,068
Serving failure (N/A)	0%	$ -	$ -	$ -	$ -	$ -
Oil leaks (maintenance)	0%	$ 79,245	$ 2,236	$ 2,236	$ 2,236	$ 707,107
> 2 feeders	0%	$ -	$ -	$ -	$ 35,355,339	$ -

Monetised Baseline Risk



Darlinghurst 33kV Feeders Replacement

Feeder 386 Age (Average): 48 years

Feeder 387 Age (Average): 48 years

Feeder 388 Age (Average): 48 years

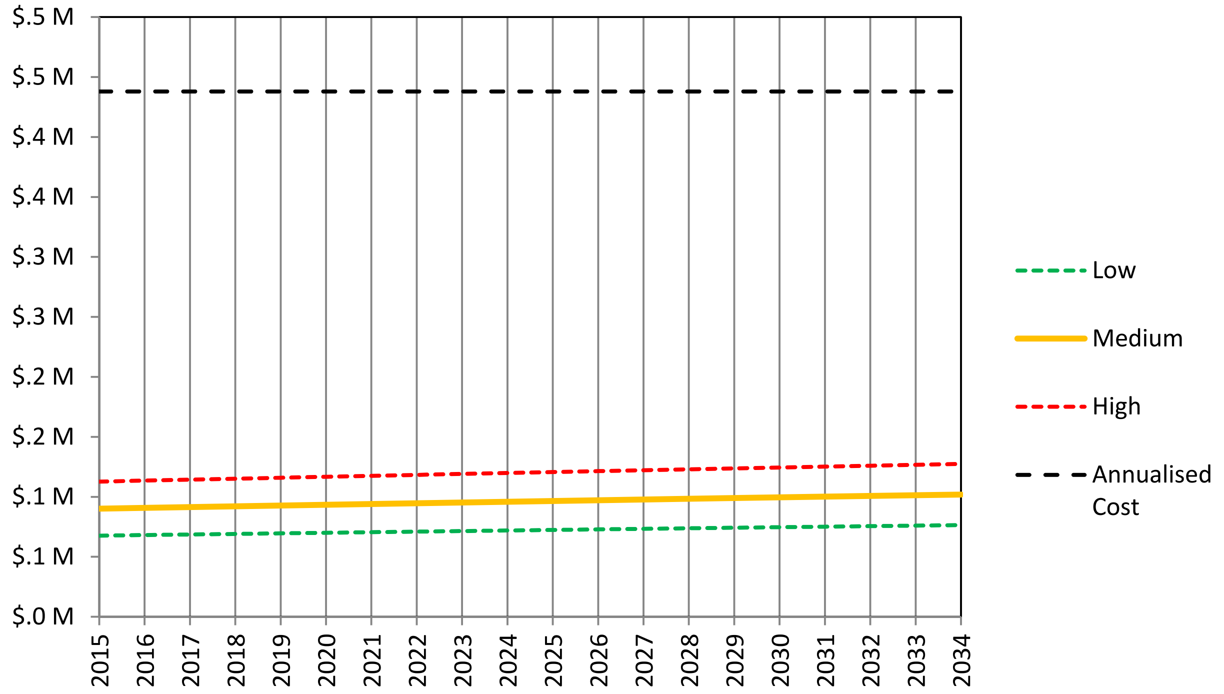
Feeder 389 Age (Average): 48 years

VCR: $44.06/kWh

Probability weighted consequence costs (β_j x $\$C_j$)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Cable joint failure	80%	$ 142,500	$ 22,361	$ 2,236	$ 2,236	$ 2,236
Insulation failure (localised)	19%	$ 142,500	$ 22,361	$ 2,236	$ 2,236	$ 2,236
Insulation failure (widespread)	1%	$ 6,257,000	$ 707,107	$ 7,071,068	$ 11,180,340	$ 2,236,068
Serving failure (N/A)	0%	$ -	$ -	$ -	$ -	$ -
Gas leaks (maintenance)	0%	$ 8,589	$ 2,236	$ 2,236	$ 2,236	$ 2,236
> 2 feeders	0%	$ -	$ -	$ -	$ 35,355,339	$ -

Monetised Baseline Risk



132kV Feeders 260/2 & 261/2 Replacement (Clovelly – Kingsford)

Feeder 260/02 Age (Average): 45 years

Feeder 261/02 Age (Average): 45 years

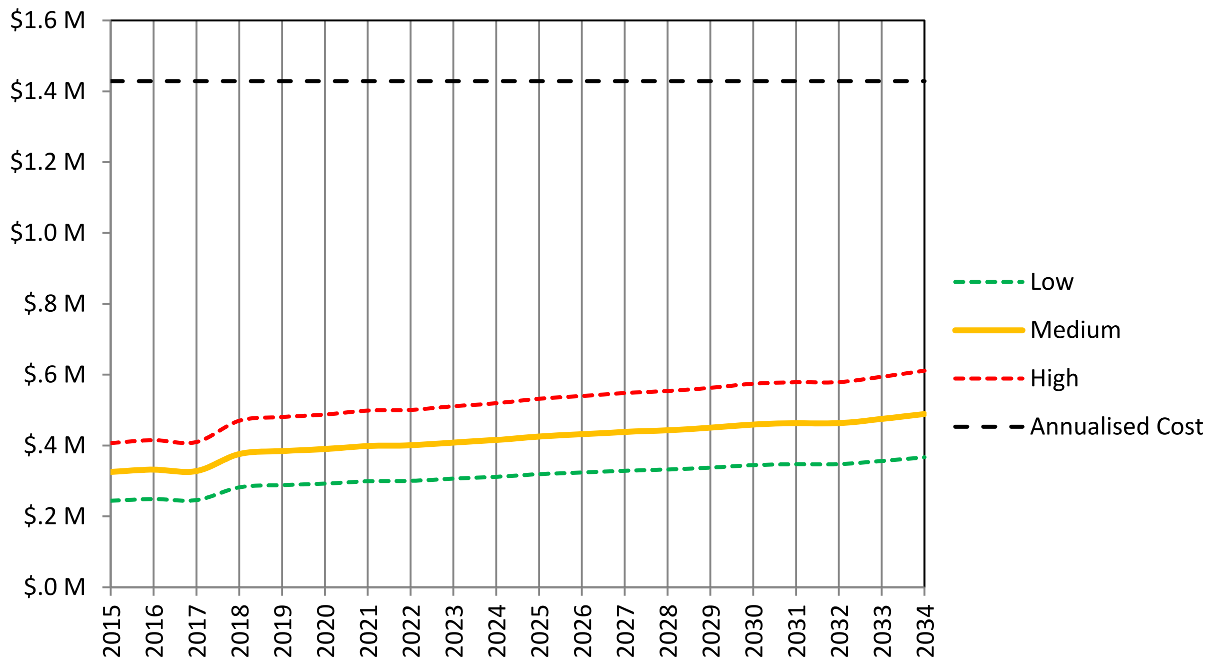
Feeder 292 Age (Average): 40 years

VCR: $36.15/kWh

Probability weighted consequence costs (β_i x $\$C_i$)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Cable joint failure	80%	$ 142,500	$ 22,361	$ 2,236	$ 2,236	$ 2,236
Insulation failure (localised)	19%	$ 142,500	$ 22,361	$ 2,236	$ 2,236	$ 2,236
Insulation failure (widespread)	1%	$ 20,409,143	$ 707,107	$ 7,071,068	$ 11,180,340	$ 2,236,068
> 2 feeders	0%	$ -	$ -	$ -	$ 35,355,339	$ -

Monetised Baseline Ris



Kotara ZS Refurbishment and 33kV Feeder 767 Replacement

Feeder 773 Age (Average): 51 years

Feeder 775 Age (Average): 51 years

Feeder 760 Age (Average): 40 years

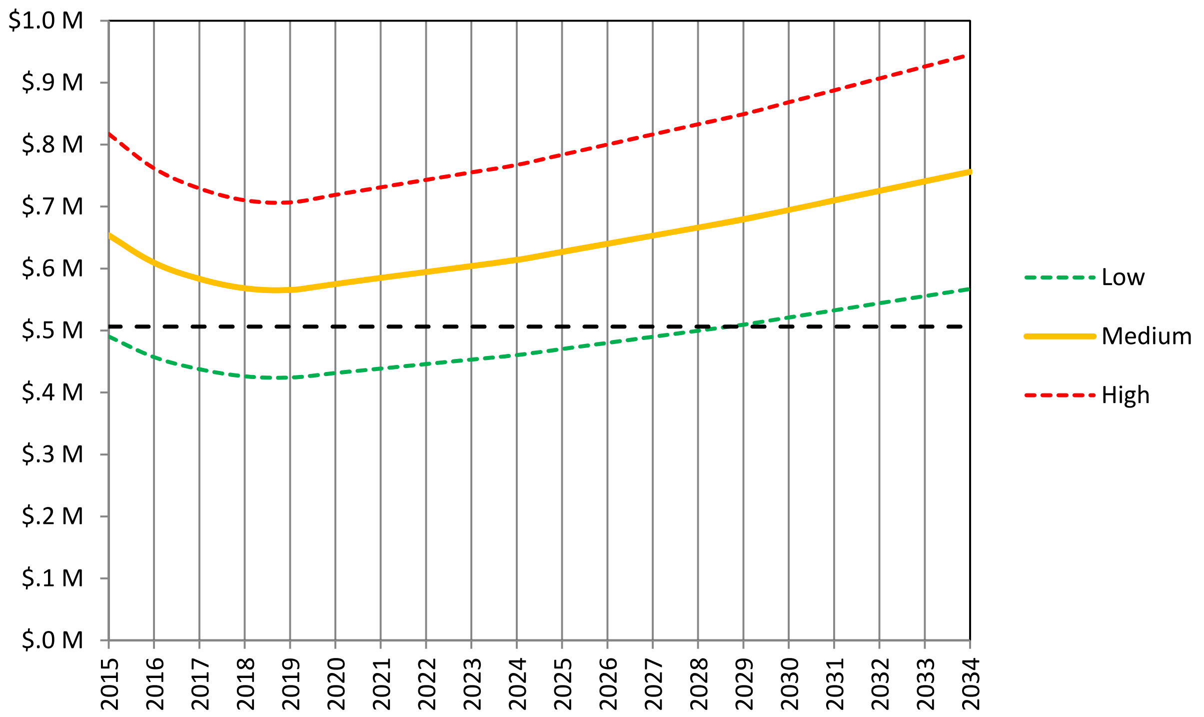
Feeder H766 Age (Average): 47 years

VCR: $35.84/kWh

<u>Probability weighted consequence costs (β_i x C_i)</u>

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Cable joint failure	75%	$ 123,539	$ 22,361	$ 2,236	$ 2,236	$ 2,236
Insulation failure (localised)	19%	$ 123,539	$ 22,361	$ 2,236	$ 2,236	$ 2,236
Insulation failure (widespread)	1%	$ 7,193,466	$ 707,107	$ 7,071,068	$ 11,180,340	$ 2,236,068
Serving failure	5%	$ 24,709	$ 2,236	$ 2,236	$ 2,236	$ 2,236
Gas leaks	0%	$ 25,540	$ 2,236	$ 2,236	$ 2,236	$ 2,236
Oil leaks	0%	$ 19,838	$ 2,236	$ 2,236	$ 2,236	$ 29,080
> 2 feeders	0%	$ -	$ -	$ -	$ 35,355,339	$ -

<u>Monetised Baseline Risk</u>



33kV Feeder 760 Replacement

Feeder 773 Age (Average): 51 years

Feeder 775 Age (Average): 51 years

Feeder 760 Age (Average): 40 years

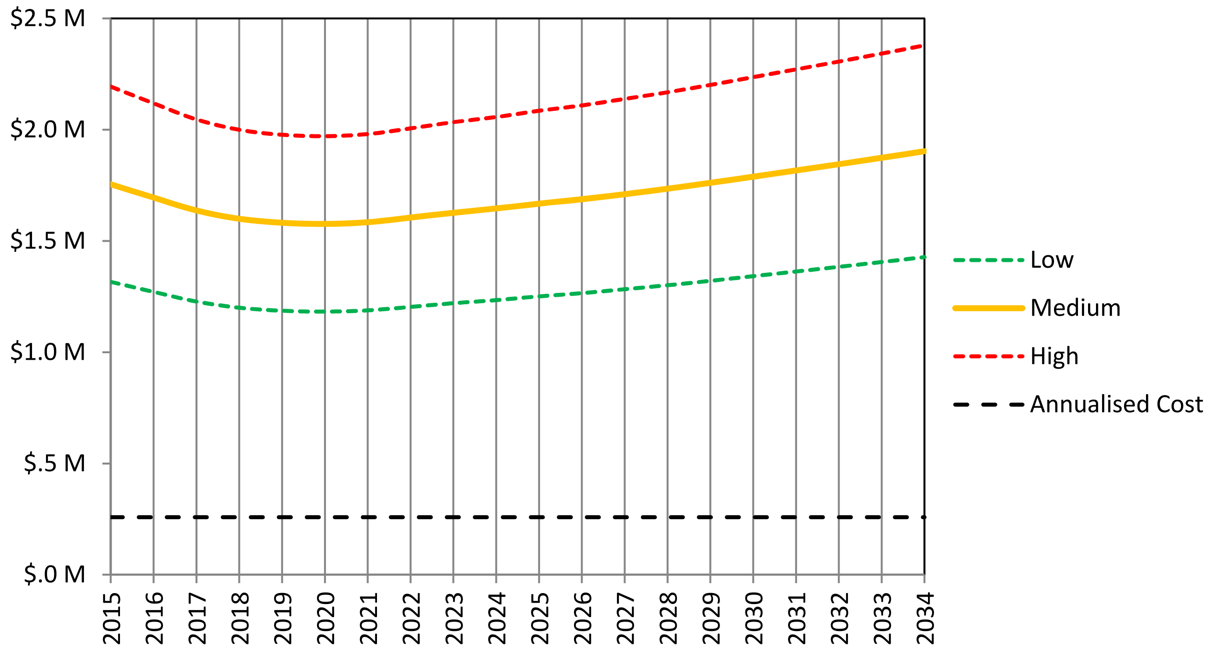
Feeder H766 Age (Average): 47 years

VCR: $35.84/kWh

Probability weighted consequence costs (β_j x $\$C_j$)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Cable joint failure	80%	$ 142,500	$ 2,236	$ 2,236	$ 2,236	$ 2,236
Insulation failure (localised)	19%	$ 142,500	$ 2,236	$ 2,236	$ 2,236	$ 2,236
Insulation failure (widespread)	1%	$ 3,692,612	$ 2,236	$ 223,607	$ 2,236,068	$ 223,607
> 2 feeders	0%	$ -	$ -	$ -	$ 5,590,170	$ -

Monetised Baseline Risk



33kV Feeder 766 Replacement

Feeder 773 Age (Average): 51 years

Feeder 775 Age (Average): 51 years

Feeder 760 Age (Average): 40 years

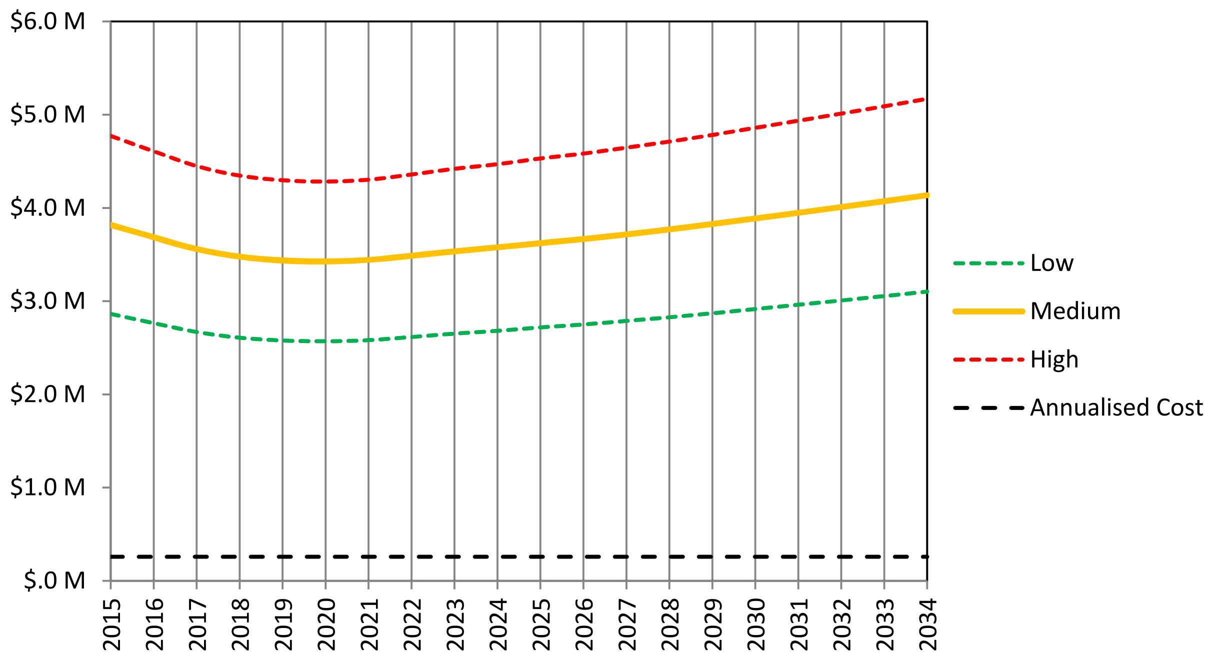
Feeder H766 Age (Average): 47 years

VCR: $35.84/kWh

Probability weighted consequence costs (β_j x $$C_j$)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Cable joint failure	80%	$ 142,500	$ 2,236	$ 2,236	$ 2,236	$ 2,236
Insulation failure (localised)	19%	$ 142,500	$ 2,236	$ 2,236	$ 2,236	$ 2,236
Insulation failure (widespread)	1%	$ 3,692,612	$ 2,236	$ 223,607	$ 2,236,068	$ 223,607
> 2 feeders	0%	$ -	$ -	$ -	$ 5,590,170	$ -

Monetised Baseline Risk



Appendix B3: Combines Projects – Assumptions and Results

Combined Strathfield South 132/11kV ZS Decommission Enfield 33/11kV ZS and Strathfield South 132kV Connections

This project replaces the aged 11kV switchboards at Enfield zone substation and the aged 33kV cables supplying Enfield zone substation.

Enfield 11kV Switchboards

Circuit breakers commissioned (Average): 1960

Switchboards commissioned: 1962

Number of aged circuit breakers: 0

Number of aged switchboards: 2

VCR: $37.31/kWh

Load transfer capacity: 777 Amps

Probability weighted consequence costs (β_i x $\$C_i$)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Isolated CB Failure	99%	$ 31,000	$ 707,107	$ 11,180	$ 22,361	$ 11,180
Propagating CB Failure	1%	$ 13,743,313	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Failure	100%	$ 13,743,313	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Fire	0%	$ 27,486,626	$ 11,180,340	$ 11,180,340	$ 11,180,340	$ 2,236,068

Enfield Feeders

Feeder 639 Age (Average): 52 years

Feeder 640 Age (Average): 52 years

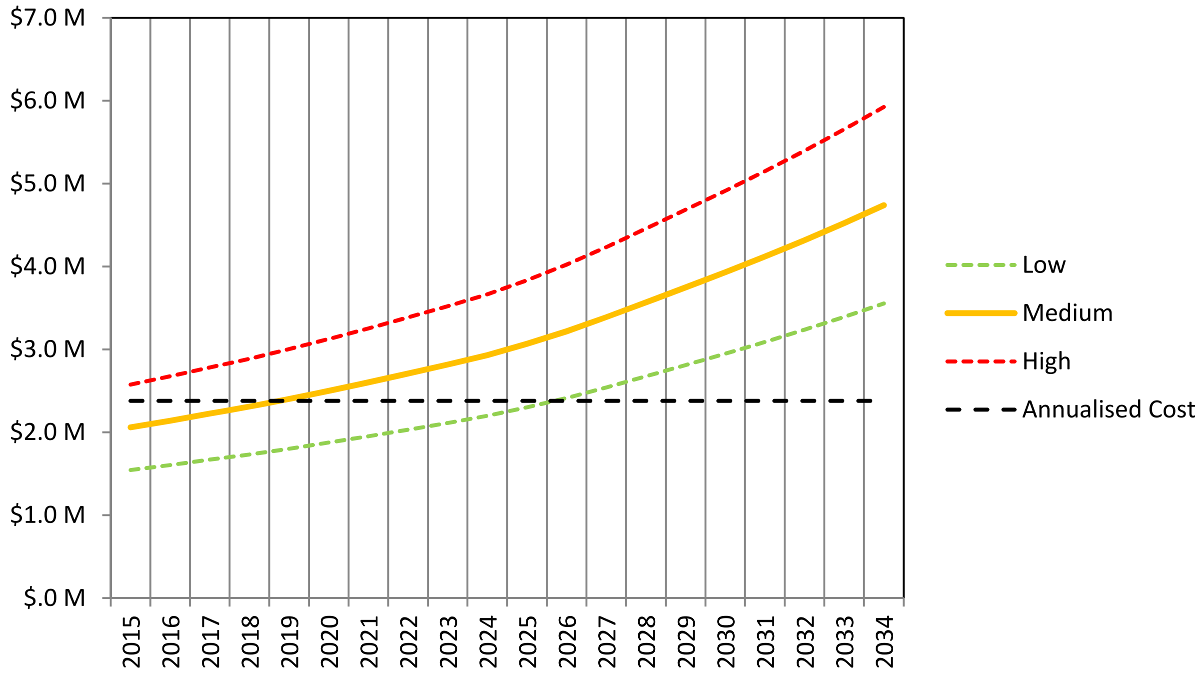
Feeder 641 Age (Average): 52 years

VCR: $44.06/kWh

Probability weighted consequence costs (β_i x $\$C_i$)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Cable joint failure	80%	$ 142,500	$ 22,361	$ 2,236	$ 2,236	$ 2,236
Insulation failure (localised)	19%	$ 142,500	$ 22,361	$ 2,236	$ 2,236	$ 2,236
Insulation failure (widespread)	1%	$ 4,719,000	$ 707,107	$ 7,071,068	$ 11,180,340	$ 2,236,068
Serving failure (N/A)	0%	$ -	$ -	$ -	$ -	$ -
Gas leaks (maintenance)	0%	$ 24,999	$ 2,236	$ 2,236	$ 2,236	$ 2,236
> 2 feeders	0%	$ -	$ -	$ -	$ 35,355,339	$ -

Monetised Baseline Risk (Combined)



Combined Dulwich Hill 33kV ZS and 33kV Feeders Replacement

This project replaces the aged 11kV switchboards at Dulwich Hill and the aged 33kV cables supplying Dulwich Hill.

Dulwich Hill 11kV Switchboards

Circuit breakers commissioned (Average): 1960

Switchboards commissioned: 1960

Number of aged circuit breakers: 0

Number of aged switchboards: 2

VCR: $36.03/kWh

Load transfer capacity: 1235 Amps

Probability weighted consequence costs (β_i x C_i)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Isolated CB Failure	99%	$ 31,000	$ 707,107	$ 11,180	$ 22,361	$ 11,180
Propagating CB Failure	1%	$ 10,933,052	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Failure	100%	$ 10,933,052	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Fire	0%	$ 21,866,104	$ 11,180,340	$ 11,180,340	$ 11,180,340	$ 2,236,068

Dulwich Hill 33kV Feeders

Feeder 636 Age (Average): 66 years

Feeder 643 Age (Average): 49 years

Feeder 644 Age (Average): 49 years

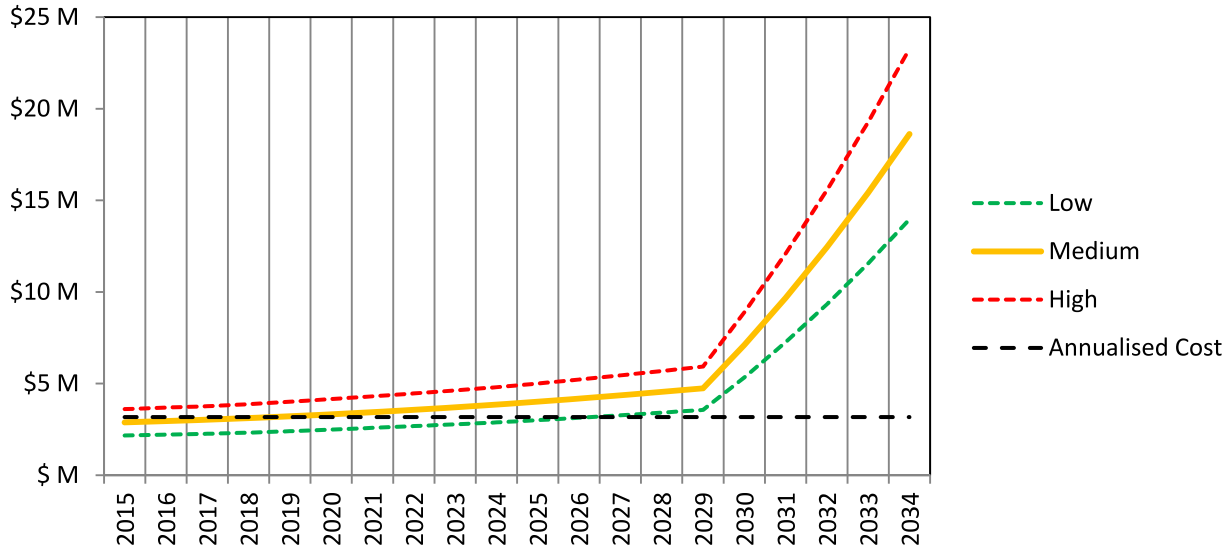
Feeder 645 Age (Average): 49 years

VCR: $26.03/kWh

Probability weighted consequence costs (β_i x C_i)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Cable joint failure	80%	$ 142,500	$ 22,361	$ 2,236	$ 2,236	$ 2,236
Insulation failure (localised)	19%	$ 142,500	$ 22,361	$ 2,236	$ 2,236	$ 2,236
Insulation failure (widespread)	1%	$ 21,866,000	$ 707,107	$ 7,071,068	$ 11,180,340	$ 2,236,068
Serving failure (N/A)	0%	$ -	$ -	$ -	$ -	$ -
Gas leaks (maintenance)	0%	$ 27,583	$ 2,236	$ 2,236	$ 2,236	$ 2,236
> 2 feeders	0%	$ -	$ -	$ -	$ 35,355,339	$ -

Monetised Baseline Risk (Combined)


$25 M
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2032
2033
2034
Low
Medium
High
Annualised Cost

Combined New Alexandria STS and 33kV Feeders Replacement

This project replaces the 33kV cables supplying both Mascot zone substation and Sydney Airport.

Sydney Airport 33kV Feeder Replacement (Alexandria STS)

Feeder 341 Age (Average): 84 years

Feeder 332 Age (Average): 66 years

Feeder 328 Age (Average): 58 years

Feeder 327 Age (Average): 66 years

Feeder 337 Age (Average): 62 years

VCR: $89.44/kWh[8]

Probability weighted consequence costs (β_j x $$C_j$)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Cable joint failure	80%	$ 71,250	$ 22,361	$ 2,236	$ 2,236	$ 2,236
Insulation failure (localised)	19%	$ 71,250	$ 22,361	$ 2,236	$ 2,236	$ 2,236
Insulation failure (widespread)	1%	$ 22,659,000	$ 707,107	$ 7,071,068	$ 11,180,340	$ 2,236,068
Serving failure (N/A)	0%	$ -	$ -	$ -	$ -	$ -
Gas leaks (maintenance)	0%	$ 84,835	$ 2,236	$ 2,236	$ 2,236	$ 2,236
> 2 feeders	0%	$ -	$ -	$ -	$ 35,355,339	$ -

Mascot 33kV Feeders Replacement (Alexandria – Mascot)

Feeder 341 Age (Average): 84 years

Feeder 332 Age (Average): 66 years

Feeder 328 Age (Average): 58 years

Feeder 327 Age (Average): 58 years

Feeder 337 Age (Average): 68 years

Feeder 360 Age (Average): 63 years

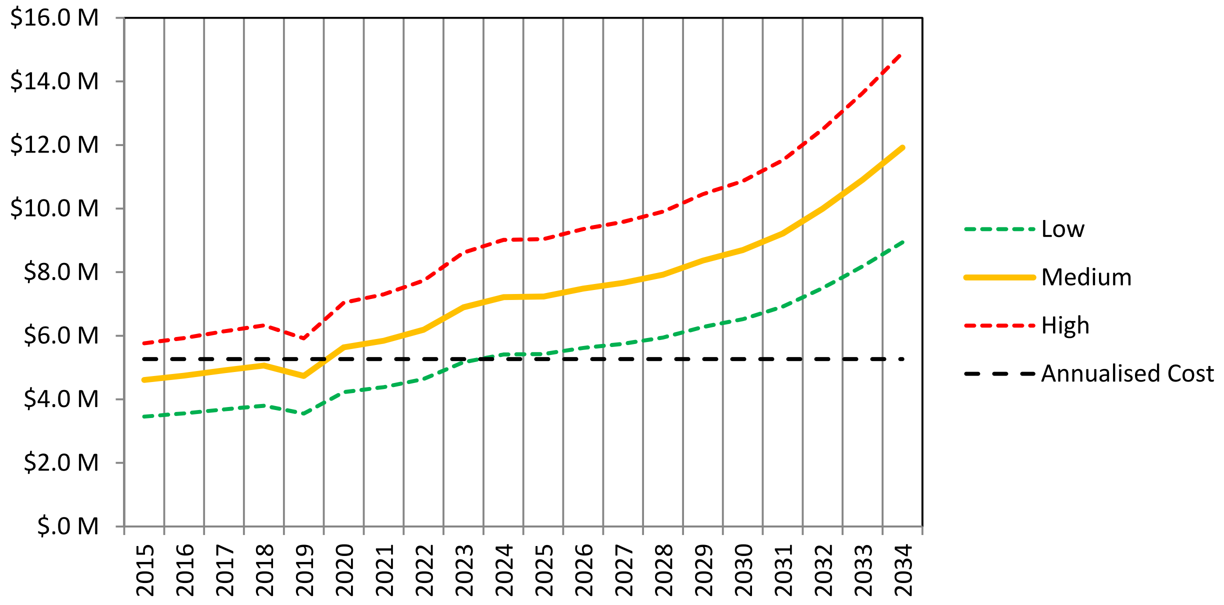
VCR: $44.06/kWh

Probability weighted consequence costs (β_j x $$C_j$)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Cable joint failure	80%	$ 71,250	$ 22,361	$ 2,236	$ 2,236	$ 2,236
Insulation failure (localised)	19%	$ 71,250	$ 22,361	$ 2,236	$ 2,236	$ 2,236
Insulation failure (widespread)	1%	$ 14,176,000	$ 707,107	$ 7,071,068	$ 11,180,340	$ 2,236,068
Serving failure (N/A)	0%	$ -	$ -	$ -	$ -	$ -
Gas leaks (maintenance)	0%	$ 86,069	$ 2,236	$ 2,236	$ 2,236	$ 2,236
> 3 feeders	0%	$ -	$ -	$ -	$ 35,355,339	$ -

[8] VCR is multiplied by 2 to account for Sydney Airport (sensitive load customer)

Monetised Baseline Risk (Combined)



Combined Lidcombe ZS Refurbishment and Auburn and Lidcombe 33kV Feeders Replacement

This project replaces the aged 11kV switchboards and circuit breakers at Lidcombe zone substation and the aged 33kV cables supplying both Lidcombe and Auburn zone substations.

Lidcombe 11kV Switchboards

Circuit breakers commissioned (Average): 1966

Switchboards commissioned: 1972

Number of aged circuit breakers: 7

Number of aged switchboards: 2

VCR: $40.32/kWh

Load transfer capacity: 558 Amps

Probability weighted consequence costs (β_i x $\$C_i$)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Isolated CB Failure	99%	$ 31,000	$ 707,107	$ 11,180	$ 22,361	$ 11,180
Propagating CB Failure	1%	$ 10,655,264	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Failure	100%	$ 10,655,264	$ 707,107	$ 111,803	$ 223,607	$ 223,607
Board Fire	0%	$ 21,310,527	$ 11,180,340	$ 11,180,340	$ 11,180,340	$ 2,236,068

Auburn and Lidcombe 33kV Feeders Replacement

Feeder 601 Age (Average): 72 years

Feeder 614 Age (Average): 60 years

Feeder 615 Age (Average): 65 years

Feeder 602 Age (Average): 61 years

Feeder 604 Age (Average): 65 years

Feeder 605 Age (Average): 61 years

VCR: $44.06/kWh

Probability weighted consequence costs (β_i x $\$C_i$)

Failure Scenario	α	Finance	Safety	Compliance	Reputation	Environment
Cable joint failure	80%	$ 142,500	$ 22,361	$ 2,236	$ 2,236	$ 2,236
Insulation failure (localised)	19%	$ 142,500	$ 22,361	$ 2,236	$ 2,236	$ 2,236
Insulation failure (widespread)	1%	$ 31,478,000	$ 707,107	$ 7,071,068	$ 11,180,340	$ 2,236,068
Serving failure (N/A)	0%	$ -	$ -	$ -	$ -	$ -
Gas leaks (maintenance)	0%	$ 63,998	$ 2,236	$ 2,236	$ 2,236	$ 2,236
> 2 feeders	0%	$ -	$ -	$ -	$ 35,355,339	$ -

Monetised Baseline Risk (Combined)