APPENDIX A - RISK vs EXPENDITURE MODEL

CONSEQUENCE VALUATION FRAMEWORK

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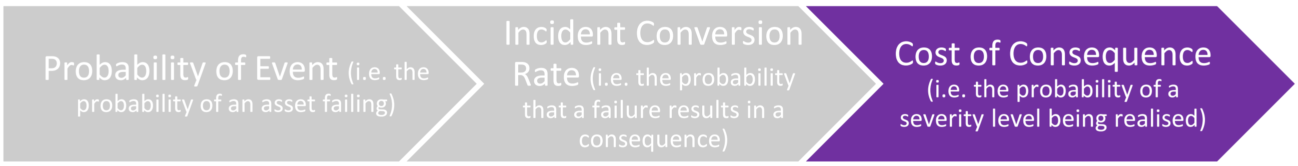
1 Introduction

1.1 Purpose

The purpose of the Risk versus Expenditure Model (REM) is to provide a strategic assessment (i.e. top-down) to the prudency and efficiency of the forecast (bottom-up) investment programme. The assessment considers how the level of network risk varies under different investment scenarios and asset class expenditure profiles (i.e. the asset classes to which the expenditure is directed), and examines how effective the overall investment is at achieving an optimal risk outcome.

The purpose of the Consequence Valuation Framework is to outline the method used to value and quantify the costs of consequence in the REM.

The REM applies a consistent valuation of consequences across all assets.



This document focusses on the *"Cost of Consequence"* in the above diagram. The "*Probability of Event*" and "*Incident Conversion Rate*" are not in scope.

1.2 Principles

The model seeks to establish economic costs, which are those costs estimated to be borne by the community due to an event occurring. In estimating the economic costs of consequences, care was taken to avoid double counting costs and to determine the appropriate economic values. The financial cost to the business associated with an event occurring is included in the economic cost.

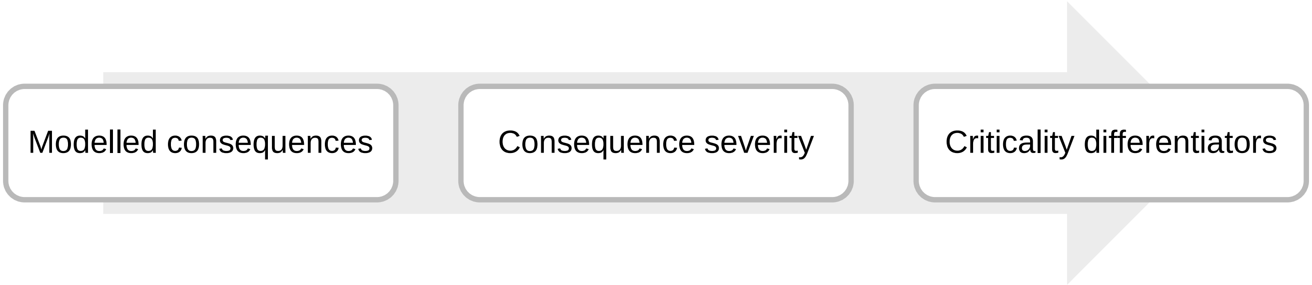
Valuing consequences based on economic costs is considered appropriate because, as a rule, it is the Network Service Provider's customers that bear the costs associated with the consequences of network risks.

The unique character of each consequence means that the framework has application for modelling and comparing risks of various network investment scenarios. The relativity of consequences is of crucial importance in the REM as the model output considers how varying expenditure scenarios impact on the risk profile of the network.

It is pertinent to note that the model's outputs vary from time to time as relevant input information is revised to reflect updated knowledge gained from industry insights and ongoing literature reviews.

2 Framework

The framework comprises three components as shown below.



2.1 Modelled consequences

The modelled consequences considered are shown in Table 1.

Table 1: Modelled consequences

CM Modelled consequences	Details
Safety (Public)	Injury to the public associated with network assets
Safety (Workforce)	Injury to network workers associated with work on the network
Outage	Loss of supply from unplanned interruptions
Fire	Losses (human and property) incurred from fires started by network assets

The quantification of modelled consequences is developed by calculating a probability weighted value based on the consequence severity, differentiated across criticality zones.

2.2 Consequence severity

Each type of consequence can occur with different severity levels. For example, an electric shock (safety incident) can range from a minor tingle (near miss) through to a fatality.

For safety (public and workforce) and fire, the consequences are quantified against a five-point severity scale. To determine a probability weighted value for the consequence, two attributes are determined and used for each severity level within the scale, an economic (i.e. community) cost and a probability of the severity level being realised.

The consequence severity categories are shown in Table 2.

Table 2: Consequence severity levels

Consequence Severity	Economic cost (for each consequence) (a)	Probability of severity being realised (b)	Weighted cost
Insignificant			a x b
Minor			a x b
Moderate	Refer 2.2.1	Refer 2.2.2	a x b
Major			a x b
Catastrophic			a x b
		Consequence value	Sum above

For consequences associated with Outage the severity of consequence was determined by the estimated average load on each asset.

2.2.1 Economic costs

Economic costs associated with consequences from network events can be challenging to value in dollar terms because their magnitude is often uncertain. To evaluate the costs for each severity level, the approach taken was to first value the "*Catastrophic*" severity level for each consequence. These values were established based on comprehensive research conducted across a wide range of literature (refer to Appendix A).

To establish values for the other severity levels, a logarithmic scale was applied. According to (Duijm, 2015), moving from minor to major injuries, and to fatalities, can be considered a logarithmic increase in severity. This is also supported by the European Railway Agency concept of 'fatalities and weighted serious injuries (FWSI)', "whereby 1 serious injury is considered statistically equivalent to 0.1 fatality" (European Railway Agency, 2008). Logarithmic relationships have also been inferred from empirically observed occurrences of different consequences. (Prem, Ng et al., 2010) has observed that the frequency of: minor injury; major injury; fatality; 10 fatalities; 100 fatalities, varies approximately by a factor of 10 from one category to the next. (Levine, 2012) advanced the case for using a logarithmic scale in that it can better differentiate between consequences with a large range.

The evaluation of the economic costs for the modelled consequences is discussed in Section 3.

2.2.2 Probability of severity being realised

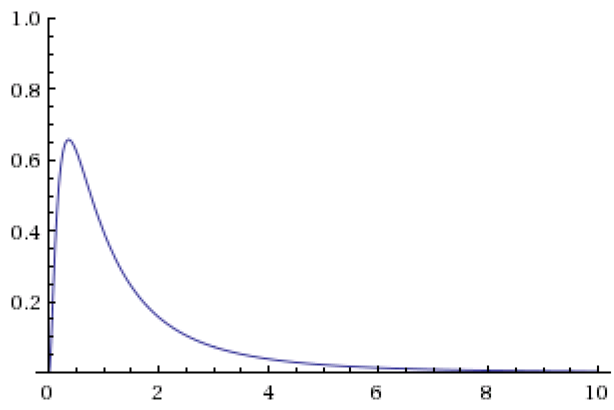
2.2.2.1 Safety and Fire

For Safety and Fire consequences, probabilities for each severity level were determined using historic claims data for NSP businesses. The steps are outlined below.

Step 1 – Apply log normal distribution to claims data

A log normal distribution was fitted to claims data from a 10-year period for safety and fire incidents. The log normal distribution was selected to ensure that there would be sufficient weight applied to the probability of high consequence, low likelihood events.

Figure 1: Probability distribution function of log normal – (x-axis is the cost)



Step 2 – Establish severity cut-offs to calculate the probability at each severity level

Severity cut-offs were applied to the log normal distribution function to calculate the probability weighting to apply at each severity level. The values selected for the severity cut-offs were established to capture a range around the economic costs of each severity level.

2.2.2.2 Outage

As mentioned above, for consequences associated with Outage, the severity of consequences was determined by the estimated average load on each asset.

2.2.2.3 Workforce

For workforce consequences, the value was set equal to the public safety cost of consequence.

2.3 Criticality differentiators

Consequence criticality differentiators were developed for consequence categories of fire and public safety to allow for differentiation between events and subsequent consequences occurring in areas of higher and lower criticalities.

The use of differentiators captures the fact that not all events across the network can be considered equally. For example, from a bushfire risk perspective, a conductor failure in a bushfire abatement zone is more critical than a conductor failure in an urban area.

For consequences associated with Outage criticality was determined by the average estimated load connected to an asset.

Workforce consequences were not differentiated by criticality considerations.

2.3.1 Safety

For safety consequences, land use classifications were used as the criticality differentiator, whereby the classification near and around the asset determine how critical the asset is.

To adjust the consequence values across the criticality differentiators, the mean of the log normal distribution was doubled for high criticality zones and halved for low criticality zones.

Table 3: Safety consequence differentiators

Criticality	Description
C1 (High)	Community facilities, town centres
C2 (Medium)	Local shopping centres, industrial areas, apartments, townhouses
C3 (Low)	Suburban, roads, open spaces around urban areas
C4 (Very low)*	Rural, farmland, national parks

**From a cost perspective C3 and C4 were combined into a single "Low" category for Evoenergy*

2.3.2 Fire

For fire consequences, the differentiator applied was each asset's assignment to rural, urban or bushfire abatement zones, where the abatement zone areas are high bushfire risk locations on the urban fringe.

Table 4: Fire consequence differentiators

Criticality	Description
C1 (High)	Bushfire abatement zone
C2 (Medium)	Urban
C3 (Low)	Rural

To adjust consequence values across the criticality differentiators, the probability of each severity being realised was moderated by considering how environmental conditions contribute to the likelihood of each severity level being realised. Catastrophic fires are only likely to occur on catastrophic fire days. Based on the NSW Rural Fire Service Total Fire Ban declarations, these conditions are only likely to occur around 1% of the time in a year in NSW (and the ACT). The values used to moderate criticalities are shown in Table 5.

Table 5: Fire criticality zone moderators

Fire consequence severity	Moderator for environmental conditions			
	C4*	C3	C2	C1
Insignificant	1	1	1	1
Minor	0.25	0.5	1	1
Moderate	0	0.03	0.075	0.15
Major	0	0.01	0.025	0.05
Catastrophic	0	0	0	0.01

**unused for Evoenergy*

2.4 Disproportionality factors

The application of AS 5577 Electricity Network Safety Management Systems in managing safety risks associated with the operation of an electricity network is called upon within the Acts and Regulations of the ACT. The standard requires network safety risks to be eliminated, and if this is not reasonably practicable, then to be reduced to as low as reasonably practicable (ALARP). A common approach applied within the industry to determine whether ALARP has been achieved is to determine whether the cost of reducing the risk is grossly disproportionate to the quantified safety benefits gained.

The application of a Disproportionate Factors (DFs) to the consequence value represents an organisations appetite to spend more than the value of the safety risk avoided to reduce the risk.

Guidance from the Health Safety Executive (UK) suggests that a DF between 2 and 10 can be used. Higher values are used for situations where extensive harm is possible if the risk event were to occur. The application of the DF allows for the REM to prioritise investment to meet community expectations that the organisation should invest a greater multiple to reduce some risks as compared to others.

Table 6 shows the disproportionality multipliers for different safety risks used within the REM. The multipliers are consistent with those in use in other utilities in Australia, the Office for Nuclear Regulation (UK), and the utility industry in the UK (OFGEM).

Table 6: Disproportionality factors used in the REM

Safety consequence	Disproportionality factor
Safety	3
Bushfire	6
Workforce	3

3 Consequence valuation

As outlined in Section 1.2, the REM considers the economic costs associated with consequences from network events.

The framework for valuing the economic costs was discussed in Section 2.2.1 whereby, the approach involves valuing the "*Catastrophic"* severity level for each consequence and applying a logarithmic scale to establish values at the declining levels of consequence severity. This approach is supported by academic research (Duijm, 2015), (Prem, Ng et al., 2010), (Levine, 2012) and the European Railway Agency (European Railway Agency, 2008).

3.1 Safety

Safety incidents were valued using the "Value of Statistical Life" (VSL). The VSL represents willingness to pay for reductions in the risk of physical harm.

In 2014, the Australian Government published a guidance note on applying VSL in regulatory impact statements and cost benefit analysis (Australian Government, 2014). Based on international and Australian research, the guidance note provided a credible estimate of the value of a statistical life of $4.2m in 2014 dollars. This value was used in the REM for the catastrophic safety consequence.

The community cost for the major severity level was determined by applying the disability weighting of the average of long-term injuries, amputations and fractures from the Australian Institute of Health and Welfare (Mathers et al 1999, pp. 202) to the VSL (the disability weighting applied to the VSL was 30%). The severity levels less than major followed a logarithmic scale based on the catastrophic severity.

Table 7: Safety cost of consequence

Severity	Cost ($ 2017)	Log normal PDF severity cut-off	Probability of severity	Probability weighted cost
Insignificant	4,523	0 – 10,000	0.72	3,260
Minor	45,229	10,001 – 100,000	0.24	10,817
Moderate	452,294	100,001 – 1,000,000	0.04	17,333
Major	1,356,882	1,000,001 – 5,000,000	0.002	2,291
Catastrophic	4,522,941	> 5,000,001	9.7×10^{-5}	437
			Safety consequence	$34,138

As discussed in section 2.2.2, the "probability of severity" was determined by fitting a log normal distribution to the historic claims data available for safety incidents.

3.1.1 Safety criticality differentiators and disproportionality adjustment

As discussed in section 2.2.2, low and high criticality differentiators for electric shock were established by doubling and halving the mean value of the log normal distribution.

Table 8: Electric shock cost of consequence by criticality differentiator

Criticality zone	Cost ($ 2017)	Cost with disproportionality factor ($2017)
C3 (Low)	11,677	35,031
C2 (Medium)	34,138	102,441
C1 (High)	100,524	301,572

3.2 Workforce

The valuation for workforce consequences was set equal to the high criticality value for safety. The high criticality differentiator was selected on the basis that network workers would be working on and near the assets, thereby exposing workers to a high level of consequence criticality. Workforce consequences were not differentiated by criticality as any work performed on an asset is equally exposed to the consequences.

Table 9: Workforce cost of consequence by criticality differentiator

Criticality zone	Cost ($ 2017)	Cost with disproportionality factor ($2017)
Constant	100,524	301,572

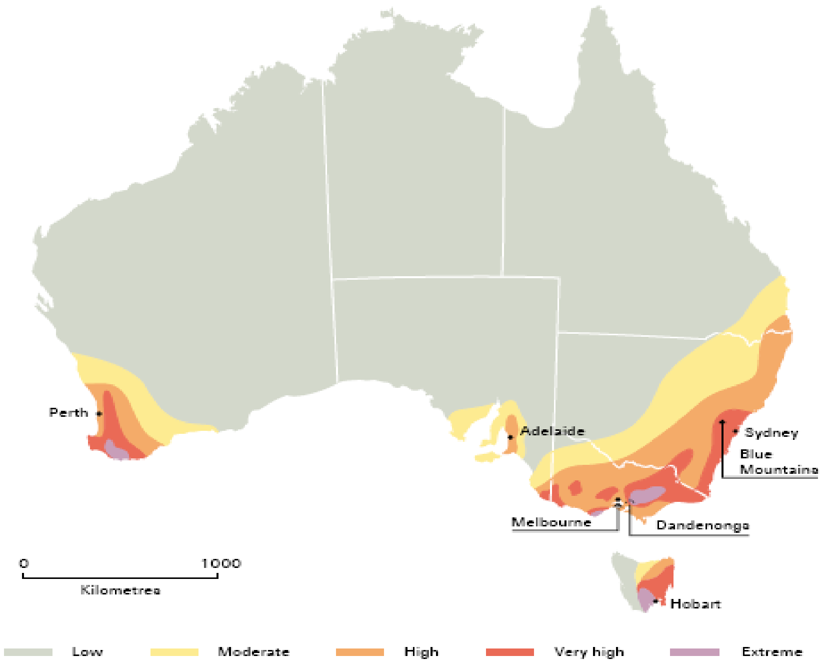
3.3 Fire

The valuation of fire risk was developed from comprehensive research conducted into establishing the value of a catastrophic bushfire in NSW (considered applicable to ACT). NSW Rural Fire Service investigation data shows that fires caused by power lines over recent years only represented in approximately 3% of total fires investigated and is therefore considered a very minor source of fire.

Reports prepared for NSW DNSPs for insurance purposes investigated the major differences between states with respect to bushfire risk. The conclusions from the investigation and modelling was that NSW had a significantly lower risk of catastrophic bushfires than Victoria. Key findings from the investigation were:

- NSW did not have any extreme bushfire potential zones whereas Victoria, Tasmania and Western Australia did.
- The regular occurrences of meteorological conditions that are conducive to fire starts on extreme bushfire prone days occurred in Victoria but not in NSW. When combining both factors, Victoria is exposed to "Extreme" bushfire risks which are not present in NSW;
- “Extreme” bushfire potential zones have 3-5 times greater frequency of house damage than a “Very High” zone;
- 30% of all historical bushfire losses are in “Extreme” bushfire potential zones;
- 90% of properties destroyed are within 100 metres of bushland. Victoria has over 9,500 houses within 100 metres of bushland in an “Extreme” bushfire potential zone, whereas NSW has none;
- Loss causing bushfires have a similar frequency in Victoria and NSW at approximately 1 in 3 years. However, Victoria has a greater magnitude of bushfire losses and severe fire days than NSW; and
- Victoria has experienced the greatest percentage of bushfire related building damage over the last 110 years
- Fire consequence modelling (Phoenix RapidFire developed by the University of Melbourne) carried out by Professor Tolhurst delivered results broadly consistent with the above observations.

Figure 2: Bushfire prone land across Australia



The valuation of the economic costs associated with 2009 Victorian bushfires estimated the cost at $4,369 million ($4.4b in 2009 dollars) with the average cost for each fire that broke out in the order of $330 million. A Regulatory Impact Statement (RIS) associated with proposed policy changes in Victoria following the 2009 fires (ACIL ALLEN, 2015) investigated a range of data and information and found that the average cost per fire over $10 million was in the order of $300 million. Of note however is those fires started by electricity assets contributes a proportion to the average. On this basis, the value applied in the RIS for the average annual cost of fires cause by electricity assets was $80 million.

Combining the analysis following the 2009 Victorian fires with the NSW investigations into bushfire risk, it is expected that on average, a catastrophic fire in NSW or the ACT is likely cost between $66 million and $110 million while the average annual cost would be between $16 million and $26 million.

The value of catastrophic bushfires in NSW and the ACT were estimated at the lower end of the range, being $66 million. The severity levels were determined by applying a logarithmic scale as discussed in section 2.2.1.

Table 10: Fire cost of consequence

Severity	Cost ($ 2017)	Log normal PDF severity cut-off	Probability of severity	Probability weighted cost	Criticality moderator			
					C1	C2	C3	C4
Insignificant	6,600	0 – 50,000	0.41	2,698	1	1	1	1
Minor	66,000	50,001 – 500,000	0.58	38,174	0.25	0.5	1	1
Moderate	660,000	500,001 – 5,000,000	0.0125	8,250	0	0.03	0.075	0.15
Major	6,600,000	5,000,001 – 50,000,000	0.0003	1,980	0	0.01	0.025	0.05
Catastrophic	66,000,000	> 50,000,001	1.3×10^{-6}	86	0	0	0	0.01
				Fire consequence	12,242	22,053	41,540	42,210

As discussed in section 2.2.2, the "probability of severity" was determined by fitting a log normal distribution to the historic claims data available for fire events.

3.3.1 Fire criticality differentiators and disproportionality adjustment.

As discussed in section 2.3.2, criticality differentiators for fire were established by moderating the probability across each criticality by how environmental conditions contribute to the likelihood of each severity level being realised.

Table 11: Fire cost of consequence by criticality differentiator

Criticality zone	Cost ($ 2017)	Cost with disproportionality factor ($2017)
C4 (Very low)*	12,242	73,450
C3 (Low)	22,053	132,315
C2 (Moderate)	41,540	249,244
C1 (High)	42,210	253,259

* not used for Evoenergy

3.4 Outage

The common approach to valuing the benefits of avoiding an outage is through the Value of Customer Reliability (VCR). In a similar manner to VSL, VCR is used when assessing the benefits and risks associated with outages on the network.

All methods for estimating VCR are prone to error and uncertainty. This is because the VCR is generally estimated indirectly from data obtained in customer surveys. Recent studies to value VCR have demonstrated the significant variations that can occur:

- VENCorp (AEMO) 2007-08 estimate of $63 per kWh;
- Oakley Greenwood's 2012 estimate of the NSW VCR of $95 per kWh; and
- AEMO's 2014 estimate of NSW VCR of $38.35 per kW.

It should be noted that AEMO do not publish an ACT specific value and instead the NSW values are adopted.

AEMO 2014 estimates for VCR were develop through a Willingness to Pay (WTP) survey and Choice Modelling (WTA). The final report identified many challenges that AEMO faced in developing the VCR. Of note, this included:

- "Functional literacy" being a common issue with many respondents having difficulties interpreting their electricity bill and grasping the underlying technical and financial concepts covered in the survey;
- It being difficult to engage and recruit customers to participate; and
- The survey being more challenging for respondents than a usual "perception" survey as it sought to quantify non-economic losses under hypothetical scenarios.

The survey was based on a sample size of 1,416 residential customers (consisting of 304 customers in NSW). Responses to the valuation questions indicated a large number of respondents (69.82%) had no willingness to pay to avoid the base case outage, thereby implying that the current level of reliability for electricity is perceived as satisfactory.

In relation to the confidence intervals applying to its VCR estimates, the AEMO's Final Report states:

> *"In order to produce confidence intervals for the overall $/kWh VCR results, additional probabilistic modelling (likely involving a Monte Carlo simulation) would have to be undertaken. Such a simulation would estimate probabilistically the net impact of the combined uncertainties from both the survey results and*

> *supporting data to determine rough confidence intervals. Due to the lack of information on the standard errors and confidence intervals associated with the supporting data (such as AER's RIN data, BREE data, and demand data), AEMO did not undertake this analysis.*
>
> *On the basis of the choice modelling results alone, the approximate confidence interval for a VCR produced in this study is +/-30%, which is an acceptable range for a survey of this nature."*

The VCR used within the REM is the lower bound of AEMO's 2014 NSW VCR, of $26.85 / kWh.

Appendix A.Literature considered in valuing consequence severity

1) Department of the Prime Minister and Cabinet: Office of Best Practice Regulation, Best Practice Regulation Guidance Note: Value of statistical life, Australian Government, 2014

2) Handbook of cost–benefit analysis, Commonwealth of Australia (2006, pp. 18–24)

3) Recommendations on the use and design of risk matrices, Nijs Jan Duijm (Duijm, Nijs Jan), Technical University of Denmark (DTU), Department of Management Engineering, Produktionstorvet, (https://www.researchgate.net/publication/273579042_Recommendations_on_the_use_and_design_of_risk_matrices)

4) Improving risk matrices: the advantages of logarithmically scaled axes, E.S. Levine, Journal of Risk Research Vol. 15 , Iss. 2,2012

5) Mathers C., Vos T., and Stevenson C. 1999, The burden of disease and injury in Australia, AIHW cat. no. PHE 17, AIHW, Canberra.

6) Health Safety Executive (UK), 'Principles and guidelines to assist HSE in its judgements that duty-holders have reduced risk as low as reasonably practicable ', http://www.hse.gov.uk/risk/theory/alarp1.htm

7) Regulatory Impact Statement: Bushfire mitigation regulations amendment, Report to Department of Economic Development, Jobs, Transport and Resources, ACIL ALLEN CONSULTING, 2015

8) NSW Value of Customer Reliability. Oakley Greenwood. May 2014.

9) Assessment of the Value of Customer Reliability (VCR). Vencorp. August 2008.