INDEPENDENT REVIEW OF CBA MODELLING

REPORT

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CutlerMerz

Ausgrid

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CutlerMerz Pty Ltd
ABN 16 607 833 590
Level 4, 398 Sussex Street
Sydney NSW 2000 Australia

www.cutlermerz.com

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Table of Contents

Executive Summary

Ausgrid engaged CutlerMerz to conduct a review and validation of the Cost Benefit Analysis modelling that Ausgrid has developed to support the replacement expenditure forecast for the 2024-2029 regulatory period.

The objective of the review and validation approach was to assess whether the approach was consistent with sound asset management and risk practices, broadly aligned with the AER Industry Practice Application Note, and is appropriate when contrasted against other DNSPs approaches to risk quantification and expenditure forecasting.

We have undertaken a review of the key artefacts and literature that was provided by Ausgrid, as well as conducted several deep dive sessions with Ausgrid's modelling and risk management teams to thoroughly understand and test the model itself. At these sessions, we were able to test the model outputs from a top-down perspective, challenging the results against the long run performance of Ausgrid's network, as well as against the relative performance of other Australian distribution networks.

We also used these sessions to thoroughly review the model from a bottom-up perspective, focussing on the methods used to derive the model input parameters and whether they were appropriate and consistent with industry practice.

The key findings from our review are summarised below.

Consistency of the approach to sound asset management and risk practices	The risk quantification framework developed by Ausgrid is consistent with sound asset management and risk management practices. At the detailed level, our review covered the asset class and sub-asset class inputs and outputs. During the course of our review, we identified several opportunities for improvement and areas where revalidation would be required. Ausgrid was able to integrate our observations and advice into their modelling processes and we subsequently revalidated that the inputs and outputs from the modelling were the best available at the time of our review.
Alignment with the AER industry practice note and appropriateness compared to other DNSPs	The risk quantification framework developed by Ausgrid is consistent with the AER's industry practice note for asset replacement planning. Ausgrid has adopted several sophisticated techniques in the risk quantification process that we have observed only a few DNSPs attempt. This is primarily due to a lack of input data points from which the modelling can be based. Ausgrid is in a reasonably unique position compared to other DNSPs as they have a sufficient amount of historic data (asset failures and incidents) from which model inputs can be established.
Conclusion	Ausgrid has developed one of the most sophisticated and granular risk quantification models for an electricity distribution network that we have observed. The quantification framework is consistent with both the AER's industry guidance note and the approach adopted by peer networks, however, the granularity with respect to the parameterisation of the model is comparatively unique. We have not identified any material concerns with the approach, model input parameters or model output results that would lead us to believe that investment decisions that rely on the outputs of the asset risk methodology would be unreasonably biased.

1 Introduction

1.1 Background

CutlerMerz has been engaged by Ausgrid to conduct an independent review of the cost benefit analysis (CBA) modelling that Ausgrid has developed and is using to support the replacement expenditure forecast for the 2024-2029 regulatory period.

The CBA modelling is an evolution of the modelling that Ausgrid developed to support the forecast replacement expenditure in the 2019-2024 regulatory proposal. The previous modelling approach and outputs were reviewed by CutlerMerz in 2019. The review concluded that Ausgrid's approach was consistent with the risk quantification methods currently being used by power networks in Australia and reasonably followed the Australian Energy Regulator's Industry Practice application note[1]. Furthermore, the review found that Ausgrid's approach to determining the probability of failure, probability of consequence and value of consequence relied on appropriate input data and that the outcomes were considered suitable for calculating risk, and therefore, the replacement expenditure forecast.

Since that time, Ausgrid has continued with the development of models to quantify asset risk, and in turn, forecast asset replacement expenditure. Whilst the basic mechanics of the quantification approach remain the same, Ausgrid has made a considerable investment to increase the sophistication of the modelling approach, refine the model inputs and test the reasonableness of the model outputs against real world performance expectations.

This report provides a description of the validation process that CutlerMerz has conducted on Ausgrid's refined quantification modelling.

1.2 Objective

The objective of the validation process was to provide assurance regarding the building blocks applied in the quantification of asset risk and provide an assessment on the reasonableness of the model outputs as they relate to asset failures, realised consequences and expenditure requirements.

1.3 Context

Ausgrid's replacement expenditure forecast for the 2024-29 regulatory period is comprised of the following categories of investment:

a) Replacement Programs (volumetric asset replacement)

b) Major Projects

c) Operational Technology & Innovation (OTI)

d) Resilience

To develop the replacement expenditure forecast across these categories, Ausgrid used the following forecasting tools:

a) Cost Benefit Analysis (CBA)

b) Historical Trend

[1] *https://www.aer.gov.au/system/files/D19-2978%20-%20AER%20-Industry%20practice%20application%20note%20Asset%20replacement%20planning%20-%2025%20January%202019.pdf*

c) AER REPEX model

d) Maintaining Risk

e) Age-based Assessment.

For the Replacement Programs investment category, Ausgrid developed a bespoke Cost Benefit Analysis model. This model is the subject of this review.

The model is described in a document titled CBA Approach for Replacement Programs.

1.4 Validation Approach

The validation approach was structured to systematically assess the method, inputs and parameters, and outputs of Ausgrid's CBA process. The validation followed a three-step process:

1. Review:

   The validation commenced with an assessment of Ausgrid's modelling documentation to gain an understanding of the modelling methodology. We held several meetings and workshops with Ausgrid's modelling personnel to work through the modelling approach and assumptions used in the model. Through these meetings and workshops, we were able to gain a detailed understanding of the inner workings of the model, including parts of the model's code (in the SAS software suite) and pre and post model calculations (Excel spreadsheets and SAS Viya reporting/visualisation software). We were also able to develop an understanding of the additional information that would be required to complete our review.

2. Validate:

   The second stage of the review involved a series of deep-dive challenge workshops with Ausgrid's modelling and asset subject matter experts to cover the specific methodology and input data relevant to the asset classes that had been incorporated into the model. The objective of these meetings was to test and confirm the application and implementation of the methodology and to allow Ausgrid the opportunity to explain the assumptions that were used within each model. The information collected during these sessions contributed to our findings in the Data Sources section of this review.

   The validation focused on the three key areas of risk quantification: probability of asset failure, likelihood of consequence, and the cost of consequence. Its aim was to assess the appropriateness of the:
   - Method and logic that was applied
   - Data sources and parameters
   - Modelled approach and parameters
   - Modelled outputs

   The findings for each key area are summarised in an overall assessment of the appropriateness of the approach and outcomes for delivering credible risk quantification outcomes.

   Where possible, the outcomes have been assessed against relevant industry experience to evaluate the reasonableness.

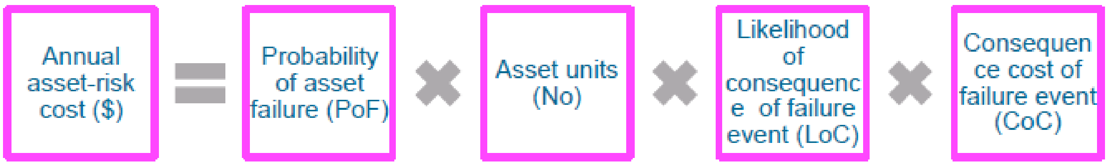
3. Report:

   This report documents the findings of the validation.

1.5 AER guidance and recent determinations

The AER *Industry practice application note for asset replacement planning*[2] (the ARP note) is the key source of regulatory requirements for asset risk modelling. Investment programs supported by modelling that is consistent with the approaches in the note are most likely to be approved by the AER.

The AER proposes the following framework structure:



The AER further details this in the following equation:

$$Risk\ cost\ per\ year\ of\ event\ n\ (\$) = \sum_{n=0}^{n} (PoFn \times Non) \times (LoCn \times CoCn)$$

Where:

- PoF_n = *Annual Asset Probability of failure event n (%)*
- No_n = *Number of assets*
- LoC_n = *Likelihood of Consequence of failure event n (%)*
- CoC_n = *Cost of consequence of failure event n ($)*
- *n = individual failure event (or failure mode)*

The AER methodology suggests the use of:

- Value of Customer Reliability (VCR) to value network reliability risk,
- Value of Statistical Life (VSL) for safety and
- Financial penalties, damages and costs for environmental, legal/regulatory and financial risks.

The AER assumes any disproportionality factors are contained within the CoC.

The AER methodology tends to require an assessment of individual failure modes and failure mode analysis to determine the LoC and CoC parameters for each. The practice note implies that more tailoring of parameters to individual cases is preferred and the parameters used must be clearly justified and traceable to historical data where possible. In practice, few NSPs have the necessary data to parameterise a model for each failure mode and instead develop assumptions for an 'average' failure mode or a small selection of distinctive failure modes.

Networks have provided risk-based modelling to justify replacement expenditure in recent submissions to the AER. Each network has approached risk modelling slightly differently using custom built models, but the high-level methodology of each has aligned to the AER practice note. In reviewing these models and replacement expenditure proposals, the AER's focus has been on the assumptions used and in particular the cost of consequence values.

1.5.1 Risk consequence areas

The AER lists a number of 'typical consequence areas':

1. Reliability and security
2. Safety and Health

[2] https://www.aer.gov.au/system/files/D19-2978%20-%20AER%20-Industry%20practice%20application%20note%20Asset%20replacement%20planning%20-%2025%20January%202019.pdf

3. Environment
4. Legal/regulatory compliance
5. Financial

The AER has communicated to some NSPs that it will in general not accept reputational risks to justify expenditure. The AER requires that any risks applied represent costs incurred by the NSP or others in the energy supply chain and that evidence can be provided that those costs were incurred.

1.5.2 Value application within regulatory submissions

The AER's standard position is that an investment should only proceed if the risk mitigated outweighs the investment cost, unless the project is compliance related, in which case the least negative NPV option should be selected.

However, when risk modelling is applied to a network's full asset base, taking an NPV approach may result in a substantial change in expenditure as well as expected risk.

To address this issue, some NSPs that use a quantified risk approach to justify repex forecasts apply a different approach. A common approach is to forecast the level of expenditure required to maintain risk at a predetermined level. Often this level is the current inherent risk of the asset base, although NSPs have struggled to provide adequate justification for why the selected level is reasonable. Other networks only apply models selectively to particular asset groups while expenditure for other assets is justified using other approaches.

Some other common themes related to either the models, values or assumptions that have been identified by the AER include:

- Making ambit claims that a higher volume of defects (because of an increase in asset inspections), increases network risk without sufficient justification.
- Mixing of concepts of failure rates and replacement rates. Some NSPs have based their failure rate projection on replacement rates, which has aspects of a self-fulfilling prophecy.
- Forecasting significantly higher numbers of failures than currently observed
- Not considering the cumulative consequences being forecast across all asset classes. For example, a small number of safety incidents are forecast for a single asset class that may, on face value, seem reasonable, but when summing all forecast safety incidents over all asset types the NSP forecasts a large number of serious injuries/fatalities that is not observed empirically
- Referring to ALARP and SFAIRP in tolerability scale documentation without providing an explanation of how an assessment was made for each of the projects and programs
- Cost-benefit analysis models that include disproportionality factors of up to 10 (and in some cases 12) for their safety-related consequences, is considered to be over-stating risk. The AER typically accept disproportionality factors between three and six.

1.5.3 Treatment of compliance obligations

The AER considers that there are few regulatory compliance obligations which are prescriptive in the sense that an NSP is required to perform a specific action or make an investment by a specific time. This is because most compliance obligations are generally set within a "best endeavours framework", with the aim of seeking avoidance of certain outcomes.

However, where regulatory compliance obligations do require a specific action or investment by a specific time, then under the NER, the least cost approach is accepted unless it can be shown that incremental benefits associated with a higher cost option outweigh the additional cost.

1.5.4 Other regulatory guidelines and expectations

A number of recent regulatory submissions have established insight into the expectations and rulings the AER has had regarding NSP risk, governance and value frameworks. Some key themes that have been identified include:

- Many governance and management frameworks lead to overstating total capex forecasts, because the AER considers that most risk frameworks overstate risk
- Forecasting methodologies have been inconsistently applied and many programs and projects lack sufficient quantified risk-based cost-benefit analysis
- Frameworks that do not support quantified risk-based cost-benefit analysis but rely on qualitative risk frameworks have not been viewed favourably as the AER state that NSP's are unable to establish that their proposed investments are prudent and efficient
- Frameworks that do not require/enable sufficient information and evidence of rigour to justify the proposed expenditure are also scrutinised. This includes limited and poorly populated risk management frameworks

These issues are best addressed through having high quality models and parameter documentation. This requires a line-of-sight from the risk parameters (PoF, LoC, CoC) and historically observed levels of asset failures, observed consequences and incurred costs.

1.6 Structure of This Document

In the following sections of this document, we describe the modelling approach used by Ausgrid, the model parameters used in the model and a validation of the parameters and outputs. Each sub-section covering an independent component of the modelling includes a summary of CutlerMerz' findings (orange box), including our opinion on the reasonableness of what Ausgrid has done.

2 Ausgrid's modelling approach

2.1 Principles

Distribution Network Service Providers (DNSPs), such as Ausgrid, are required to follow the investment scrutiny processes within the National Electricity Rules (NER) and are compensated for efficient investment and operation of electricity services through a regulated return on investment. The NER are designed to make sure DNSPs do not seek return on investment in assets that are inefficient or otherwise not aligned with the National Electricity Objectives.

The National Electricity Objectives are:

"to promote efficient investment in, and efficient operation and use of, electricity services for the long term interests of consumers of electricity with respect to:

- *price, quality, safety and reliability and security of supply of electricity*
- *the reliability, safety and security of the national electricity system."*

The mechanisms to achieve the National Electricity Objectives are described in the NER. The NER sets out, amongst other things, the process for investment in the electricity network. The NER defines the capital expenditure objectives associated with a DNSP's expenditure forecast as follows:

1) *meet or manage the expected demand for standard control services over that period;*
2) *comply with all applicable regulatory obligations or requirements associated with the provision of standard control services;*
3) *to the extent that there is no applicable regulatory obligation or requirement in relation to:*
    (i) the quality, reliability or security of supply of standard control services; or
    (ii) the reliability or security of the distribution system through the supply of standard control services,

    to the relevant extent:

    (iii) maintain the quality, reliability and security of supply of standard control services; and
    (iv) maintain the reliability and security of the distribution system through the supply of standard control services; and
4) *maintain the safety of the distribution system through the supply of standard control services.*

Ausgrid's modelling approach intends to achieve the capital expenditure objectives by evaluating the monetised value of risk as related to the capital expenditure objectives and comparing this to the value of risk treatments (such as replacement) in order to derive an expenditure forecast that results in efficient investment to achieve the National Electricity Objectives.

2.1.1 Coverage

Ausgrid's Replacement Programs investment category contains the high volume, low value assets within Ausgrid's asset base. For these assets, Ausgrid's Consolidated Asset Replacement CBA Model (CBA model) aims to determine the optimal timing for replacement based on a comparison of the risk of the asset failing against the cost the replacement. Where the benefit (i.e. the quantum of risk reduction due to replacement), is greater than the cost of the replacement, the result is a benefit to cost ratio (BCR) greater than one (1). For investments where the BCR is greater than one, the investment is considered efficient.

The CBA model is currently designed to forecast replacement expenditure for the following asset classes:

- Communications, Control & Protection
- Overhead Mains
- Overhead Support Structures
- Switchgear

- Transformers & Reactive Plant
- Underground Cables

The above asset classes are further segregated into 30 sub-asset classes for which separate model parameters can be defined. An example is the Overhead Support Structures asset class having sub-asset classes of Pole Top Structures, Poles and Towers.

We note that the 30 sub-asset classes defined by Ausgrid for the CBA model are used to inform the expenditure forecast for the 2024-2029 regulatory period.

It is reasonable to limit the coverage of the CBA Model to assets that exhibit risk characteristics that are aligned to the model's methodology. Using alternate forecasting approaches for other assets is more appropriate than 'forcing' those assets into an inappropriate model. Ausgrid's approach should produce fit-for-purpose forecasts for each sub-asset class.

Ausgrid's choice of sub-asset classes using the CBA Model (and by extension the choice of those that use alternate forecast approaches) aligns with general expectations for assets for which a risk based investment methodology driven by condition deterioration that is correlated to time/age is appropriate.

2.1.2 Asset specific approach

The model uses data specific to individual assets (i.e. a single pole) and forecasts the journey of each of these assets through time. The aggregation of the risk and expenditure for each asset contributes to the total investment forecast and residual network risk. This approach is consistent with a bottom-up forecasting approach where each individual asset contributes to the total.

The model optimises asset investments with the objective of maximising customer benefits (i.e. risk mitigation for amount invested). The CBA model provides a probability weighted expenditure forecast of aggregate asset investment needs across Ausgrid's network for specific classes of assets (see 2.1.1).

Using individual asset data and characteristics to forecast aggregate expenditure requirements is consistent with the modelling approaches being adopted by many of Ausgrid's peers. Ausgrid uses the model output to inform the replacement expenditure forecast and conducts additional top-down checks and sensitivity tests to verify the reasonableness of the forecast.

2.1.3 Risk and condition based

In order to align with the NEO and NER, an investment forecast is required to be based on efficient investment that would maintain, to the relevant extent, the reliability and safety of the distribution system.

In this respect, only those risks that are in the long-term interests of consumers and relate to the price, reliability and safety of the supply of distribution network services are included within the valuation of the risks and benefits.

In the case of consequences associated with fire and public safety, Ausgrid's model quantifies risks to all persons that may be negatively affected by the failure of an Ausgrid asset, not only those who are bill paying customers.

We do not consider that the inclusion of risk costs to those directly impacted by the failure of a distribution network asset to be unreasonable. The negative impacts of an asset failure can impact on Ausgrid's ability to provide distribution services efficiently, and therefore, avoiding these consequences would be in the long-term interests of consumers.

2.1.4 Definition of asset failure

For the purposes of the CBA Model, an asset failure is any asset functional failure or a defect that will lead to a functional failure if it is left untreated. A functional failure is any failure mode of an asset that requires a discrete asset (e.g. a pole) to be replaced (i.e. is not repairable) as it no longer provides its primary function.

Asset defects that meet this criteria may be treatable with repairs/refurbishment and are not limited to cases where the defect can only be treated by the replacement of the asset.

Asset defects that do not lead to a functional failure are not considered in the CBA Model.

For the purposes of parameterising the model, assets that have a defect are given an estimated remaining life based on the defect priority (category 1-4, planned date range, unrestricted and not assigned). This incorporates the knowledge that the asset has not yet failed and should be treated differently to known asset failures.

The definition of asset failure as a functional failure applies to both the historical asset data used to parameterise the model and the replacement volume and cost forecasts produced by the model.

Ausgrid's approach to defining a functional failure as requiring replacement is consistent with its peers and previous models used by Ausgrid.

The inclusion of asset defect data is reasonable as any forecasting model must reflect the fact that most asset failures are avoided through early intervention so the calibration of a model to observed failures would significantly underestimate the potential for future asset failures. Applying an estimated remaining life to assets with defects that are treated (through refurbishment, repair, early replacement, etc.) is appropriate so that calibration does not bring forward failures that are expected in the future.

2.1.5 Risk inclusions and avoiding overlap with other investment categories

The CBA Model is limited to assessing consequence categories that are contained in the Ausgrid Customer Value Framework[3]. Risks must be the result of the condition-based failure of the asset, and this is applied through the model parameterisation process, where the expected number of risk events is baselined at the number of those events that had an asset condition cause that were witnessed over a previous five-year period.

The CBA Model excludes weather related asset failures and the associated risks that are incurred during these events. This ensures that the model's scope does not overlap with Ausgrid's Climate Resilience asset investment forecasts, which address growth in weather related asset failure risks.

The CBA Model is baselined to the most recent five-year historical period. This is to ensure that asset management practices in the forecast are consistent with those that were in place during the baseline period. Asset related opex, such as inspection, repair and conditional failure criteria are therefore presumed to be consistent in the model between historic performance and forecast performance.

Any overlap of the asset replacement programme for the CBA modelled sub-asset classes with Ausgrid's network augmentation programme is not considered. The CBA Model produces an aggregate forecast of expenditure and is not intended to predict the volume of individual assets that are prudent to replace in practice. As both programmes only affect a small percentage of the existing asset base, the likelihood of overlap between the CBA Model and asset augmentation (where an asset to be replaced during an augmentation also contributes to the replacement forecast) are expected to be very small.

The CBA model does not produce forecasts for assets installed after the base year (network extensions or augmentations). As these assets are brand new, their contribution to aggregate risk is expected to be negligible for forecasts within a regulatory period.

[3] Customer Value Framework, December 2022

The approach used by Ausgrid is reasonable and should ensure there is minimal overlap with other components of Ausgrid's regulatory forecasts.

2.1.6 Maximising net benefits

The model produces an investment portfolio that maximises net benefits through optimisation of the investments included in the portfolio. Benefits are restricted to a reduction in risks as quantified in Ausgrid's Customer Value Framework and direct financial benefits to Ausgrid (through lower whole of life asset costs). Other benefits not contained in the Customer Value Framework are not considered.

The CBA Model maximises net benefits across all sub-asset classes rather than only optimising within each sub-asset class.

The CBA Model can do a range of sensitivity tests and scenario analysis that prioritise other criteria, such as maintaining risk levels, targeting specific risks or achieving predefined risk or expenditure levels. However, the forecasts produced using these objectives are not the primary forecast produced by and used from the CBA Model.

The capital expenditure objective in the National Electricity Rules requires that Ausgrid maintain service and safety performance unless there is a jurisdictional requirement to achieve an alternative outcome. Ausgrid's modelling approach intends to achieve the capital expenditure objectives by evaluating the monetised value of risk as related to the capital expenditure objectives and comparing this to the value of risk treatments (such as replacement) in order to derive an expenditure forecast that results in efficient investment.

Maximising net benefits is consistent with requirements in the National Electricity Rules and AER guidance. The outputs of the model provide a reasonable basis for determining a prudent an efficient expenditure forecast; however, we note that the model outputs are subject to further scrutiny and testing via other mechanisms to provide assurance that the forecast expenditure that is adopted meets the NER requirements.

2.1.7 Model Forecast Use in the Investment Planning Process

The model is only intended to set a quantitatively based starting point for investment planning. Ausgrid asset management specialists, customers and other stakeholder views that are not directly quantifiable will be incorporated into the final investment portfolio. The model is not to be the end-point of the investment forecasting process but should support the final investment portfolio.

It is reasonable to use any modelling as a starting point rather than fully relying on a modelled outcome. Models depend on high quality input data and may produce outputs that should be interpreted by organisational expertise and only used where the forecast is deemed reasonable and achievable. Ausgrid's approach is reasonable as long as any deviation from the modelled forecast is well documented.

2.2 Investment Forecasting Process

2.2.1 Risk Assessment

Ausgrid's CBA Model calculates risk for each asset in its network using the following simplified formula:

$$Risk \;=\; PoF \; x \; PoC \; x \; VoC$$

Where PoF is the Probability of Failure, PoC is the Probability of Consequence (equivalent to LoC in the AER's guidance note) and VoC is the Value of Consequence (equivalent to CoC in the AER's guidance note).

However, the full model has multiple values at each level in the formula. A more accurate representation is:

$$Risk = PoF \times \sum_{hazardous\ event=e}^{E} \left[PoE_e \times \sum_{severity\ level=s}^{S} \left(PoS_{e,s} \times VoC_{e,s} \right) \right]$$

The risk for an asset is dependent on:

- The **PoF (Probability of Failure)**, the probability that an asset will fail in a given year. Each asset has a single PoF value which changes over time according to the PoF function
- The **PoE (Probability of Event)**, the probability that, given an asset has failed, the failure will result in a realised hazardous event. There may be multiple hazardous events for each failure, reflecting the various outcomes that can occur following an asset failure.
- The **PoS (Probability of Severity)**, the probability that a hazardous event consequence will be of a particular severity level. The PoS values across all severity levels for a hazardous event sum to 100%.
- The **VoC (Value of Consequence)**, the monetised value of the risk that is incurred for a particular hazardous event at a particular severity level.

The PoC in the simplified equation is the product of the PoE and PoS in the detailed formula.

The risk value is calculated using the same formula for two scenarios, the first where the existing asset is retained and the second where the asset is replaced. Where the asset replacement is like-for-like, the only value that changes between the two scenarios is the PoF.

Ausgrid's risk assessment approach correctly calculates the risk of each asset. Ausgrid's approach is more complex than that used by some of its peers due to the inclusion of 'hazardous events' as a component, which adds additional detail to the calculation. Ausgrid's approach is more data intensive as it requires knowledge of the frequency of each hazardous event for each sub-asset class.

2.2.2 Cost Benefit Analysis and Investment Evaluation

Ausgrid's CBA Model uses a CBA ratio to assess and prioritise investment expenditure across all assets on the network passing through the CBA model. The CBA ratio uses the following formula:

$$CBA\ Ratio = \frac{Benefit}{Cost} = \frac{Risk_{no\ investment} - Risk_{Investment} + Other\ Benefits_{Investment}}{Investment\ Cost - \frac{Investment\ Cost}{1 + discount\ rate}}$$

The formula used by Ausgrid is for a single year CBA ratio. When the CBA ratio is greater than 1.0 the benefit of reduced risk over the coming year is greater than the financing cost of the investment, which means that the benefit is greater than the cost saving from waiting one more year before investing. This can be repeated annually until the CBA ratio is greater than 1.0, which is the optimal investment timing for the asset.

Ausgrid's approach to assessing whether an investment is better than deferral is reasonable for determining if an investment is worthwhile. It is also reasonable to only consider the financing cost in this case.

However, the use of this formula does not guarantee that the investment will provide a positive NPV over the lifetime of the investment as it does not consider the 'return of capital' or depreciation component of the asset lifetime cost. Ausgrid's approach does not consider the growth in benefits over time (due to the increasing PoF of the asset in the no investment case). In most cases this can be expected to be larger than the depreciation component and therefore should result in a more conservative outcome.

Although a full investment lifetime NPV calculation, with investment occurring in the year when that NPV is maximised (and positive[4]) is optimal, this is a complex calculation and is not likely to materially change the forecast.

2.2.3 Portfolio Analysis and Reporting

The CBA Model uses the results from each asset unit to build up an investment portfolio for each year of the forecast. The investment portfolio is limited to individual asset investments that have a BCR greater than 1.0. Some smoothing of the investment portfolio over time is applied as the backlog of good investments that have not yet been implemented would result in a spike in investment in the first year of the forecast.

For each asset replaced in the selected portfolio, the number of asset failures is reduced by one. Where the number of replacements is less than the number of failures predicted by the model in a given year the remaining failures incur a reactive replacement (and associated costs and risks are incurred).

The CBA Model produces detailed output reports, which are accessed via Ausgrid's SAS VIYA web portal.

The CBA Model does not natively produce an NPV for the investment portfolio. This is because the model itself operates with a single year time horizon for assessing individual investments. However, through utilising the detailed data outputs produced by the model, an approximated NPV for each sub-asset class and the overall portfolio has been developed. This calculation takes place in an Excel spreadsheet with direct links to the raw model output files.

Ausgrid produces three variants of NPV:

1. Customer: Costs and benefits are from the perspective of the customer. Investment costs are spread over time to simulate the recovery of capex through customer bills (inclusive of expected incentive scheme payments) rather than upfront. Risk reduction benefits are counted in the year that the benefit is observed.

2. Market: Costs and benefits are from the perspective of the market (or electricity system). Investment costs are incurred in the year the investment is made. Incentive scheme payments are transfers between market participants so are not counted. Risk reduction benefits are counted in the year that the benefit is observed.

3. Shareholder: Costs and benefits are from the perspective of Ausgrid shareholders. Investment costs are incurred in the year the investment is made. Benefits are the revenues received from customers as the capital costs are recovered over time. This includes incentive scheme revenue received by Ausgrid. Risk reduction benefits (excluding direct financial costs) are excluded from this NPV variant as those risk costs are incurred by customers, not shareholders

The market NPV is the primary NPV used for assessing the investment portfolio and is the NPV variant most commonly applied by the AER in assessing business cases.

In addition to NPV, the Internal Rate of Return is calculated for the same three variants and the Value Investment Ratio[5] is calculated for the market variant.

Ausgrid has a suite of sensitivity tests that are applied to the CBA Model. The model is flexible and assumptions can be easily adjusted, but sensitivity testing is limited by the long run time for the model.

Ausgrid currently runs a large number of sensitivity tests in the broad categories of:

- Loss of supply consequence
- Near miss weightings

[4] In general, assets that do not have a positive NPV for replacement at any age should be run to failure.
[5] The Value Investment Ratio is the NPV divided by the Net Present Cost. This measure scales the NPVs based on the size of the investment to make the values easier to compare between large and small investments.

- Consideration of greenhouse gas emissions (i.e. SF_6) and noise impacts within the environmental consequence
- Consideration of the environmental damage value metric of plantation loss within the bushfire consequence
- Grossly disproportionate factors
- Probability of failure
- Portfolio risk change, and
- Maintaining portfolio risk at the total network and asset class levels

Ausgrid's approach to building an investment portfolio is reasonable. The Market NPV is the correct NPV to use for assessing the overall value of the investment portfolio and is aligned to industry practice and AER guidance.

Ausgrid has a comprehensive sensitivity testing capability that can be used to build confidence in the model's results.

2.3 Model Software Environment

Ausgrid has designed and built the CBA model in-house, using contract resources as needed. The model is primarily built within the SAS software suite, with some model functions (mostly input data processing and output data analysis and processing) taking place within Excel spreadsheets and the PowerQuery module inside Excel. Reporting and Visualisation utilises the SAS Viya platform.

Ausgrid had a governance check of the coding framework completed by SAS Professional Services[6] that confirmed the code meets the intended scope, has been designed and built based on a set of principles and that the delivery life cycle for each component was adhered to.

Ausgrid's selection of modelling tools is reasonable. We were able to review the tools and the code to confirm good practice modelling approach were adopted. The governance check conducted by SAS Professional Services supports that the coding framework used by Ausgrid is fit for purpose.

Our review included a detailed (albeit not thorough) review of the model's code and functionality, and we had access to the full model code base as well as all Excel spreadsheets throughout our review. During this process we raised individual minor issues with Ausgrid, all of which were addressed prior to the finalisation of the model and our preparation of this report.

[6] 22078032_Ausgrid_Letter for CBA process and requirements alignment SOW06_15112022.pdf

3 Model parameters

This section discusses the approach used to populate the model with input parameters.

For each of the sub-asset classes, Ausgrid has analysed historic asset performance to derive the parameters required for the risk quantification process. The analysis of the historic performance of each sub-asset class has been confined to only those asset failures where the root cause was related to asset condition / deterioration. Where the root cause was an external event, such as nature induced (i.e. a tree falling on an overhead line); third party damage to an asset; amongst others, the failure and hazardous event performance data was disregarded in the determination of the relevant model input parameters for replacement.

The analysis of historic performance is conducted on a rolling 5 yearly basis. We consider that this is not an unreasonable approach as it is a sample that is representative of the most recent asset maintenance and operating conditions that the assets have been subjected to.

There is one asset class (towers) where there was limited history of failures related to asset condition / deterioration within the 5-year window. For this asset class, organisational expertise was utilised to estimate the base year failures.

3.1 Probability of Failure (PoF)

Probability of failure (PoF) is the probability that an asset will experience a failure in a given year[7]. The PoF is in most cases the most significant input into any risk-based asset model as it determines the evolution of risk over time and therefore the asset investment requirements to appropriately and efficiently maintain, manage and mitigate risks.

In this section we cover the method and logic Ausgrid have applied to forecast PoF, the data sources and parameters used by Ausgrid in calculating PoF, the logic programmed into the CBA model to utilise the PoF in the calculation of asset investment needs, the resulting modelled PoF parameters and finally the modelled PoF outputs.

3.1.1 Method and logic validation

Ausgrid used data-driven statistical approaches to forecast the probability of failure for each asset. This is made possible by Ausgrid operating one of the largest electricity distribution networks in Australia, which provides a sufficiently large sample size of asset failure data across modelled asset classes. Data used includes detailed information on Ausgrid’s current asset base and five years of asset failure data.

Ausgrid has used one of two industry standard asset failure probability functions depending on the type of asset being modelled:

- Weibull probability function for discrete assets (such as poles, switches), and
- A modified CROW-AMSAA probability function for linear assets (such as overhead mains and underground cables), consistent with modern methods.

Each of these methods generates a probability of failure that depends on time, which can be generalised as asset age.

The use of the Weibull distribution and CROW-AMSAA is well established for forecasting asset failures. There is substantial literature supporting the use of these two approaches for electricity distribution network assets[8].

The sub-sections below discuss Ausgrid’s approach to modelling each of these probability functions.

[7] The definition of an asset failure is described in detail in section 2.1.4
[8] Refer to Ausgrid’s methodology document for relevant reference material.

3.1.2 Weibull parameter estimation

The Weibull function has two parameters that require estimation, β and η. The remaining input, T_n, is the conditional age of the asset (n) being evaluated. These parameters determine the characteristics of the Weibull distribution and therefore the PoF of the asset at any particular age. The PoF is given by the Weibull distribution hazard function:

$$PoF_n = \frac{\beta}{\eta}\left(\frac{T_n}{\eta}\right)^{\beta-1}$$

Ausgrid has estimated the Weibull function parameters β and η for each asset class using the Median Rank method[9]. Five years of Ausgrid's historical data are used to calculate the Weibull function parameters using this method.

Within each asset class, Ausgrid has applied asset information factors that adjust the η parameter for individual assets that have that factor. This has been performed when data on factors that describe the assets are available (this must be known for the assets in the asset base and the assets that have failed over the five-year performance period) and it can be shown statistically that the inclusion of the factor improves the explanatory power of the statistical model.

To determine the influence of each factor, Ausgrid used regression analysis, whereby factor weightings are calculated using a multi-variable regression model and the resultant Weibull median rank results are tested for statistical significance of the additional factor.

Factors are only retained if they result in an improvement in the *Adjusted* R^2 of the regression, which is a statistical measure of the amount of variation in the input data that is explained by the factors adjusted for the improvement that can be attributed to random chance (as additional factors will always result in an improvement in a standard R^2 irrespective of whether there is a statistical relationship).

There are 19 factors tested by Ausgrid, with some of these only being applicable to a sub-set of asset classes. Some of the factors included are:

- Location type – assets in different locations are exposed to different climate and geological effects that may result in different degradation rates, such as indoor and outdoor equipment
- Material sub type – assets material types may degrade at different rates, so that two similar assets made of different materials (such as wood and concrete poles) may have different degradation rates
- Timber species – for wooden assets, different species of timber can exhibit differing degradation rates
- Strength Rating – for assets that hold other assets (e.g. poles), the strength rating (at time of installation) can provide information to predict the PoF of otherwise similar asset units, such as stronger poles being more resistant to damage (all else held equal)
- Voltage – assets that serve different voltages may have different failure profiles. For example, higher voltage poles tend to be larger and more durable but carry additional weight due to the thicker conductors and longer spans used for higher voltage overhead conductors.

Ausgrid normalises the final result to ensure the number of asset failures predicted for a single asset class equals the average number of asset failures observed for that asset class over the five year performance period. The factors used are also reviewed by Ausgrid's SMEs to check for unexpected/unlikely results that may be caused by the uncertain nature of statistical analysis techniques.

The median rank method for estimating the parameters of a Weibull function for physical assets is established in statistical literature and is a reasonable approach for Ausgrid to use.

[9] Ebeling, C.E. 1997, An Introduction to Reliability and Maintainability Engineering. Chapter 12.2.3

This estimation approach is dependent on having sufficient historical data, particularly for asset failures, to produce useful outputs. For many of Ausgrid's peers with small networks and therefore collections of asset failure data, this approach is not practical and can produce unexpected results.

The multi-variable regression model approach used by Ausgrid is novel. The concept of adjusting the PoF for asset sub-groups within a wider asset class is well established, with most of Ausgrid's peers applying some type of adjustment for factors that are known to influence the failure rate or mean lifetime of assets. The approach developed by Ausgrid appears to have favourable statistical properties and the normalisation step ensures that the final results will be closely aligned to historically observed asset failure rates.

Ausgrid's factor-based approach addresses shortcomings in alternate approaches. The most common alternate approach is to simply have more asset classes and calculate Weibull functions for each, but permutations of factors result in parameterising PoF functions with very small sample sizes. Ausgrid's approach uses a statistical test for the significance of additional factors applied as weightings for each factor, sub-groups with multiple factors receive the weighted sum of the effects of each individual factor so sample size issues are less of an issue.

The use of an Adjusted R^2 as a statistical test for inclusion of a factor is reasonable. Additional tests can be applied, such as the F-Test or T-tests of the individual factors in a multivariate function. All models have been checked for reasonableness by an SME, which should catch unrealistic factor effects that can be created whenever statistical approaches are used (such as results with unexpected signs or magnitudes of effect)

3.1.3 CROW-AMSAA parameter estimation

The CROW-AMSAA function has two parameters that require estimation, β and λ. As with the Weibull distribution, these parameters determine the characteristics of the CROW-AMSAA distribution and therefore the PoF of the asset at any particular age. The CROW-AMSAA function used in the modelling is:

$$\rho_n = \lambda \beta {T_n}^{\beta - 1}$$

Ausgrid estimated β using a linear regression approach. The log of asset age or time was regressed on the log of cumulative defects per kilometre using five years of failure data.

From the regression, β is the regression coefficient on the log of cumulative defects. The λ is a scale parameter that is derived from the intercept term in the regression as $e^{intercept}$.

The same factor-based approach described for Weibull estimation is also used for CROW-AMSAA estimation (see above) to add additional tailoring of PoF to asset sub-groups.

The modified CROW-AMSAA approach used by Ausgrid has been previously validated[10] and was used by Ausgrid in its modelling supporting the 2019-24 regulatory period forecasts submitted to the AER. It was also the subject of a large amount of scrutiny due to its use in justifying TransGrid's Powering Sydney's Future project.

3.1.4 Data source and parameter validation

The PoF functions used by Ausgrid are calculated using the following data:

- Current asset base from Ausgrid's corporate EAM system SAP and GIS
- Failure data for previous five years from Ausgrid's corporate EAM system SAP.

For each asset class the failure data was filtered to remove failures that were not relevant to the model and the investments being considered within the model.

[10] https://www.aer.gov.au/system/files/Ausgrid%20-%20Revised%20Proposal%20-%20Attachment%205.13.M.20%20-%20Cutler%20Merz%20independent%20CBA%20validation%20-%20January%202019.pdf

Filtering included:

- Removing failures with an external cause (weather, vehicle hits, animals, etc.)
- Removing failures that do not deteriorate over time or do not lead to a functional failure
- Retaining only the highest priority failure for each asset and removing any additional failure notifications that were recorded in any given financial year.

When the model is run the PoF for each asset in each year is calculated using the characteristics of assets in the current asset base (the same data used to calculate the PoF function) and the calculated PoF function for each assets' asset class.

The data applied in calculating probability of failure is consistent with data applied in other areas of the risk model and provides for uniformity in the quantification process.

The approach of filtering the failure data is consistent with industry practices and considered appropriate.

The input data and parameters are aligned with industry practices and are considered appropriate for providing credible risk appraisal outcomes. Ausgrid has a greater reliance on its own historic asset data than other networks that tend to rely on industry average or typical values for PoF functions due to having a smaller asset base or less developed data collection and cleansing processes. Using the network historic data is preferred over alternate sources, but care must be taken to ensure sample sizes are large enough to avoid unexpected statistical outputs driven by outlier events.

As an additional validation of the failure forecasts, the base year failures are represented as a percentage (%) of the population to assess the reasonableness of the failure forecast. An inherent failure rate of 1% per annum means it is expected that each asset will last 100 years until replacement.

3.1.5 Model logic validation

The PoF function for each sub-asset class is calculated and is updated infrequently as new underlying source data becomes available.

Within the model, the PoF is calculated for each individual asset in each forecast year using the PoF function. Where asset information factors are included in the PoF function, the relevant factors are obtained from the model input data for the individual asset and PoF function is evaluated at the conditional age of the asset in the forecast year, with the relevant factor weightings applied. The conditional age is set at a starting point based on initial asset actual age and condition data and is then incremented for every year in the modelled forecast.

The formula for the expected risk of an asset is calculated using this PoF value. The PoF is also calculated for the same asset if an investment is applied. An investment will result in the conditional age being reduced. In the case of an asset replacement, the conditional age is set to 0.5 years, so that the PoF function results in a lower PoF and expected asset risk. If the asset replacement is not like-for-like then there may be changes to the hazardous events associated with the asset (e.g. a hazardous event may no longer be applicable, such as oil loss events not being applicable if the replacement asset is air insulated).

The probabilistic nature of the model results in no particular asset failing with certainty. The probability of failure, rather, represents the likelihood of an asset failure that can be expected to be realised in a given year.

The model logic for how PoF is applied is consistent with guidance provided by the AER[11].

[11] ibid 1

3.2 Probability of Consequence (PoC)

Where PoF represents the probability of an asset failing, the Probability of Consequence (PoC) represents the probability that an asset failure converts into a consequence. Ausgrid's PoC is equivalent to the Likelihood of Consequence (LoC) in the approach documented in the AER guideline.

3.2.1 Method and logic validation

Ausgrid has defined five categories of consequence that can occur due to the failure of an asset. The consequence categories have either single or multiple impacts as shown in:

Consequence category	Consequence impact
Worker safety	Electric shock, Physical impact / Fall, Hazardous materials / atmosphere
Public safety	Electric shock, Physical impact, Hazardous materials / atmosphere
Environment	Oil and SF6 spills and leaks, Noise, Flora and fauna impacts
Fire	Fire incidents caused by network assets
Loss of supply	Supply of electricity to end-customers is interrupted

Table 1: Consequence category mapping to consequence type

If a particular consequence were to result from an asset failure, it can have different levels of severity or impact.

The probability of consequence is therefore the likelihood that an asset failure will result in a particular consequence type and of a particular level of severity. The PoC is made up of these two components as per the following formula:

$$Probability\ of\ Consequence\ (PoC) = Probability\ of\ Hazardous\ Event\ (PoE) \times Probabilty\ of\ Severity\ (PoS)$$

The PoC is fixed at the base year values (where the asset does not change or is replaced like-for-like[12]) and remains constant over the forecast period, so the number of consequences only changes over time if the number of asset failures changes. The model could be enhanced in future iterations to incorporate effects that could cause PoC to increase over time, such as increasing frequency of fire danger days due to climate change and increased population density.

The approach to calculating each of the components of PoC are discussed in the sections below.

3.2.2 Probability of Hazardous Event

Ausgrid has identified eighteen (18) hazardous events that could lead to a consequence occurring within the defined consequence categories. These hazardous events and the applicable consequence categories are shown in the following table.

Hazardous Event	Consequence Category
Contact with live electrical equipment inadvertently energised	Public Safety
	Worker Safety
Contact with live fallen wires	Public Safety
	Worker Safety
Domestic shocks	Public Safety
Exposure to arc flash	Public Safety

[12] For example, if an oil insulated asset is replaced with an air insulated asset, the PoC for oil environmental risks is reduced.

Hazardous Event	Consequence Category
	Worker Safety
Exposure to excessive EMF and RF	Public Safety
	Worker Safety
Exposure to hazardous atmosphere	Worker Safety
Exposure to hazardous chemicals and materials	Public Safety
	Worker Safety
Exposure to uncontrolled release of a pressurised substance (gas / fluid / air)	Public Safety
	Worker Safety
Fall from heights	Worker Safety
Fire starts	Fire
Leak, spill or discharge of a contaminating substance into the environment	Environment
Loss of electrical continuity	Loss of Supply
Slip, trip or fall	Public Safety
	Worker Safety
Struck by expelled object	Public Safety
	Worker Safety
Struck by falling object	Public Safety
	Worker Safety

Table 2: Hazardous event mapping to consequence category

A single sub-asset class may have multiple possible hazardous events within each consequence category. For example, an overhead conductor can produce the hazardous events of 'contact with live fallen wires' and 'struck by falling object' that both have a public safety consequence.

Ausgrid calculated the PoE at a sub-asset class level using historic data. The PoE for an asset class is the number of hazardous events observed after failures of similar assets divided by the total number of failures within that sub-asset class (noting that near misses also receive a weighting as discussed in 3.2.4 below).

Ausgrid's approach considers a detailed range of hazardous events with their own probabilities occurring for each sub-asset class. This is more detailed than similar models used by some of Ausgrid's peers, which usually only consider the probability of a risk at the consequence category level rather than specific hazardous events. Ausgrid's approach is more data intensive but should allow for more detailed reporting of forecast risks to be possible.

3.2.3 Probability of Severity

3.2.3.1 PoS - Safety

For each of the safety (i.e. worker and public) consequence categories, five severity levels have been used that align with Ausgrid's corporate risk framework: insignificant, minor, moderate, major, and significant. For each severity level, a probability is applied based on the potential of an incident converting into that level of consequence severity. The PoS values across the five severity levels always sum to 100%.

The PoS was calculated at an aggregate network level for each of the hazardous event/consequence category combinations. The PoS was calculated at this level because of small sample sizes for consequences in some severity levels and because it is likely that a consequence being of a particular severity is independent of the asset that caused the hazardous event (for example, if a member of the public comes into contact with live fallen wires, the probability of a major injury or fatality is the same regardless of whether it was the pole, cross-arm or conductor that failed).

The PoS values were calculated using the same five years of historical data as used for PoF and other model parameters. The use of only five years of data means that there were very few events of the Major and Significant severity levels at the network level and for most asset classes there were zero, so calculating PoS at the network level rather than an asset class level enabled more of the model's PoS inputs to be calculated using Ausgrid's own data rather than resorting to external sources of values.

The PoS for a severity level is calculated as the number of historic occurrences of a hazardous event at that severity level divided by all occurrences of that hazardous event.

For many of the hazardous event/consequence category combinations Ausgrid did not have a record of any historic events during the performance period used for parameterising the model. As it is possible for hazardous events to occur at these severity levels, a default value was applied to ensure there is some probability in the model of those events occurring.

The default values were set at a network level in terms of years to event, with consideration given to the similarity of some hazardous events to avoid over-estimating the likelihood of certain outcomes occurring. The years to event values are converted into probabilities based on the frequency of the hazardous event occurring, across all assets that can cause the hazardous event.

Ausgrid conducted checks of the results to ensure that there was not a significant increase in the frequency of major and significant severity hazardous events at a network level due to the use of the default values.

The default years to event for each hazardous event/consequence category combination is shown in Table 3 below. These are only used when no historical data is available.

Table 3: Default Years to Event

Hazardous Event	Consequence Category	Insignificant	Minor	Moderate	Major	Significant
contact with live electrical equipment inadvertently energised	Public Safety	4	10	40	100	200
contact with live electrical equipment inadvertently energised	Worker Safety	6	15	60	150	300
contact with live fallen wires	Public Safety	4	10	40	100	200
contact with live fallen wires	Worker Safety	6	15	60	150	300
domestic shocks	Public Safety	50	50	50	100	200
emission of greenhouse gas into the atmosphere	Environment	50	75	100	125	150
exposure to arc flash	Public Safety	16	40	160	400	800
exposure to arc flash	Worker Safety	6	15	60	150	300
exposure to excessive asset noise	Environment	50	75	100	125	150
exposure to excessive EMF and RF	Public Safety	20	50	200	500	1000
exposure to excessive EMF and RF	Worker Safety	20	50	200	500	1000
exposure to hazardous atmosphere	Worker Safety	20	40	160	400	800
exposure to hazardous chemicals and materials	Public Safety	20	50	200	500	1000
exposure to hazardous chemicals and materials	Worker Safety	16	40	160	400	800
exposure to uncontrolled release of a pressurised substance (gas / fluid / air)	Public Safety	20	50	200	500	1000

Hazardous Event	Consequence Category	Insignificant	Minor	Moderate	Major	Significant
exposure to uncontrolled release of a pressurised substance (gas / fluid / air)	Worker Safety	20	40	160	400	800
fall from heights	Public Safety	20	50	200	500	1000
fall from heights	Worker Safety	20	50	200	500	1000
fire starts	Fire	50	75	100	125	150
leak, spill or discharge of a contaminating substance into the environment	Environment	50	75	100	125	150
slip, trip or fall	Public Safety	16	40	160	400	800
slip, trip or fall	Worker Safety	16	40	160	400	800
struck by expelled object	Public Safety	20	50	200	500	1000
struck by expelled object	Worker Safety	20	50	200	500	1000
struck by falling object	Public Safety	16	40	160	400	800
struck by falling object	Worker Safety	16	40	160	400	800

Ausgrid's approach of applying the safety PoS values at the hazardous event level is reasonable as in most circumstances the expected probabilities will be the same regardless of the asset that caused the hazardous event. Although there may be cases where this is not true, the benefit of having a larger sample size of data to parameterise the model is likely to outweigh any model bias caused by the approach.

The use of default values to represent events that have not occurred but are possible/probable is appropriate. Using only historic data for a network that has been operated in a safe manner (few major and significant risks observed) could result in a model that assumes this performance will be maintained with degrading assets. However, there is a certain subjectivity to setting default values. Ausgrid's approach of working backwards from years to event at a network level is a reasonable 'top-down' approach to setting the default values. This results in a model that produces results that are within the 'plausible' range based on organisational experience.

Alternate methods, such as using data from other networks or international sources, have drawbacks as well. Using external data introduces bias as those sources involve different networks, with different assets in different operating environments. It is understood that external information guides the asset management specialists when setting Ausgrid's top-down approach but is not directly used.

3.2.3.2 PoS – Environment, Fire and Loss of Supply

The approach to determining the Probability of Severity for the environment, fire and loss of supply consequence categories is accounted for in the calculation of the Value of Consequence.

This approach allows for the severity of the impact to be determined based on the characteristics of each individual asset, such as the number of customers impacted (loss of supply), the amount of oil contained / spilled, and the location. Accordingly, the PoS for the environment, fire and loss of supply is set at 1 in the PoC formula.

Ausgrid's approach to determining the non-safety PoS values is reasonable. In most circumstances, the expected impact from each asset failure can be determined for these consequence categories and Ausgrid has data to parameterise the model appropriately.

3.2.4 Data source and parameter validation

All data used in the PoC calculation is from internal Ausgrid corporate systems. The historic consequence data was sourced from:

- Worker Safety dataset based on internal employee recorded incidents
- Public Safety dataset based on call centre incident records
- Environmental dataset based on worker recorded incidents
- Fire dataset based on worker recorded incidents
- Outage dataset from Ausgrid's Outage Management System

All historic consequences from the above datasets were mapped to a sub-asset class where possible for use in the model.

In the PoE step the same asset failure data used for the PoF is used as the denominator in the formula (see 3.2.2 above).

Data cleansing was undertaken to identify and remove incident categorisation and duplication anomalies and to remove incidents that were not caused by asset failure. This process involved an automated cleansing followed by a manual review and verification by Ausgrid subject matter experts.

For safety consequences, near misses were also considered to be incidents. Near misses are treated as follows:

- Near misses are initially weighted with a 0.5 multiplier
- Near misses are given a severity of insignificant
- Near misses are given an additional weighting to cap the total contribution based on the number of realised incidents.
  - The weighted contribution of near misses cannot exceed the total number of realised incidents.
  - Where no realised incidents have been recorded the total contribution of near misses cannot exceed 1 incident.

The use of internal Ausgrid data is appropriate. A significant amount of data cleansing was conducted by Ausgrid to remove incidents that were not relevant to the scope of the model.

Including near misses has the potential to inflate risk forecasts as similar events in future may continue to be near misses at a similar rate to the historic data. It is noted that there is often a fine line between an event and a near miss such that an event could have easily occurred and that the frequency of near misses can inform the likelihood of consequence events going forward. Ausgrid's approach to parameterising the model will result in the risk from the additional forecast consequences being offset by a shift in the PoS towards the insignificant severity level, which may cause total risk to be similar to if the near misses were excluded. Therefore, the inclusion of near misses is reasonable, although the sensitivity of the model results to the weighting factor should be considered.

3.2.5 Model validation

The PoC in the model is a moderating factor that recognises that not every asset failure results in a consequence occurring. The risk following an asset failure considers the historic likelihood that such a failure would result in a consequence and if it does, then the severity of the consequence is also taken into account.

In the model, the PoF for each individual asset is multiplied by the PoC for each hazardous event/consequence category/severity level. The product of the PoF and each PoC is the probability that the relevant consequence will occur over a single year.

Ausgrid's use of PoC in the model is similar to the LoC parameter in the AER's guidance note and is modelled in an identical way. The only difference is that Ausgrid's PoC is more detailed and there are more PoC values for each asset due to Ausgrid's more granular modelling of risks.

3.3 Value of Consequence (VoC)

Value of Consequence is a monetised value that represent the expected cost to Ausgrid, Ausgrid's customers and other stakeholders in the electricity system when a hazardous event is initiated by an Ausgrid asset.

3.3.1 Method and logic validation

Ausgrid sources all of its VoC values from the Ausgrid Customer Value Framework. The Customer Value Framework was developed alongside the CBA model but its application is broader than the CBA model. A detailed framework document has been developed that details how these values were calculated[13].

The CBA Model only covers the consequence categories of Worker Safety, Public Safety, Environment, Fire, Loss of Supply and Direct Financial Costs. The Customer Value Framework contains additional risk consequence categories that are not used in the CBA Model.

3.3.2 Data source and parameter validation

3.3.2.1 Public and Worker Safety

The VoC for safety risks is calculated across a severity scale, with five values ranging from Insignificant to Significant.

The first four severity levels apply the disability weighted value of life approach while the insignificant severity level uses a Work Health & Safety (WHS) cost approach. The WHS cost approach is used because the value of life approach is too coarse to apply to very low severity injuries.

The approach is presented in Table 4 below and further explained in Ausgrid's Customer Value Framework document.

Table 4: Safety Value of Consequence by Severity Level

Severity Level	Ausgrid Description	Value Metric Assumption	Calculation Assumption
Insignificant	Low level injury/symptoms requiring first aid only	Minor injury requiring limited treatment. Valued using SafeWork Australia short term absence cost.	OHS Cost (Short term absence)
Minor	Non-permanent injuries/work related illnesses requiring medical treatment	Temporary injury that limits the victim's quality of life for 1 year. Valued using VLY multiplied by the weighting for a minor injury (e.g. nerve damage, sprain, dislocation).	VLY * 0.07
Moderate	Significant non-permanent injury/work related illnesses requiring emergency surgery or hospitalisation for more than 7 days	Temporary injury that limits the victim's quality of life for 1 year. Valued using VLY multiplied by the weighting for a bone fracture of a major bone (e.g. femur, pelvis).	VLY * 0.25
Major	Permanent injury/work related illnesses to one or more persons	Severe injury that permanently reduces the victim's quality of life. Valued using VSL multiplied by the weighting for an arm/leg amputation.	VSL * 0.3

[13] Customer Value Framework, December 2022

Significant	One or more fatalities. Multiple significant permanent injuries/work related illnesses	Fatality or severe injury that prevents the victim from working for the rest of their life. Valued using VSL.	VSL * 1

3.3.2.1.1 Grossly Disproportionate Factors

The VoC contains a grossly disproportionate factor (GDF) for safety related risks and a portion of the value of the Fire category that is attributable to safety consequences (fire also includes property damage).

A GDF accounts for the obligations that Ausgrid has under the WHS Act to eliminate risks to health and safety so far as is reasonably practicable (SFAIRP), and if it is not reasonably practicable to eliminate the risks, to minimise the risks SFAIRP.

In discharging the duty under the WHS Act to eliminate, or minimise risks SFAIRP, risk controls (such as replacement) can only be ruled out if the cost involved in implementing them are considered grossly disproportionate to the benefits gained from their use.

The concept of what is reasonably practicable, and whether costs to avoid risks are grossly disproportionate to the risk are closely related.

The GDF applied by Ausgrid uses a sliding scale, where the more severe the risk the higher the GDF. The GDF values used by Ausgrid are shown in the table below.

Severity Level	Insignificant	Minor	Moderate	Major	Significant
Grossly Disproportionate Factor	**2**	**4**	**6**	**8**	**10**

The selection of a value or values for the GDF is often the subject of much deliberation as there is no authoritative guidance from the Courts as to what this factor should be. Using an increasing scale for GDFs as the consequence severity increases is consistent with the principle that as the risk increases, so should the degree of disproportion that should apply before the costs of mitigation is 'gross'.

Ausgrid's Customer Value Framework is documented and follows a robust methodology that is consistent with industry best practice and previous AER guidance.

The use of a GDF is common among Ausgrid's peers and is required for compliance purposes. There are multiple different approaches to the application of GDFs by other asset operators. The use of a sliding scale is reasonable as it ensures that low value risks (to which society is generally more tolerable of) are not treated with the same level of disproportionate investment as more severe consequences, such as serious injuries and fatalities.

Ausgrid's approach to GDFs differs to AER guidance, which is to use a single value (6) for Public Safety and a lower value (3) for Worker Safety. Ausgrid has made a reasonable case that its tolerance for worker injuries is no higher than its tolerance for injuries to members of the public and that the use of a single set of values is consistent with that.

As the severity level of consequences are heavily weighted towards the lower levels (via the PoS input parameter which forms part of the PoC), the average GDF applied in Ausgrid's modelling is lower than the AER's guide values. On this basis, we consider that the application of the GDFs proposed by Ausgrid is not unreasonable.

3.3.2.2 Environmental

The consequence values for the Environmental are calculated for remediation (oil loss), greenhouse gas emissions (SF6 loss) and noise (cost per impacted house).

Environmental costs may be incurred without the functional failure of an asset. This includes when an asset has defects that cause the leaking of liquids or gasses into the environment or defects that cause excessive noise.

Environmental costs are also incurred when an asset functionally fails and the failure mode results in some or all of the stored liquid or gas being released into the environment.

The VoC for environment is applied to those assets with characteristics that would result in an environmental consequence if it were to fail. The approach ensures that the value of the consequence is scaled to the relative impact for each individual asset. The approach is appropriate and consistent with the approach being adopted by peer networks.

3.3.2.3 Fire

Fire consequences are valued using modelling by the University of Melbourne and IGNIS / Phoenix rapid fire model.

The model considers three components of fire risk:

1. **Safety consequences** represents the costs to society of injuries and fatalities caused by fire.
2. **Property damage** represents the replacement cost of property damaged or destroyed by fire.
3. **Environmental damage** represents the cost to society of damage to the environment caused by fire.

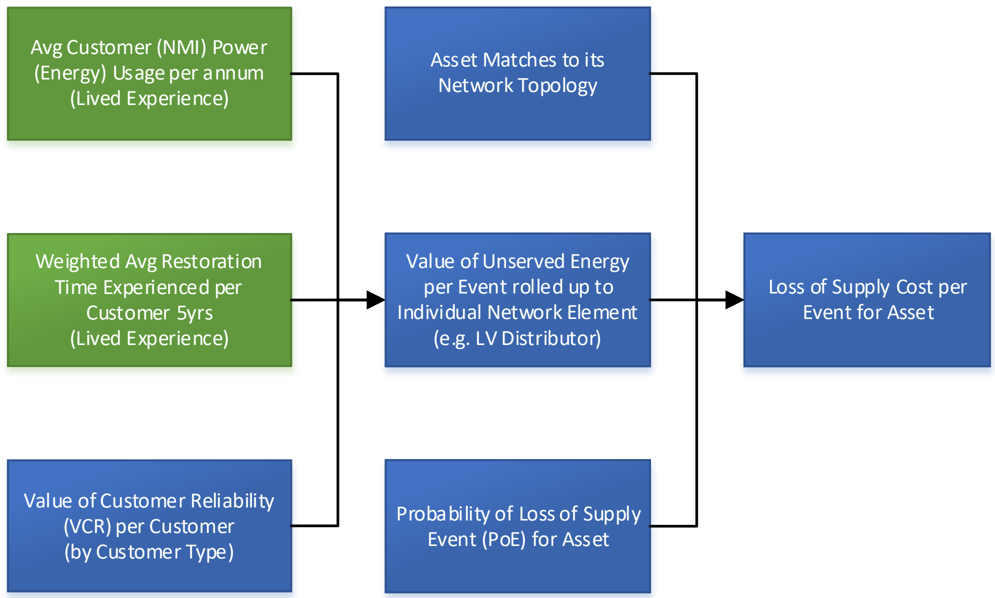
The safety component utilises the same VoC values as Public and Worker safety, but the volume of injuries / fatalities for each fire is derived from the Phoenix model.

The VoC for fire is based on sophisticated bushfire simulation modelling. There are a range of values of consequence determined for each suburb that are based on the Forest Fire Danger Index and proximity of the fire start to bushland. The upper end of the VoC values for each suburb is circa $18m.

3.3.2.4 Loss of Supply

Ausgrid determines the potential of loss of supply based upon the value of unserved energy. Unserved energy is valued using the ‘Value of Customer Reliability’ (VCR) approach. This is outlined in Figure 1 below.

Figure 1: Value of Loss of Supply (Value of Unserved Energy) Metric



Unserved energy for a given event is valued according to the following equation:

$$Value\ of\ Unserved\ Energy = Restoration\ Time \times \sum_{i=1}^{I}(Energy\ at\ Risk_x \times VCR_i)$$

The restoration time is measured in hours and reflects the average duration of the outage for the affected customers. When using the average duration of outages for the restoration time, the actual duration experienced for individual customers in specific circumstances may differ, although using average historical outage performance with average energy at risk provides an appropriate average unserved energy for a given event (kWh) metric. The value of unserved energy for a given event can be monetised by multiplying this by the VCR ($ per kWh).

In the CBA Model, the value of unserved energy is calculated for each customer and this is aggregated to the Energy Group (feeder/distributor/network). This aggregated value is then used for valuing loss of supply consequences following asset failure for the assets within the group, which results in loss of supply consequences that differ across the network.

The VoC for loss of supply (usually the largest contributor to asset risk) is localised to individual assets so that assets with higher loads (more customers or larger customers) will have a higher VoC value and therefore may be prioritised within the model.

3.3.2.5 Direct Financial Costs

The financial consequence cost associated with an asset failure has been limited to those costs related directly to the asset restoration with other event-related costs captured in the risk areas of safety, loss of supply, environmental and fire as appropriate. It has been defined as the repair or replacement cost to return the asset to its pre-fault state.

The unit cost applied in each asset category has been determined as a weighted average of historical repair and replacement costs.

For assets that are not replaced but then fail, a reactive replacement markup is applied. Ausgrid uses a markup of 17%, which is the same across all assets. The markup was calculated internally using Ausgrid's historical reactive asset replacement data. The premium accounts for the additional cost of doing work in an emergency manner as well as costs incurred due to the deferral of other work so that crews can be redeployed to the emergency asset replacement task.

Ausgrid has calculated the VoC values using appropriate data sources and has used its own data where appropriate.

The inclusion of a reactive replacement premium is common practice in the industry. Ausgrid's reactive replacement premium is in line with premiums of ~20% we have observed being used by Ausgrid's peers.

3.3.3 Model validation

The CBA Model takes the predefined values entered into the model for the risk categories and multiplies then by the probability of the risk occurring from the PoF and PoC.

The VoC is applied correctly within the model.

4 Validation of parameters and outputs

The following sections qualitatively compare the approaches used by other NSPs to the value measures applied by Ausgrid.

4.1 Probability of Failure

4.1.1 Model parameter validation

The PoF function parameters were calculated by using an empirical data driven approach (see Section 3.1). A PoF function was calculated for each sub-asset class, although Ausgrid aggregates these to a higher level for reporting purposes.

Ausgrid's approach allows for different parameters to be used within each sub-asset class to reflect certain individual asset unit characteristics. For comparability purposes, average PoF function parameters for each sub-asset class have been calculated that are broadly representative of the individual assets in each group.

The parameters that make up the PoF functions (β, η and λ) have meanings that are derived from the underlying statistical distributions.

For both the Weibull and CROW-AMSAA PoF functions, the β parameter follows the rules:

- $\beta < 1$, PoF decreases with time/age
- $1 < \beta < 2$, PoF increases with time/age at a decreasing rate (logarithmic-like PoF curve)
- $\beta = 2$, PoF increases linearly with time/age (straight line PoF curve)
- $\beta > 2$, PoF increases exponentially with time/age

Ausgrid expects the β parameter to be greater than or equal to 2 for all assets. This is because electricity network assets are expected to experience condition degradation over time and will fail more frequently as their condition worsens, which can be approximated by the passage of time, or asset age.

Consideration was given to constraining values that may be considered too high ($\beta > 7$), or to low ($\beta < 2$) but Ausgrid took the view that given the vast majority of the values were within most expectations of a reasonable range the outliers were reflective of the asset data and should be retained.

The η parameter in the Weibull function determines the characteristic age of failure. The Weibull distribution will always result in 63.2% of assets failing by age η.

The λ parameter in the CROW-AMSAA function is similar to the Weibull η and is a scale parameter and shifts the PoF curve up and down.

The average values of β, η and λ for each sub-asset class are presented in Table 5 below.

Table 5: Ausgrid PoF Function Parameters by Sub-Asset Class

Sub-Asset class	Asset Type	Statistical Distribution	Beta (β)	Eta (η)	Lambda (λ)
AFLC	Discrete	Weibull	2.60	43.21	
Batteries	Discrete	Weibull	3.89	30.11	
Comms, Control & Protection - Protection	Discrete	Weibull	2.42	93.99	
Comms, Control & Protection - SCADA	Discrete	Weibull	3.00	25.80	
Overhead Mains - HV	Linear	Crow-AMSAA	2.87		2.75E-05
Overhead Mains - LV	Linear	Crow-AMSAA	3.59		8.30E-05
Overhead Mains - Service	Discrete	Weibull	2.84	79.74	

Sub-Asset class	Asset Type	Statistical Distribution	Beta (β)	Eta (η)	Lambda (λ)
Overhead Mains - Streetlighting	Linear	Crow-AMSAA	3.55		1.19E-06
Overhead Mains - TR	Linear	Crow-AMSAA	4.71		7.29E-07
Pole Top Structures	Discrete	Weibull	4.17	147.22	
Poles	Discrete	Weibull	4.64	106.43	
Switchgear - HV Breaker	Discrete	Weibull	2.01	31.62	
Switchgear - HV Switch - Ground (Fuse Switch/RMU)	Discrete	Weibull	2.73	54.16	
Switchgear - HV Switch - Ground (I&E)	Discrete	Weibull	3.55	85.81	
Switchgear - LV Breaker	Discrete	Weibull	2.56	32.60	
Switchgear - LV Switch - Overhead	Discrete	Weibull	2.74	114.54	
Switchgear - TR Breaker	Discrete	Weibull	2.15	50.85	
Switchgear - TR Switch - Ground (I&E)	Discrete	Weibull	1.94	51.72	
Switchgear - TR Switch - Overhead	Discrete	Weibull	2.09	29.97	
Towers	Discrete	Weibull	7.78	75.81	
Transformers & Reactors - Distribution - Ground	Discrete	Weibull	2.94	62.03	
Transformers & Reactors - Distribution - Pole	Discrete	Weibull	3.04	88.65	
Transformers & Reactors - Instrument	Discrete	Weibull	2.27	48.23	
Transformers & Reactors - Power	Discrete	Weibull	3.78	42.56	
Underground Cables - HV	Linear	Crow-AMSAA	3.04		1.84E-05
Underground Cables - LV	Linear	Crow-AMSAA	5.32		1.64E-08
Underground Cables - Service	Discrete	Weibull	3.00	191.29	
Underground Cables - TR	Linear	Crow-AMSAA	5.01		3.93E-08
Underground Equipment - LV/HV Terminations	Discrete	Weibull	3.00	112.38	
Underground Equipment - Pillars & Pillar standards	Discrete	Weibull	2.28	110.26	

One of the asset categories has a $\beta < 2$. This may indicate that the empirical data used to generate the Weibull parameters is biased and not reflective of the true population failure rates. Some network assets are known to be impacted by early life failures due to manufacturing defects present in some manufacturer/model combinations. This can contribute to values for β of less than 2, although statistical discrepancies and small sample sizes for asset failures can also cause this result.The Weibull functions calculated by Ausgrid are backed by actual data and calibrated to observed failures over the last five years.

The β parameters calculated by Ausgrid are broadly reasonable, being in the range 2-7. The η parameters for some sub-asset classes, particularly those not covered in the AER Repex model (such as underground equipment and underground services), are high and in some cases represent implausibly long asset lifetimes.

We have previously observed that many of Ausgrid's peers produce similarly implausibly long asset lifetimes due to the need to calibrate PoF functions to historic failure rates, as well as due to differences in the scope of models to what is reported in the RIN (used by the AER Repex model). This calibration tends to result in some unrealistic asset lifetimes as actual asset failure profiles differ to theoretical failure profiles from probability distributions. In our opinion, it is more important to calibrate to historic failure volumes than to have the expected mean lifetime be at a 'reasonable' level. Therefore, we believe Ausgrid's PoF functions are reasonable.

4.1.2 Model output validation

As the PoF model is normalised to always start with the average historical failure rate, the base year modelled outcomes are considered reasonable. There is some risk of bias due to the historical data not reflecting changes in the condition of the assets and/or the possibility of an unusually high or low level of failures during the time period used; however, this approach aligns to that used elsewhere in the industry, most notably in the

AER Repex model calibrated scenario. Ausgrid performed checks on the base year asset failures and the reasonableness of those values. Therefore, we consider that the initial modelled PoF is not unreasonable.

Ausgrid's PoF functions result in an increase in asset failures over time. This is an expected result as the average age of Ausgrid's assets will increase, resulting in condition deterioration over time. Observed failures will not rise at these rates due to intervention, but the underlying risk of failure is growing.

There is no direct way to validate the outputs for PoF as failure rate projections are complex and dependent on a large number of asset specific factors.

CutlerMerz reviewed the checks that Ausgrid conducted and performed our own high-level assessment of the asset class level base year failures forecast by the CBA model and found the results to be reasonable.

4.2 Probability of Consequence

4.2.1 Model parameter validation

An assessment between the PoCs in the CBA model and equivalent values used by Ausgrid's peers was performed. To enable comparisons, the implied PoCs for the CBA model are derived from the model's forecast outputs by dividing the number of forecast risks in each category by the forecast number of asset failures. The model inputs for PoC in the CBA model are more detailed as they vary by hazardous event (and not all hazardous events occur with the same probability) so conducting a validation using outputs is necessary to allow comparison with the sample of industry values that were available.

Minor variances between the PoCs were identified. It is not appropriate to directly compare one distribution network's PoC against another as all networks have unique characteristics that have the potential to make the results of the comparison misleading. Furthermore, many of Ausgrid's peers do not have access to the necessary data to derive their own PoCs (due to small sample sizes of observed risks) and instead rely on external sources, such as Ofgem. Notwithstanding the limitations of a direct comparison, we did compare Ausgrid's PoCs to PoC data we have on other Australian distribution networks to assess the reasonableness of the modelled PoC outcomes.

Comparable data was not available for all the asset classes and risk categories modelled by Ausgrid. Where comparisons were possible, these have been considered representative of the overall reasonableness of Ausgrid's PoC parameters. The outcomes of this reasonableness test are provided in the figures below.

The comparison revealed that Ausgrid's modelled ICRs generally fall within or below the industry range for worker, public and fire safety.

Figure 2 – Worker safety PoC comparison

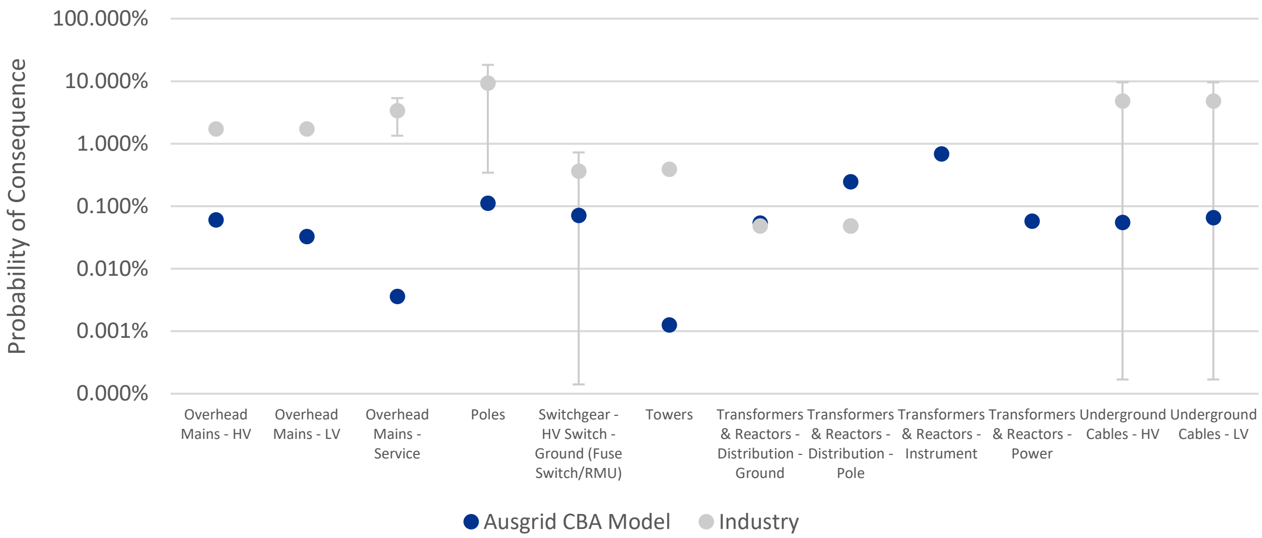


Figure 3 – Public Safety PoC comparison

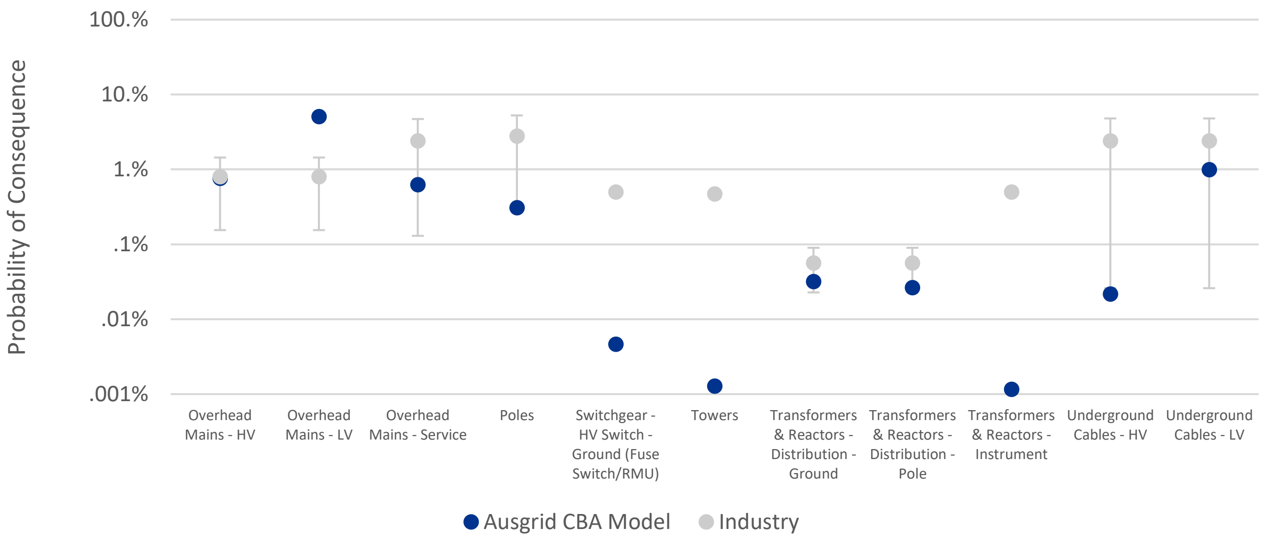
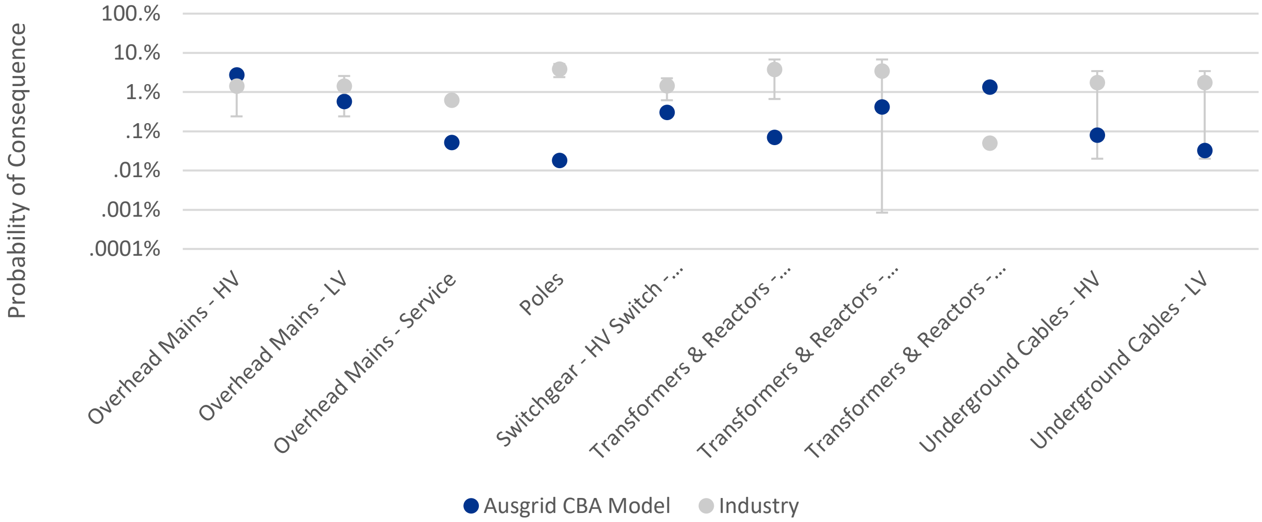


Figure 4 – Fire PoC comparison



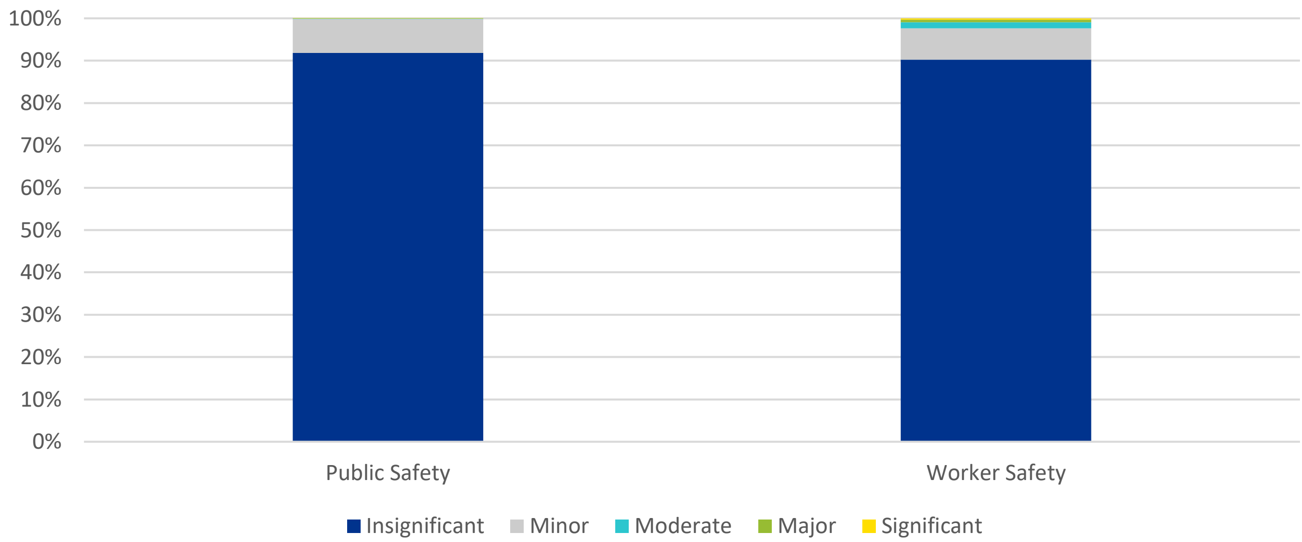
The PoC values predicted by Ausgrid's historical data and PoC calculation methodology appear to be reasonable compared to values we have observed being used in the wider industry. PoCs for Worker Safety risks are lower than other values we have seen, which is to be expected when historical data is used given the relatively low occurrence of worker injuries due to strong controls that are implemented by networks in Australia. The higher industry values are generally from international sources and are used due to the very low sample sizes available to Australian networks.

4.2.2 Model output validation

The PoC parameters, in combination with the PoF used for each asset in the model produces a forecast of the number of risk consequences across the risk categories included in the model.

The figure below presents the breakdown of forecast risks (FY25-29) by severity level across the two risk categories that use severity levels. The overwhelming majority of risks are in the insignificant category.

Figure 5 – Safety consequence severity breakdown



At an aggregate level the model forecasts 0.02 public safety and 0.01 worker safety consequences in the significant category (which represents fatalities) in the forecast base year (FY22). This is equivalent to a fatality caused by the failure of an Ausgrid asset every 32 years.

The table below shows the expected number of years to get a fatality for asset groupings using base year (FY22) probabilities. The rate of fatalities is very low, with overhead mains the highest risk group with a fatality expected less than once a century.

Asset Class	Public Safety	Worker Safety
Communications, Control & Protection	56,082	18,308
Overhead Mains	105	419
Overhead Support Structures	247	339
Switchgear	810	396
Transformers & Reactive Plant	899	464
Underground Cables	267	525
Network Aggregate	**51**	**84**

The table below shows how the modelled base year risk consequences compare to Ausgrid's current performance, which is the data that was used to calibrate the parameters used in the model.

	FY17	FY18	FY19	FY20	FY21	FY22
	Historic (actual)					Base Year (modelled)
Environment	27	17	15	37	24	17
Fire	38	35	34	60	19	29
Public Safety	96	115	93	109	120	104
Worker Safety	1	2	7	5	5	4
Loss of Supply	2,169	2,340	2,071	2,732	2,294	2,270

The average counts across the historic period are 24 (environment), 37 (fire), 107 (public safety), 4 (worker safety) and 2,321 (loss of supply). The model base year forecasts (FY22) are lower than the recent historic values for environment and fire and in line for the other risk categories.

The reduction in aggregate consequences between the historic average and the modelled base year is attributable to individual asset data record anomalies. Some of the consequence probability is unable to be assigned to individual assets that do not have complete records.

Modelled base year risk outcomes, before accounting for proactive repex programmes, are in line with or lower than what Ausgrid has observed in recent years. This indicates that Ausgrid's CBA model is not overestimating the frequency of risks being observed.

We note that future improvements to data records may better align the modelled base year risk consequences to the average of the historical actuals.