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TransGrid Revenue Proposal 2018-23

Review of aspects of TransGrid's forecast capital expenditure

Report to

Australian Energy Regulator

from

Energy Market Consulting associates

June 2017

This report has been prepared to assist the Australian Energy Regulator (AER) with its determination of the appropriate revenues to be applied to the prescribed transmission services of TransGrid from 1st July 2018 to 30th June 2023. The AER's determination is conducted in accordance with its responsibilities under the National Electricity Rules (NER). This report covers a particular and limited scope as defined by the AER and should not be read as a comprehensive assessment of proposed expenditure that has been conducted making use of all available assessment methods.

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Except where specifically noted, this report was prepared based on information provided by AER staff prior to 29 May 2017 and any information provided subsequent to this time may not have been taken into account.

Some numbers in this report may differ from those shown in TransGrid's regulatory submission or other documents due to rounding.

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About EMCa

Energy Market Consulting associates (EMCa) is a niche firm, established in 2002 and specialising in the policy, strategy, implementation and operation of energy markets and related network management, access and regulatory arrangements. EMCa combines senior energy economic and regulatory management consulting experience with the experience of senior managers with engineering/technical backgrounds in the electricity and gas sectors.

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Executive Summary

Purpose of this report

1. The primary purpose of this report is to provide the Australian Energy Regulator (AER) with technical advice on the reasonableness of aspects of TransGrid's proposed capital expenditure (capex) forecast, the main component of which is replacement capital expenditure (repex). The advice is based on a review of requested components of the proposed capex forecast to identify any systemic issues in the governance, management and forecasting processes applied in developing the forecast, supported by our review of a sample of projects and programs.

2. The assessment contained in this report is intended to assist the AER in establishing an appropriate capex allowance as an input to its Draft Decision on TransGrid's allowable revenue for the 2018-2023[1] Regulatory Control Period (RCP).

3. Specific focus has been requested on the reasonableness of the asset risk assessment framework and calculations of risk cost as used by TransGrid as key inputs in substantiating its proposed capex allowance, and its validity in determining the prudency and efficiency of this proposed allowance.

4. The AER has also sought an opinion on the reasonableness of the methodology, assumptions, and the input parameters used by Ausgrid to forecast cable unavailability for the Ausgrid cables that supply inner Sydney and the CBD. This is an input to TransGrid's assessment of the timing for its proposed expenditure for the Powering Sydney Future (PSF) project.

Scope of work

5. Our assessment is based on a limited scope review of certain aspects of TransGrid's capex forecast.[2] It does not take into account all factors or all reasonable methods

[1] 1st July 2018 to 30th June 2023

[2] The scope of our review of capex considers (i) augex projects driven by economic benefits, (ii) repex including security & compliance capex, and (iii) IT capex. This expenditure is a subset of the capex within TransGrid's Revenue Proposal.

for determining a capex allowance in accordance with the National Electricity Rules (NER).

Governance and management

6. From our review of TransGrid's governance and management policies, processes and systems, we consider that provided they are applied consistently in practice they should provide a reasonable framework for guiding and managing the capital requirements of its business. However, TransGrid's new risk model was developed in 2015/16 and for some parts remains a work in progress. We found evidence of issues that collectively reflect a bias for over-estimation of risk and therefore a bias to over-estimation of TransGrid's capex forecast:

   - We did not see evidence of an effective or robust challenge process being applied that considered, amongst other things, the base case risk assessments, current RCP performance or long-term asset planning requirements; and
   - We found instances where the application of TransGrid's risk assessment methodology overstates risk-costs and therefore the benefits of treating the identified risks, and which TransGrid has relied upon in undertaking its project evaluation.

7. Specifically, we find evidence of bias in TransGrid's risk assessment methodology:

   - Parameters, including Probability of Failure (PoF), Likelihood of Consequence (LoC) and Consequence of Failure (CoF) used in risk-cost evaluations were often not adequately justified and appeared to be overstated;
   - The risk cost calculations did not include reasonable moderation factors, and instead TransGrid often relied on an assessment of the worst-case series of events and the worst-case consequence leading to an over-stated risk cost assessment;
   - The effect of the nominated parameters and other key assumptions led, in many of the sample of projects we reviewed, to a risk cost that appeared overstated; and

8. In the absence of a robust challenge process, the application of the risk assessment methodology to projects as part of business as usual decision-making has, the potential to result not only in over-forecasting but also to over-spending of the program.

Forecasting methods

9. For the expenditure categories we were asked to consider, TransGrid has generally demonstrated a prima facie case for the need for some activities of the types described in its proposal, to be undertaken in the next RCP. However, at a project/program level, we find evidence of insufficient rigour in the development of TransGrid's expenditure forecasts, which has resulted in a bias to overestimate the forecast expenditure. In addition to issues with TransGrid's risk assessment methodology (as described above), we find that:

   - There is a lack of consideration of the timing of the work, with options for extending the programs (or some portions of them) beyond the end of the RCP generally not considered and TransGrid's risk cost methodology not used to determine optimal timing;

- In some cases, options analyses were undertaken for a combination of sub-projects and it was not clear if the sub-projects each presented a positive NPV; and
- In other cases, TransGrid benefits are 're-used' across multiple projects where the individual contribution from each of the identified projects is not clear.

10. At the portfolio level, the bottom-up aggregation of individual projects is also likely to lead to overstating the expenditure required in the next RCP due to:
    - Absence of a rigorous top-down challenge to its portfolio (i.e. including the consideration of scale and scope economies) that in our experience typically results in a material reduction in the total required expenditure; and
    - Bias towards commencing and completing projects within the next RCP. The relatively small proportion of expenditure in the next RCP attributed to continuation of work programs commenced in the current RCP is a further indication that TransGrid appears to be constraining its work to occur within RCP boundaries.

Findings on forecast for projects driven by economic benefits

11. In our review of TransGrid's proposed economic benefits-driven expenditure and dynamic voltage control projects, we find evidence of the following issues:
    - Inadequately justified risk cost parameter assumptions;
    - Flawed calculation of LoC factors; and
    - Lack of rationale for the timing of the work.
12. From the assessment of the projects and programs that we have undertaken, and in the absence of compelling evidence to address the issues we identified, we consider the forecast capex for TransGrid's proposed augmentation projects driven by economic benefits, to be over-stated.

Findings on forecast for repex including security & compliance

13. In our review of TransGrid's proposed replacement and security & compliance projects, we find evidence of the following issues:
    - Inadequate justification of the PoF, LoC, and CoF parameters;
    - Flaws in the application of the LoC and ALARP test; and
    - Inadequate justification of additional functionality or inclusion of expenditure for reasons other than condition and risk drivers.
14. We therefore consider that the risk cost assumptions relied on by TransGrid in developing its forecast are over-stated, and result in a bias that inflates the forecast expenditure.
15. We also find that some potentially feasible options were not assessed, and that TransGrid has not provided sufficient justification for all the proposed activity to be undertaken in the next RCP. Based on the information provided and the projects we have reviewed, we find that:
    - Some of the risks identified at high risk or critical locations are existing and likely to be justified for remedial action within the current RCP, rather than deferring them into TransGrid's forecast for the next RCP;

- A proportion of the program has not been reasonably justified for inclusion in the forecast, for example where other projects address the identified risk or where benefits are recycled across projects; and
- In some cases, TransGrid has not provided sufficient evidence that the proposed work is required within the next RCP and indications from the background material we reviewed are that it could prudently be deferred to beyond 30 June 2023.

16. We therefore consider that overall, TransGrid's proposed replacement and security & compliance capital expenditure is over-stated.

Findings on forecast for IT projects

17. From our assessment of TransGrid's proposed IT projects and programs, we find that TransGrid has presented:

- Inadequate justification for the assumed risk cost parameters, and which appear high; and
- Inadequate options analyses, including (i) unrealistic Base Case options (typically 'do nothing'); and (ii) lack of consideration of life-extension and other mitigation strategies.

18. In the absence of compelling evidence in support of a higher capex requirement for the next RCP, we consider that TransGrid's average actual expenditure is more likely to reflect a prudent and efficient level of forecast expenditure than its RP2 forecast.

Specific review of unavailability of selected Ausgrid cables

19. In our review of the information provided by Ausgrid we find that:

- The methodology for predicting the frequency of failure of the oil-filled cable population and the individual oil-filled cables relevant to the PSF project is reasonable;
- The methodology for predicting the unavailability of the individual oil-filled cables is reasonable; and
- The key parameters and assumptions underpinning the calculations of the frequency of failure and unavailability are likely to be reasonable.

20. We consider that Ausgrid's models are likely to provide a reasonable estimate of cable unavailability for the cables we reviewed, namely the eight Ausgrid 132kV cables identified for replacement in the PSF project.

21. In accordance with our scope of work, we have not considered how TransGrid has applied the Ausgrid 132kV cable unavailability data in its own analyses, nor have we reviewed any information pertaining to TransGrid's analysis or modelling.

Implications for capex forecast

22. We have been requested to consider the implications of our assessment of the projects and programs that we have undertaken, and to quantify the impact where the risk has been over-stated by TransGrid for its proposed asset replacement (repex) allowance (including security and compliance), and for its IT capex forecast. In the absence of compelling evidence to address the issues we identified, we find that the impact of the systemic issues are likely to have resulted in:

- an over-estimation of the expenditure forecast of between 15% and 25% for the aggregate of replacement and security & compliance expenditure; and
- an over-estimation of the expenditure forecast of between 15% and 20% for IT capex.

23. We consider that expenditure forecasts, reduced by amounts of this order, are more likely to reflect a prudent and efficient forecast of required expenditure.

1 Introduction

1.1 Purpose of this report

24. The purpose of this report is to provide the AER with an expert review of the capex forecast in TransGrid's revenue proposal for the next RCP.

25. The assessment contained in this report is intended to assist the AER in its own analysis of the capex allowance as an input to its Draft Decision on TransGrid's revenue requirements.

1.2 Scope of requested work

26. The AER is seeking an expert review of capex forecasts included in TransGrid's transmission network Revenue Proposal (RP) for the next RCP, and which was submitted to the AER in January 2017.[3]

27. The scope of this review will cover TransGrid's proposed ex- ante capex (excluding contingent projects) and which covers reviews of TransGrid's
    (i) specific components of the load-driven augmentation capital (augex) forecast,[4]
    (ii) repex forecast (including security and compliance),
    (iii) its proposed allowances for non-network information technology programs, and
    (iv) specific aspects of Ausgrid's risk assessment relied upon by TransGrid in its PSF project including the methodology and the input parameters used by Ausgrid to determine cable un-availability and the probability of cable un-availability for the Ausgrid cables that supply inner Sydney and the CBD.

28. A particular focus of this project involves reviewing TransGrid's assessment of risk-cost in its justification for proposed expenditure allowances.

[3] As described in the *Request for quote – TransGrid 2018-23 reset – capex, March 2017* and subsequent advice received by email on 20th March clarifying the scope of works

[4] specifically, the projects proposed as delivering economic benefits, and dynamic voltage support

1.3 Our approach

29. In undertaking our review, we:

- completed a desktop review of the information provided to us by the AER followed by preparing requests for information to TransGrid;
- undertook an onsite review meeting with TransGrid, to ensure we correctly understood the methodology and assumptions being applied to the expenditure requirements;
- we also undertook an onsite review meeting with Ausgrid (at TransGrid's offices) in relation to our assessment of the cable unavailability methodology and assumptions provided to TransGrid from Ausgrid;
- completed a top-down and bottom-up assessment of the expenditure forecast, including by reviewing a sample of projects. While risk-cost is a substantial driver of the proposed expenditure, our understanding is that the AER is seeking an overall opinion on the proposed capex categories within the scope of our review, and we have therefore considered other drivers and justifications, to the extent that they are relevant and sufficiently material; and
- documented our findings in a report.

30. The limited nature of our review does not extend to advising on all options and alternatives that may be reasonably considered by TransGrid, or on all parts of the capex forecast. We have included additional observations in some areas that we trust may assist the AER with its own assessment.

1.4 Structure of this report

31. The following sections of our report include:

- In section 2, we present background information to provide context to our review;
- In section 3, we describe our assessment of TransGrid's governance and management framework;
- In section 4, we describe our assessment of TransGrid's expenditure forecasting methodology;
- In section 5, we provide our findings from review of economic benefits-driven augex, that forms a part of TransGrid's proposed non-load driven augex forecast;
- In section 6, we provide our findings from review of repex, including security and compliance driven capex;
- In section 7, we provide our findings from review of IT capex, that forms a part of TransGrid's proposed non-network capex; and
- In section 8, we provide our findings from review of Ausgrid's cable unavailability assumptions that TransGrid has relied upon for its PSF project.

1.5 Information sources

32. We have examined relevant documents provided by TransGrid in support of the projects that the AER has designated for review. TransGrid provided further information at the on-site meetings and further documents in response to our information requests. These documents are referenced directly where they are relevant to our findings.

33. We observed a difference in cost estimates at the project level between the Revenue Proposal (including Appendices), Capital Accumulation Model and the supporting documents. We have not sought to validate or explain the differences observed, rather we have nominated where we have sourced the information relevant to our findings.

1.6 Rounding of numbers and real conversion

34. Numerical totals in tables may not present as being equivalent to the sum of the individual numbers due to the effects of rounding. This report refers to costs in real June 18 dollars unless denoted otherwise.

2 Background

2.1 Introduction

35. In this section, we provide an overview of TransGrid’s capex forecast for the next RCP and we contrast this with an analysis of the corresponding expenditure in the current RCP for the elements of the expenditure forecast under review. We describe the categories of expenditure we have been asked to review, and for which our assessment has been based in the remainder of this report.

2.2 Overview of proposed capex

36. TransGrid defines its capex forecast into four broad categories: augex, repex, security/compliance and non-network (business support) capex.

37. TransGrid has forecast total capex for the next RCP of $1,612.3m. TransGrid considers that this expenditure is reasonably required to achieve the capital efficiency objectives.

38. Due to the differences in the length of the RCPs, we calculated the average annual capex over the RCPs as shown in Table 1 and Table 2. The average annual forecast for the next RCP of $322.5m is 36% higher than the average annual actual/estimated expenditure during the current RCP, and $151.2m (or 32%) lower than the average annual actual expenditure during the previous RCP.

Table 1: Current RCP capex ($m, real June 2018)

Category ($m June 18)	Actual 2014/15	Actual 2015/16	Estimate 2016/17	Estimate 2017/18	Total RCP	Average annual
Augmentation	31.90	61.90	7.40	9.60	110.80	27.70
Replacement	173.60	166.80	161.80	139.80	642.00	160.50
Security / Compliance	24.90	6.30	14.10	27.30	72.60	18.15
Non-network (business support)	38.50	23.80	26.10	32.00	120.40	30.10
Total	**268.90**	**258.80**	**209.40**	**208.70**	**945.80**	**236.45**

Source: EMCa analysis of data from TransGrid Revenue Proposal 18/19 to 22/23

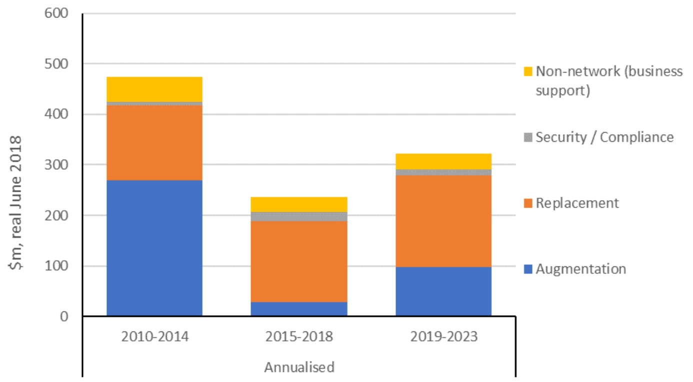
Table 2: TransGrid's proposal for next RCP capex ($m, real June 2018)

Category ($m June 18)	2018/19	2019/20	2020/21	2021/22	2022/23	Total RCP	Average annual
Augmentation	27.60	75.60	73.20	148.20	167.10	491.70	98.34
Replacement	134.90	181.60	214.30	185.60	191.30	907.70	181.54
Security / Compliance	7.40	7.80	11.00	11.80	16.10	54.10	10.82
Non-network (business support)	25.50	41.80	39.40	24.40	27.70	158.80	31.76
Total	**195.40**	**306.80**	**337.90**	**370.00**	**402.20**	**1,612.30**	**322.46**

Source: EMCa analysis of data from TransGrid Revenue Proposal 18/19 to 22/23, Table 5.1

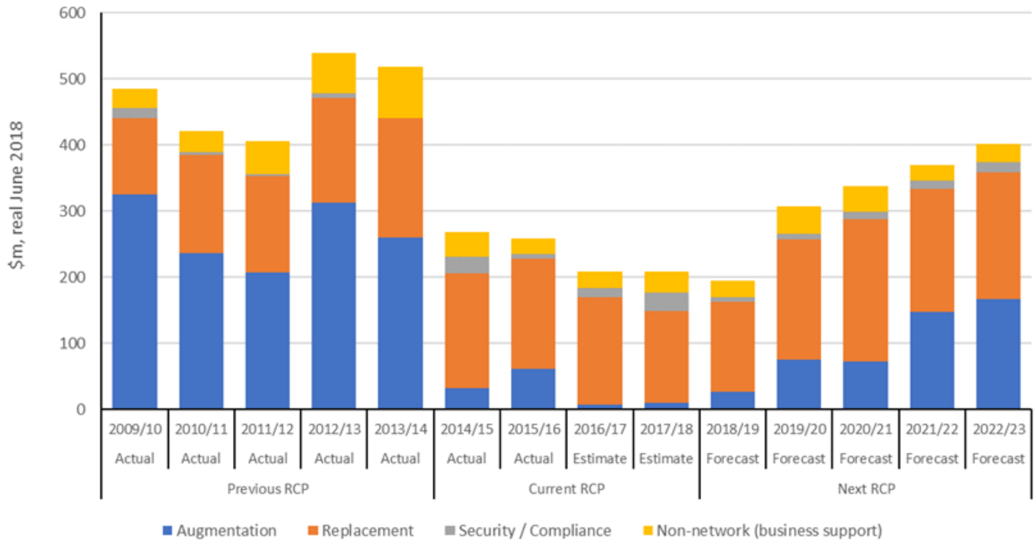
39. The differences in annual average expenditure for the previous RCP, current RCP and next RCP are shown in Figure 1. We show the composition of expenditure over time which illustrates the large variability of augex between each of the RCPs in Figure 2.

Figure 1: Annualised actual and forecast capex - ($m, real June 2018)



Source: EMCa analysis of data from TransGrid Revenue Proposal 18/19 to 22/23

Figure 2: Actual and forecast capex ($m, real June 2018)



Source: EMCa analysis of data from TransGrid Revenue Proposal 18/19 to 22/23

2.3 EMCa observations on prior RCP trends and performance

2.3.1 Overview

40. TransGrid expects to underspend its capex forecast for the current RCP by $177.6m (-16%). Whilst the AER published its Final Decision for the current RCP with TransGrid's capital allowance designated against the expenditure categories as shown in Table 3, TransGrid has advised that it does not impose operating constraints by expenditure category, rather it manages within the total capital allowance that the AER applied in its last regulatory decision. The variances provided in Table 3 are therefore not necessarily indicative of the expenditure performance forecast by TransGrid for the current RCP.

Table 3: Current RCP capex ($m, June 2018)

Category ($m June 18)	Final decision	Current RCP	Variance	
Augmentation	150.17	110.80	-39.37	-26%
Repex (incl security & compliance)	812.06	714.60	-97.46	-12%
Non-network (business support)	161.13	120.40	-40.73	-25%
Total	**1,123.37**	**945.80**	**-177.57**	**-16%**

Source: AER Final Decision TransGrid 2015–16 to 2017–18, Attachment 6, Table 6-3 and TransGrid Revenue Proposal 2018/19 – 2022/23, Table 5.24

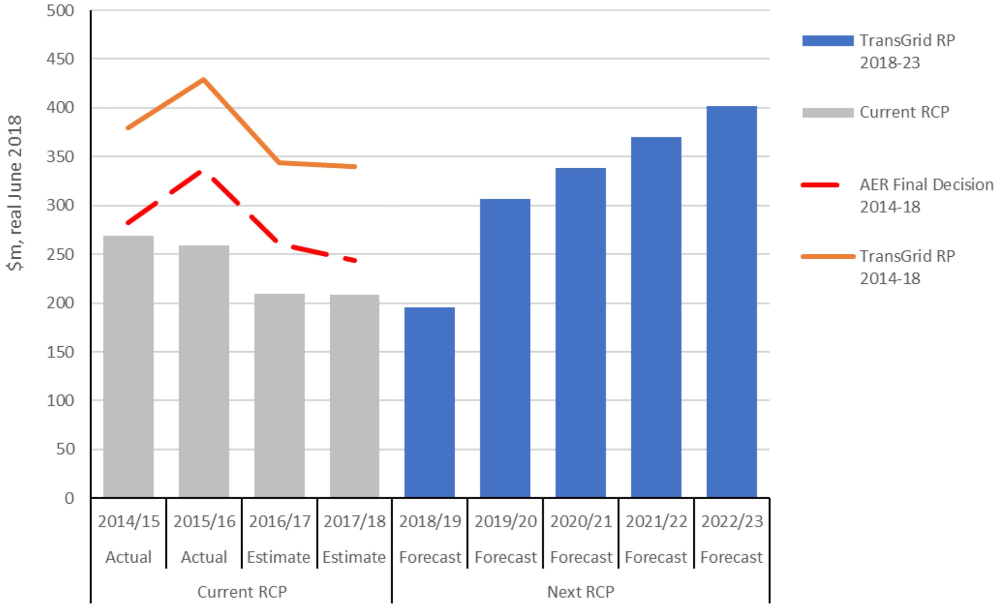
41. In Figure 3, we show the comparison between the previous TransGrid RP (2014-18), the AER's Final Decision for 2014-18, TransGrid's actual/estimated capex for the current RCP and TransGrid's forecast capex for the next RCP. We observe that

(i) the forecast expenditure for the next RCP is similar to TransGrid's initial proposal for the current RCP;

(ii) TransGrid underspent the AER final decision in the current RCP; and

(iii) The AER significantly reduced the capital allowance from the capex level forecast in TransGrid's previous Revenue Proposal.

Figure 3: Actual and forecast capex ($m, real June 2018)



Source: EMCa analysis of TransGrid Revenue Proposal 18/19 to 22/23, Table 5.1 and 5.24

42. In its RP, TransGrid provides two main reasons for the underspend:[5]

- Augmentation is at historically low levels; and
- TransGrid has developed and implemented a new investment and risk framework, resulting in prudently reducing capex.

43. TransGrid states that it has de-scoped or removed approximately $110m of projects from its work program by: (i) applying its new approach to risk (which it developed from 2015/16 and applied in 2016/17);[6] (ii) challenging existing investment proposals in light of updated asset condition information; and (iii) changes in circumstances (not defined).[7]

44. TransGrid states that its forecast is higher than in the current period due to:[8]

- Inclusion of the PSF project, totalling $330.9m (or 73% of the load-driven augex forecast); and
- Higher replacement expenditure arising from the latest condition information and risk model.

45. TransGrid also states that a number of efficiency improvements have been built into its forecast, estimated at $6.0m per annum. [9]

2.3.2 Link between expenditure and outcomes

46. In the performance information we were provided by TransGrid at a summary level, there did not appear to be any adverse performance outcomes or material increase

[5] *TransGrid Revenue Proposal 18/19 to 22/23 – January 2017*, page 72

[6] TransGrid response to AER Information Request #030 - question 13, page 1

[7] *TransGrid Revenue Proposal 18/19 to 22/23 – January 2017*, page 73

[8] *TransGrid Revenue Proposal 18/19 to 22/23 – January 2017*, page 73

[9] *TransGrid Revenue Proposal 18/19 to 22/23 – January 2017*, page 74

in risk that led to a worsening of performance as a result of the forecast underspend in the current RCP.

2.4 Summary

47. TransGrid currently expects a $177.5m (-16%) underspend of its capex allowance by the end of the current RCP.

48. According to the information provided by TransGrid, the drivers of the underspend were:

- lower augex than forecast; and
- the new investment and risk framework which resulted in a prudent reduction of capex.

49. The increasing trend of forecast expenditure requires review to confirm if any of the bias that led to over-forecasting in the current RCP is likely to be sustained into the next RCP, resulting in further underspend. We therefore looked for any systemic bias in the forecast.

3 Assessment of governance and management framework

3.1 Introduction

50. In this section, we describe our assessment of the governance, risk and asset management frameworks used by TransGrid to plan and approve its capex projects and which TransGrid has used to develop its five-year capex forecast to the AER.

51. TransGrid states that it has made a number of improvements to its capex process in the last two years including:[10]

- Identification of asset replacement needs;
- Introduction of investment risk tool;
- Forecast validation – top-down long-term view of capex using probabilistic model; and
- Portfolio optimisation.

52. We comment on TransGrid's governance and management framework and approach in the following sections, and on the methods used to establish its forecast expenditure in section 4 of this report.

[10] *TransGrid Revenue Proposal 18/19 to 22/23 – January 2017*, page 69

3.2 Capital expenditure governance

3.2.1 Overview of framework

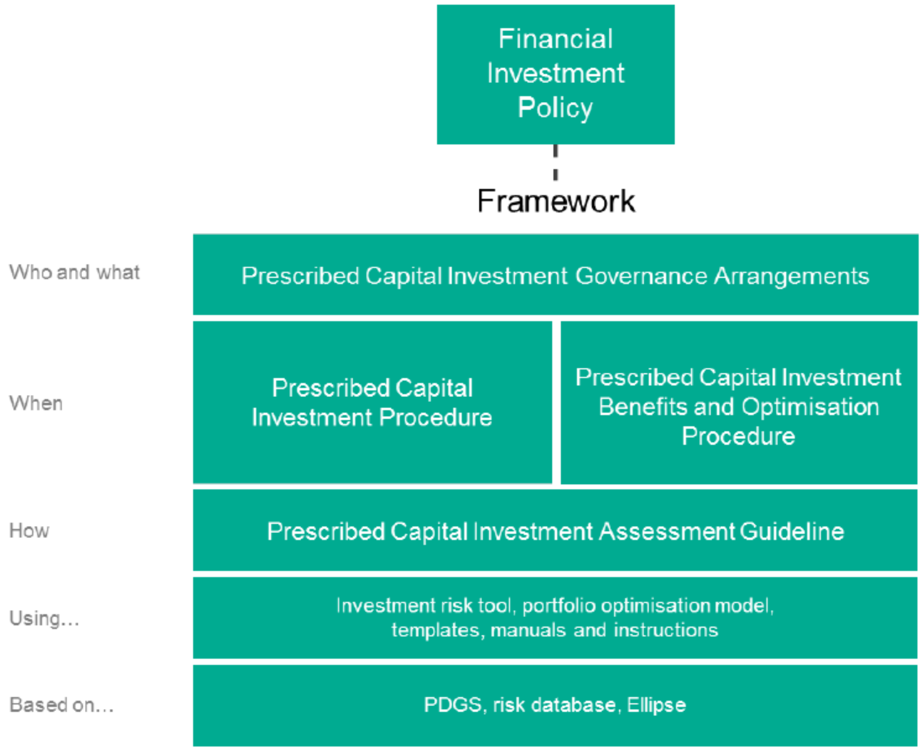
53. TransGrid describes its governance arrangements applicable to the capital investment framework[11] as applying to the initial identification of needs and opportunities through to the end of the acquire phase and delivery of the Post Project Review (PPR) report. The capital investment framework is shown in Figure 4 and comprises:[12]

- The *Prescribed Capital Investment Governance Arrangements* identifies the structures and individuals accountable for making the investment decisions;
- The *Prescribed Capital Investment Procedure* sets out the process and supporting documentation required to identify and justify projects and programs. The process involves a number of milestones known as Decision Gates;
- The *Prescribed Capital Investment Benefits and Optimisation Procedure* sets out how the expected benefits are identified, tracked and reported as well as the process for optimising the overall investment portfolio; and
- The *Prescribed Capital Investment Assessment Guideline* sets out the criteria used to make the investment decisions as well as how the quantification of benefits, is carried out.

[11] *TransGrid Prescribed Capital Governance Arrangements*, page 3

[12] *TransGrid Prescribed Capital Investment Framework*, page 6

Figure 4: Capital investment framework



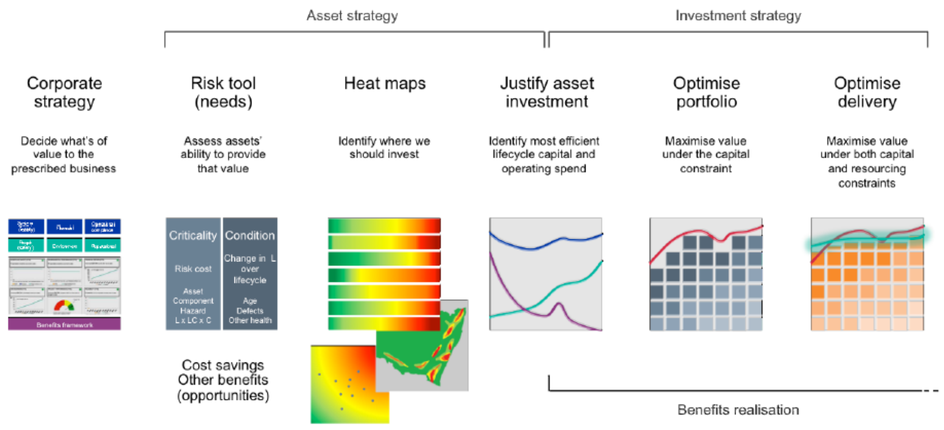
Source: TransGrid prescribed capital investment framework, Table 1

54. TransGrid also articulate its capital investment framework as shown in Figure 5, comprising:[13]

- Corporate strategy – TransGrid states that the Corporate Strategy and Risk Appetite Statement are key inputs into its Network Asset Risk Assessment Methodology and the Renewal and Maintenance Strategies;
- Risk tool – TransGrid has developed a tool to document the risk for its options analysis;
- Heat maps – This is a visual summary of the health of TransGrid's major assets, with emphasis on those that require immediate attention;
- Justification of investment – TransGrid describes the justification of investment by selecting the technically feasible option with the highest NPV;
- Optimisation of portfolio – TransGrid describes this as ranking the projects with the highest positive NPVs. Projects that have a negative NPV and are considered as meeting its ALARP test or regulatory requirements (including reliability standards) are also included, the least negative NPV option that meets the ALARP test or regulatory requirement is selected; and
- Optimisation of delivery – This involves improving efficiency in the execution phase of the project, such as the efficiency of location-based repex programs.

[13] TransGrid response to AER information request 026, Question 1 Explanation of framework overview

Figure 5: Capital investment framework overview



Source: TransGrid prescribed capital investment framework, Attachment 1

3.2.2 Our assessment

55. Whilst the elements in Figure 5 generally reflect aspects of good practice, we did not see evidence of how all of these steps were consistently applied in determination of a prudent and efficient forecast. For example, the documentation provided by TransGrid indicated to us that optimisation was done once a project was approved for delivery, and any portfolio optimisation was limited to a ranking of projects rather than optimisation of the forecast.

56. In its RP, TransGrid states that its "*investment framework and asset management strategies have been transformed since TransGrid's previous revenue proposal.*" [14] We understand this is a further reference to "*A number of improvements made since the last revenue proposal relate to:*

- *the treatment and quantification of risk in asset condition assessment, investment option evaluation and capital program optimisation*
- *improved alignment to the Corporate Risk Framework and a more objective based replacement strategy*
- *the development of area plans, which present a transparent view of the range of factors impacting planning in a particular network area in the future, including those related to generators and customers*
- *developing a "top-down" asset replacement model to provide a useful cross-check to bottom up plans."* [15]

57. We looked for evidence of the outcomes of the improvements claimed by TransGrid in the sample project and program reviews we undertook, as discussed in sections 5-7.

Capital investment framework lacks effective portfolio optimisation process

58. TransGrid's capital investment framework includes most of the elements of an effective capital governance framework consistent with good industry practice. However, we consider that the capital investment framework does not incorporate an

[14] *TransGrid Revenue Proposal 18/19 to 22/23 – January 2017*, page 62

[15] *TransGrid Revenue Proposal 18/19 to 22/23 – January 2017*, page 54

effective portfolio optimisation process, in developing its capex forecast. From the information provided to us, it is not evident that TransGrid's management and the Board have adequate information to assess TransGrid's risks and investment requirements over the forthcoming regulatory period, at the portfolio level. For example:

- We sought, but were not provided with compelling evidence that TransGrid deploys a decision-support tool to help it ensure that all the proposed activity is required at the estimated (aggregate) cost;
- TransGrid does not have an overall network risk profile;[16] and
- We sought, but were not provided with compelling evidence that the TransGrid Executive (or its sub-committees) and/or Board (or its sub-committees) having undertaken a challenge process of the capex forecast, including where changes were considered and/or amendments made.

59. We also note that TransGrid does not appear to have yet applied its gating process for all aspects of its capex forecast, namely preparation of its IT capex forecast.

60. In preparing its forecast for the next RCP, the information available to TransGrid is preliminary in nature, which emphasises the importance of reasonable controls to remove any systemic bias that may exist.

Approval of the capex forecast formed part of the submission

61. TransGrid has undertaken engagement with its Executive, Board and Security Holders which primarily concentrate on the methodology and process for developing the capex forecast. It included a presentation to the Board Audit and Regulatory Committee covering the asset risk assessment process over 2016.[17]

62. TransGrid engaged an engineering consultant, Aurecon, to review is asset management framework and resulting capital forecast. In addition, an engineering and forecast assurance review was undertaken by Aecom to support the corporate governance processes.

63. TransGrid advised that the capex forecast, was approved as part of the RP by the Board for submission to the AER on 24 January 2017.

Capital portfolio comprises individual projects

64. In its RP, TransGrid explains that its capital investment framework generates a capital portfolio containing projects justified and prioritised on the basis of economic and compliance based decision criteria.[18] We review the method of including projects into the expenditure forecast in section 4.

65. TransGrid illustrate how its capital investment framework components apply to the asset lifecycle phases and stages, including the relationship to key supporting documents in Figure 6 below.

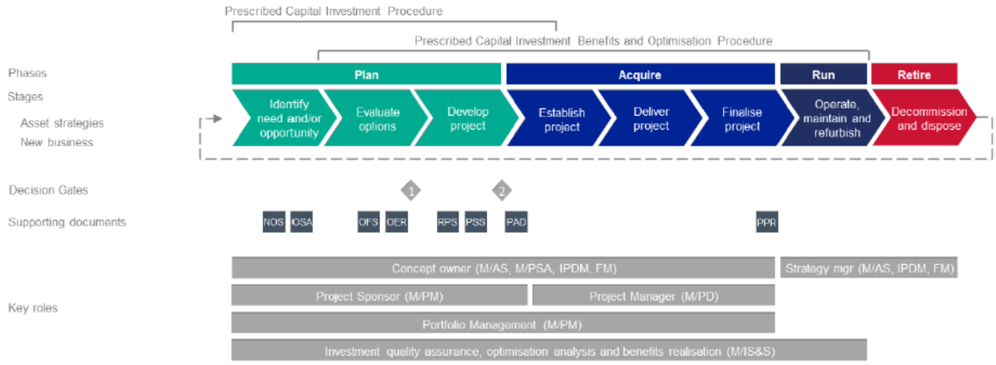
---

[16] TransGrid response to AER information request 006

[17] TransGrid response to AER information request 030, Question 3

[18] *TransGrid Revenue Proposal 18/19 to 22/23 – January 2017*, page 62

Figure 6: Capital investment framework components



Source: TransGrid prescribed capital governance arrangements, Figure 2

Capital portfolio remains subject to approval to proceed

66. TransGrid has advised that all projects in the capex forecast have been prepared to Decision Gate 1 (DG1),[19] request for funding to proceed to scoping. At this point, the estimates are within a +/-25% accuracy range. However, during the onsite meeting we held with TransGrid, it advised that given the rapid rate of change in IT solutions, the IT programs have not yet been prepared for DG1.

67. TransGrid's documentation suggests that each project, subject to its financial value, is ready to be approved to proceed past DG1. During the onsite meeting, TransGrid advised that it was submitting a decision paper to its Board in May requesting approval to proceed with all projects included in the forecast, rather than follow the existing process described in its documentation.[20] We have not been provided with a copy of the submission, or any decisions arising from the planned Board meeting in May.

3.3 Asset management framework

3.3.1 Overview of asset management strategy

68. TransGrid has developed an overarching asset management strategy, and network vision for its transmission network that is informed by the risk management framework and TransGrid business plan, as shown in Figure 7. TransGrid states that its asset management strategy is consistent with ISO55001 and that it has achieved certification of its asset management system to this standard.[21]

Asset renewal strategies

69. TransGrid has developed asset class renewal strategies that describe the historical renewal practices, relationship to its maintenance plans, emerging issues and its mitigation strategies. Details of the asset population are also provided, along with high level performance trends.

[19] *TransGrid Revenue Proposal 18/19 to 22/23 – January 2017*, page 63

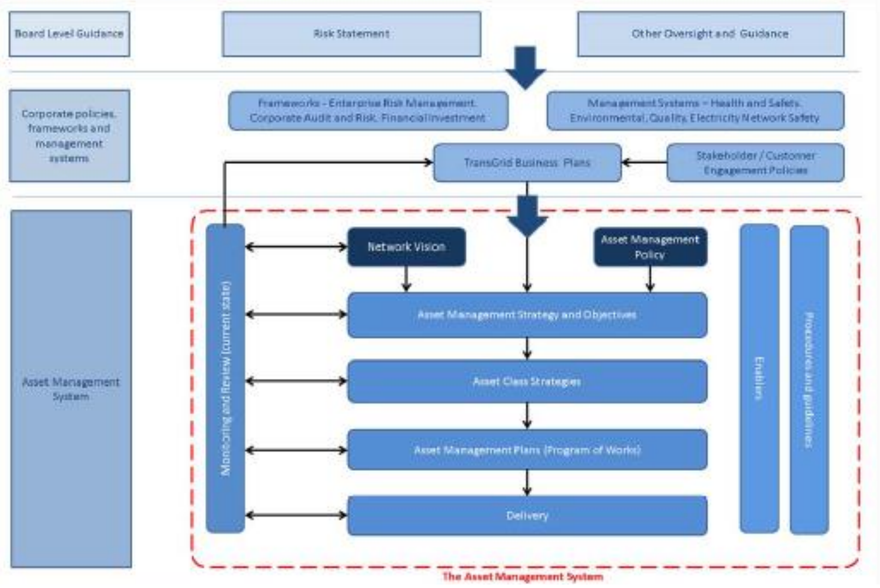
[20] The Prescribed Capital Investment Procedure refers to approval of individual projects (via approval of the respective business case) by the Board, CEO, or EGM in accordance with the Financial and Process Authorities at DG1, not as a single Board submission

[21] *TransGrid Revenue Proposal 18/19 to 22/23 – January 2017*, page118

70. TransGrid does not include an assessment of risk by asset class. During the onsite meeting, TransGrid did demonstrate a risk heat map which illustrated the change in transformer risk levels across RCPs.

71. Examples of initiating investigations prior to project commencement, to gather more information on asset condition, or prioritise asset renewal options were provided in these documents.

Figure 7: Asset management approach



Source: TransGrid Revenue Proposal 18/19 to 22/23, Figure 4.3 (with asset lifecycle depiction removed)

Asset condition assessments

72. TransGrid described the changes in its condition assessment process including introduction of Asset Inspection Manager. This has introduced more structured criteria, including images, to assist inspectors assess asset condition.

73. TransGrid states that this change in approach contributed to assets' assessed condition being better than originally assessed, and thereby work was able to be prudently deferred.

Long term capital planning

74. TransGrid has developed a long-term forecast of asset age and proposed expenditure requirement, which we understand is an output of its modification to the AER's Repex Model. We saw some evidence of consideration of project needs across RCPs within its management strategy documents.

Asset management approach to IT expenditure

75. TransGrid has established an IT asset management framework for IT assets, which differs from the approach described in Figure 7. The IT asset management framework states that:[22]

[22] *TransGrid IT Asset Management Framework*, page 4

> *"TransGrid's general principle is that IT assets must remain within vendor support windows unless a compelling Business Case supported by appropriate risk analysis is available.*
>
> *For each asset class, a useful life is established and the assets are replaced at end of useful life. The useful life takes into consideration length of available warranty, potential cost to repair and financial depreciation schedules. The lifecycles are reviewed regularly and adjusted where appropriate.*
>
> *The maintenance philosophy for IT assets is designed to ensure that each asset class is able to meet its target availability service level while minimising the cost to TransGrid."*

76. TransGrid's IT asset management framework defines IT asset classes, IT asset maintenance principles and useful life for each asset class.

3.3.2 Our assessment

77. We consider that TransGrid has established an asset management strategy and supporting elements that are consistent with good industry practice for management of its network assets. Notwithstanding the additions to its long-term capital planning approach, we found a bias for defining projects within RCP boundaries rather than as a program of works that had a project or program scope that reflected an optimal level and timing of expenditure based on risk-cost trade-offs and delivery efficiency.

78. For its IT assets, the link between the corporate risk management framework, business plan and asset management strategy is not evident. The replacement and renewal decision therefore appears to be primarily based on an assumed end-of-life, in accordance with predefined useful lives without sufficient consideration of business risk, alternative options and cost.

79. We consider the application of TransGrid's asset management strategy and framework to the capital forecast in our review of the sample of projects and programs of expenditure in sections 5-7.

3.4 Risk assessment

3.4.1 Overview of risk assessment framework

80. TransGrid has a corporate risk framework that includes a risk appetite statement determined by the Board of Directors. It includes a threshold at which risk mitigating actions and plans must be put into place, and requires risk registers to be developed and maintained on a regular cycle. The framework and approach is based on AS31000.

Approach / methodology for assessment of risk

81. TransGrid has developed a methodology that assesses the risk cost associated with a hazardous event, that it applies as part of its capital investment framework, and that has been relied upon for the development of its capital forecast.

82. Specifically, TransGrid applied its Risk Assessment Methodology (RAM) to network assets. Asset health is used to estimate the remaining life of an asset, and to forecast the associated likelihood of failure of the asset now and into the future.

83. For IT, TransGrid follows a similar methodology to the RAM, albeit it relies on a simplified determination of probability of failure (PoF). In its methodology for assessment of risk, we did not see evidence of a strong linkage to the corporate risk framework.

84. The tools that support the application of the RAM include:

- Isograph Availability Workbench (AWB) for calculation of probabilities of failure based on conditional age; and
- Microsoft Access based Investment Risk Tool (IRT) for risk quantification, risk forecasting, and registration of risk assessments.

85. The RAM describes the approach to develop a monetised value of risk as expressed in the equation in Figure 8, as the sum of the risk costs for people, environmental and system impact (reliability) risks and the direct financial cost multiplied by the PoF for each failure mode.

Figure 8: Monetised value of risk

$$\text{Monetised value of risk (\$)} = \sum_{K=0}^{Y} P(\alpha_K).(\$C_P.\beta_P + \$C_E.\beta_E + \$C_S.\beta_S + \$C_F)$$

Where:

$P(\alpha_K)$ *is the likelihood of failure attributable to failure mode K*

$\$C_P$ *is the people safety consequence cost*

$\$C_E$ *is the envirnoment consequence cost*

$\$C_S$ *is the system impact consequence cost*

$\$C_F$ *is the financial consequence cost*

β_P *is the likelihood of the people safety consequence occuring*

β_E *is the likelihood of the environment consequence occuring*

β_S *is the likelihood of the system impact consequence occuring*

Source: TransGrid Risk Assessment Methodology, Page 11

Identification of key hazardous events

86. TransGrid has developed its assessment of risk using the concept of hazardous events. TransGrid defines a hazardous event as[23] "*an event that poses a potential threat to cause harm or damage to the assets, property, the environment, our workforce, the general public and/or the viability of the business.*"

Risk cost modelling

87. For each hazardous event, TransGrid defines a risk cost as the combination of risk cost components including injury, environment, reliability, investigation, litigation and compliance consequences. Each has a combination of a likelihood of consequence and risk consequence value.

88. In Figure 9, an overview of the steps undertaken by TransGrid to develop its risk cost for repex projects is shown. The key features include assessment of: (i)

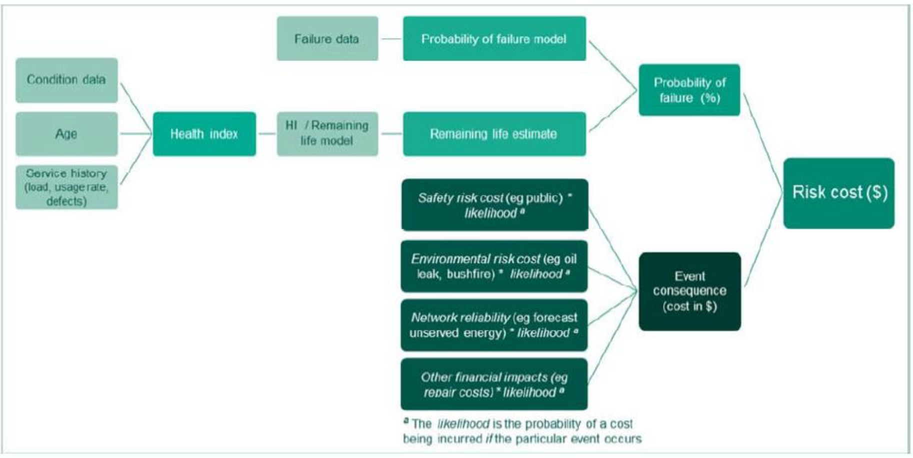
[23] *TransGrid Network Asset Criticality Framework*, page 3

condition of the asset, (ii) health index, (iii) effective age, (iv) probability of failure, (v) hazardous event (including consequence cost and likelihood of consequence), and (vi) annual risk cost.

89. These process steps were generally followed for forecast capex within the scope of our review with some exceptions:

- For security & compliance, a remaining life estimate did not appear to be derived however the factors of age, asset condition and obsolescence were considered in the estimate of PoF.
- For augex projects driven by economic benefits, the explicit calculations for the PoF of components of the network used in its risk costs calculations were not provided, however we infer these are based on similar principles for major assets as described for repex or derived directly from that generated for repex.
- For IT capex, we were not able to discern the relationship of the PoF calculation to the elements in Figure 9. As described in our review of IT projects and programs, TransGrid applied a step change to the PoF, from a zero base to a value of 50%[24] at the end of the nominated useful life.

Figure 9: Overview of the development of risk cost



Source: TransGrid Revenue Proposal Figure 5.6 Development of risk cost

90. TransGrid has developed a risk modelling tool to develop risk costs for its options analysis including the base case and options for each of its projects, known as the Investment Risk Tool (IRT). The manual provided with the IRT states that a number of default values are provided for the CoF and LoC values, and provision for the user to nominate scenarios and force change to these values. The manual also states that the user should annotate where values have been changed. We did not find comments provided by TransGrid in these instances.[25]

91. In the onsite meeting, TransGrid stated that the structure of the IRT was prohibitive in circumstances where the reliability risk cost was determined, and in many cases an external calculation of annual reliability risk costs was undertaken. To input this

[24] The PoF of 50% varied across projects.

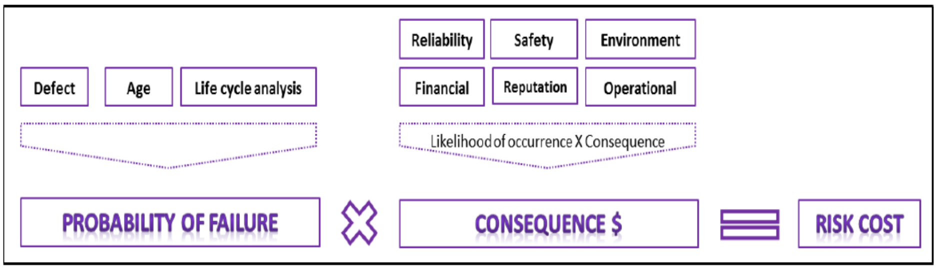
[25] *TransGrid Network Asset Criticality Framework*, page 17

into the IRT, the input values were forced to arrive at the correct output value. However, the IRT was not annotated in this way.

92. TransGrid states[26] "*Note that the risk costs for the majority of repex projects are calculated on a project specific basis in Excel workbooks outside the risk tool and then reconfigured and entered into the risk tool. The risk tool and the backend database have been provided to the AER in April 2017*."

93. We asked TransGrid to provide copies of the external calculations and input values that it had relied upon in developing its capex forecast, and we reviewed these as part of our review of a sample of projects and programs.

Figure 10: IRT manual



Source: TransGrid-Forecasting methodology, Figure 4 Investment Risk Tool

94. In addition to the parameters shown in Figure 10, the IRT includes the ability for adding multiple consequence types against hazardous events, and aggregating these to develop a composite risk cost. The principle formula in which the risk cost calculation for each for each hazardous event can be expressed as is:

$$Risk\ cost\ (\$) = \ No.x\ PoF\ x\ CoF\ x\ LoC \qquad (Equation\ 1)$$

where,

No. is the Number of assets

PoF is the Probability of failure

CoF is the Consequence cost of the failure

LoC is the Likelihood of the consequence occurring

95. Whilst the *No.* and *PoF* are held constant for a particularly asset class, the values of *CoF x LoC* are often varied with different consequence types.

96. The risk costs for each hazardous event are then summed to provide the total risk cost on an annual basis. For reporting purposes, TransGrid also separate this into Reliability, Financial, People (safety), Environmental, Reputational and Operational costs.

3.4.2 Our assessment

Consequence of failure determined for worst case events

97. TransGrid describe that it has developed its risk consequence costs as the outcome of an event expressed qualitatively or quantitatively, affecting TransGrid's objectives. Whilst TransGrid identifies a range of possible outcomes associated with an event, it

[26] TransGrid response to AER information request 026, Question 1

often selects the worst-case value for use in its risk cost analysis. A sample of the worst-case consequence costs is provided in Table 4 below.

Table 4: Example CoF values used by TransGrid

Hazard type	Consequence type	Cost of consequence
Community cost of bushfire	Bushfire Urban fringe	$400,000,000
Compensation of injury	Fatality	$10,000,000
Legislation breach	Extreme breach	$5,000,000
Litigation type	Extreme - Supreme Court	$5,000,000

Source: TransGrid risk consequence table, TransGrid Asset Criticality Framework

98. TransGrid has applied a Value of Statistical Life (VSL) of $10m as the standard consequence cost for a fatality. This is much higher than the $4.4m ($2017) VSL in the Australian Government's Office of Best Practice Regulation 2008 Guidance Note (BPR Guide), which, according to TransGrid, the AER has indicated the VSL should be based on.[27] TransGrid considers that the BPR Guide systemically undervalues the occupational safety risks that are most relevant for TransGrid's risk framework because it is heavily weighted by results for the health sector. TransGrid instead refers to AS/NZS 7000:2010, and to Australian and international studies relevant to the occupational health sector, which "*provides a range of $6.8m to $11.2m on a 2006 dollar basis (or approximately $8.5m to $14.1m in 2017 dollars*)."[28] It therefore considers its VSL to be reasonable. We have reviewed the literature sources cited by TransGrid and believe there is merit in considering the Australian study results focused on the occupational health sector, for the reasons stated by TransGrid. We do not however consider that TransGrid has provided sufficiently compelling information to support the use of $10m, given that the 'Health of Nations' report which it predominantly relies upon, notes that the mean Australian VSL is $5.5m ($6.9m in 2017 dollars), excluding the outlier study.[29, 30]

99. The reliability risk consequence, expressed as a dollar per hour ($/hour),[31] is biased to extreme consequences of low probability, such as failure events occurring at times of peak load including 'Black Start'– that is, the de-energisation of the entire NSW transmission grid.[32] Further, the assumptions used in its analysis are not sufficiently supported by TransGrid, including:

[27] TransGrid response to AER information request 030, Question 4 VoSL, page 1

[28] *TransGrid, op. cit.* page 4

[29] Viewed from website at https://www.safeworkaustralia.gov.au/system/files/documents/1702/thehealthofnations_value_statisticallife_2008_pdf.pdf, page 55, Table 4-4

[30] In *AS/NZ 7000:2010 Overhead line design – Detailed procedures* a value for VSL of $10m is used in a worked example, without any indication that this is a recommended value nor any supporting rationale for its selection. Based on the information provided we do not consider that it has any probative value

[31] based on an assessment of the combinations of unplanned and planned outages of other network elements which may result in an Energy Not Served (ENS) event during the duration of the hazardous event

[32] Included as the reliability risk associated with the failure of a protection system on the NSW 500 kV and 330 kV network

- Reasonableness of using a black start consequence for protection failure for an un-cleared fault;[33]
- Reasonableness of estimating the potential load at risk based on the next worst contingency/contingencies on the network in terms of supply connections to load, system voltage management and system security, occur; [34]
- Explanation of the differences in approach to calculating average demand and load at risk using both a factor of 0.65 from peak load, apparent derivation from annual energy consumption, and inclusion of uncertainty allowances; and
- Explanation of the selected load interruption times assumed in the analysis, with reference to TransGrid's own experience.

Conservative estimate of moderating factors, LoC

100. TransGrid defined its LoC as[35] "*the likelihood that the full value of the consequence eventuates given the hazardous event has actually occurred.*" Given the magnitude of the worst-case consequence values in Table 4, it appears that TransGrid has adopted moderating factors in determining the LoC as a mechanism to recognise the probability of particular worst-case events occurring.

101. However, we have identified a number of examples from TransGrid's application of its LoC that suggest that the moderating factors are not effective:

- In its assessment of safety risk for transmission lines, TransGrid identifies the event as failure of a structure or conductor. The consequence is identified as a fatality (by impact or electrocution). In determining the LoC for a particular line, TransGrid adds the likelihood that one of its workers will be in the vicinity of the line, to the likelihood that a member of the public will be in the vicinity of the line. We consider that this approach is likely to overstate the LoC of a fatality because it assumes that there is a 100% likelihood that if the event occurs, the person in the vicinity of the line will be killed. We consider that this likelihood is much less than 1.
- In its assessment of environmental risk for transmission lines, TransGrid identifies the event as failure of a structure or conductor. The consequence is a bushfire of the magnitude and destruction of the 2009 Victorian bushfire. In determining the LoC for a particular line, TransGrid seeks to determine the likelihood of a NSW equivalent of the 2009 Victorian bushfire occurring. TransGrid multiplies the likelihood of 'major NSW bushfire weather conditions' by a scaling factor to account for location-specific bushfire impact/propagation features and multiplies this by the proportion of time that the region has very high or greater bushfire ratings. Our principle concern is that TransGrid's approach does not appear to adequately account for the likelihood that a broken transmission structure/conductor will start a bushfire.[36] This factor would be much less than 1.0 and lower than the equivalent moderating factor for

[33] In TransGrid's *Network Asset Criticality Framework*, it states that the concurrent failure of both independent protection systems was the only asset related scenario considered with the potential for causing an uncleared fault. Note, there is currently no record of this ever occurring on TransGrid's network.

[34] *TransGrid Network Asset Criticality Framework*

[35] Network Asset Criticality Framework, page 3

[36] From the information provided, TransGrid's PoF parameter does not appear to take this into account

distribution networks (which were involved in the 2009 bushfire) due to differences such as the effectiveness of protection systems;

- In its assessment of reliability risk at substations, TransGrid identifies the event as failure of steel structures within a substation. The consequence is loss of the entire substation for 720 hrs (30 days). TransGrid determines the LoC to be 2% or approximately once in the lifetime of every substation. We do not consider this to be a credible LoC.[37]

102. We requested explanation from TransGrid of the CoF and LoC values that it had relied upon in the development of its forecast expenditure, and the basis for their calculation. At the time of preparing this report this has not been provided to us.

Sensitivity analysis is required to manage uncertainty

103. The development of risk cost is an approximation for the prudent timing of expenditure on the network. We therefore consider that TransGrid should apply confidence bands and sensitivity analysis to provide greater confidence in the results of the risk cost analysis.

104. During our onsite review meeting, TransGrid advised that it had undertaken sensitivity analysis on the selection of the values used in its analysis, however we have not been provided with this analysis.

Aggregate impact of risk cost modelling is not credible

105. In considering the impact of a potential bias to over-stating the risk cost observed in the capital forecast we considered the aggregate level of risk that TransGrid claims existed in its transmission network. TransGrid advised its risk-cost calculations produce a pre-investment risk cost of $1.6 trillion per annum,[38] and the proposed expenditure would reduce this to $132m per annum. A large proportion of the risk cost saving is associated with augex related projects. TransGrid advised that for repex only, the risk cost saving is $344m per annum. We consider that these values do not represent a reasonable estimate of the current level of risk to TransGrid. If the current risk exposure were credible, it suggests that the Board should be investing a greater amount of expenditure in its network in the current RCP to prudently manage the risk to consumers, and it has not decided to do so. This indicates to us that the risk cost claimed by TransGrid is over-stated.

[37] In our experience, steel structure failure within substations is rare and to our knowledge, structure failure causing loss of 1300MW supply for 30 days or anywhere near that has not occurred in Australia.

[38] Based on the summation of pre-investment risk from the project list provided by TransGrid in response to AER information request 026, question 2

3.5 Probability of failure analysis

3.5.1 Overview

General approach applied for network assets

106. PoF is a key component of the risk cost calculation described above. TransGrid describes its approach to determine the PoF for a given asset class as comprising the following eight steps:[39]

(i) Obtain failure data for past 10 years;

(ii) Establish wear-out failures by excluding failures that (i) did not result in asset replacement, (ii) were associated with infant mortality (life< 5years), (iii) were due to incorrect design/installation or maintenance;

(iii) Input time to fail data for wear-out type failures into its modelling software (Availability workbench);

(iv) Input time-to-fail data for non-failure type asset replacement into its modelling software, and mark these as suspended data;

(v) Run simulation of modelling software and calculate Weibull parameters;

(vi) Verify and calibrate with external data sources and subject matter experts;

(vii) Model additional failure data; and

(viii) Apply the failure data relationship to the asset fleet, compare to historical experience and accept/re-calibrate.

107. This method is applied to each of the asset classes to derive a PoF characterised by a 2-parameter or 3-parameter Weibull distribution. We show a summary of the Weibull parameters in Table 5 below.

Table 5: Summary of Weibull parameters for failure rates

Asset class	Weibull parameters			Notes
	eta	beta	gamma	
Transformers	59.74	4.196	0	to be combined with type tap changer failure mode as required
Oil reactors	50.17	4.945	0	modified following SME input
Circuit breakers	57.58	4.484	0	
Oil CTs	253.1	26.38	-189	
MVT	61.52	3.748	0	
CVT	305.5	1.367	0	
Disconnector	67	4.8	0	modified following SME input
Surge arrestor	55	3.2	0	
Transmission lines	-	-	-	Weibull function not determined
Secondary systems	-	-	-	Weibull function not determined

Source: TransGrid Network Asset Health framework

108. The Weibull parameters can be explained as follows:

- Beta values (sometimes referred to as the 'shape factor' or slope) are an indicator of the failure behaviour of equipment or component. We would expect to see Beta values greater than one, as this represents wear-out type failures.

[39] *TransGrid Network Asset Health Framework*, Attachment B.2

Beta values in excess of three typically suggest aggressively increasing failure rates;

- Eta values (sometimes referred to as the 'characteristic life' or 'scale parameter') are an indicator of the time where 63.2% of the equipment or components in service are likely to have failed. Therefore, the eta value provides an estimate of how long components might last after being put into service; and
- Gamma values (sometimes referred to as the 'location parameter') are included in 3-parameter Weibull distributions. Gamma values are an indicator of the earliest time to failure, and often used in modelling to fit to a straight line on a probability plot.

109. We observe that the derived beta values in Table 5 are all high (except for CVTs), indicating wear-out rates that increase rapidly with time. We also observe that the eta values are also high, generally higher than the value of economic life generally assigned to the respective asset class. This indicates to us that whilst the equipment is taking longer to fail, the failure rate is increasing more rapidly with age.

110. TransGrid states that[40] "*…it is important to understand the influence of TransGrid's use of 'effective age' in moderating the effect of the 'aggressive' β values that have been recognised by the AER. As TransGrid's Health Index is based on the 'effective' rather than 'natural' life of an asset, the Health Index assessment itself acts to dampen the impact of the β values in the time-failure relationships for individual assets (by 'resetting' their effective life to a more 'benign' part of the curve in cases where older assets remain in demonstrably 'good' condition).*"

111. We observe that TransGrid has used non-failure asset replacements in its analysis as 'suspended' data to ensure that the analysis does not overstate the probability of failure.[41]

112. TransGrid advised that alternative methodologies were used to calculate failure rates for Transmission line assets and secondary systems, as discussed below.[42]

Approach for transmission lines

113. TransGrid advises that its approach to calculating transmission line PoF differs from that used for substation assets because:[43]

- A transmission line is a compound group of many asset components;
- Transmission lines are geographically distributed and all its components function together to provide a service; and
- A single failure of a key component makes the transmission line service unavailable.

[40] TransGrid response to AER information request 026, Question 12 Weibull distribution

[41] TransGrid response to AER information request 026, Question 9, Probability of failure

[42] *TransGrid Network Asset Health Framework*, and TransGrid's response to AER information request 026 Question 7, Time to failure

[43] *TransGrid Network Asset Health Framework*

114. TransGrid firstly determines the condition and PoF for each component of the line, then the aggregate of the weighted average for each component is used for the transmission line. For example:

- structures – based on the historical design methodology of TransGrid transmission line towers in accordance with engineering standards.[44] The actual failure data of towers in TransGrid's system has been used to moderate the predicted PoF calculations applied by TransGrid;
- wood poles – similar to that undertaken for structures (incl towers). However, TransGrid advised that historical failure data of wood poles was unavailable and therefore the failure data could not be moderated against any actual records. Whilst TransGrid considers the estimate to be conservative,[45] it has instead calculated probability of failure based on the age of the pole, year of construction and material type;
- structures, tower grillage foundations – as with the towers, in the calculation of the PoF for tower grillage foundations, members are premised on an initial loss of section (from AECOM's report), and further loss over the years is based on the corrosion environment;
- structure, earthing - PoF for structure earthing was based on defect rates. A sample test was conducted on the structure earthing of 13 randomly selected towers;
- conductor and earthwire fittings - combination of defect rates (where available) were analysed to calculate the base PoF, and age of the transmission line; and
- conductor and earthwire – no PoF was developed for conductors, as all conductors were assessed to be in good condition. PoF for earthwire based on recent experience, moderated by corrosion level.

Approach for secondary systems

115. TransGrid advised that the PoF of secondary systems is determined from the past failures and observations by taking a linear trend forecast for that relay model with a zero intercept set at its earliest year of available defect data. TransGrid advised that it has planned to develop the relationship between the PoF and relay health index in the future.

Approach for information technology

116. TransGrid did not provide evidence of its assumptions surrounding PoF rates, rather these appeared to be somewhat arbitrarily assigned to individual projects that increased significantly at the end of the warranty period.

Data validation / verification

117. TransGrid stated that it undertook the following steps to remove any bias that may have existed in the input data relied upon for its analyses:[46]

- *"Exclusion of 'old' or non-relevant data*
- *Exclusion of 'infant mortality' failures*

---

[44] Specifically design wind pressures and equivalent return periods as per AS1170.2

[45] Due to factors such as structure utilisation, safety factors, terrain effects and span lengths

[46] TransGrid's response to AER information request 026, Questions 12, also Questions 10, 13 and 16

- *Verification of Weibull Model*
- *Model verification using external studies*
- *Model verification using observed failures"*

3.5.2 Our assessment

118. The method for determining the PoF for network assets as used for the repex forecast, makes use of TransGrid's own experience and observations, with additional verification and validation steps in developing a PoF.

119. We have not undertaken a detailed audit of the calculations and factors applied in TransGrid's derivations of its PoF estimates, nor have we audited the extent of validation and verification steps it has undertaken. The inclusion of asset replacement data as suspended data in the estimate of PoF is representative of good industry practice, and is likely to improve the estimate of PoF, by including all assets that have survived to the point at which they were replaced.

120. TransGrid has sought to verify its PoF estimates with its own experience, and moderate results, where required, as a part of its development process. On balance, we consider that TransGrid has applied a reasonable process, and that application of its process is likely to produce a reasonable estimate of the PoF. We looked for evidence of the calculations for the PoF rate assumptions relied upon in the project and programs reviews that we undertook.

121. For IT assets however, TransGrid did not provide evidence of its assumptions surrounding PoF rates, rather these appeared to be somewhat arbitrarily assigned to individual projects that increased significantly at the end of the warranty period. Similarly, we did not see evidence of verification undertaken for the IT capex.

3.6 Implications for proposed expenditure forecast

Governance framework is reasonable, if applied properly and consistently

122. TransGrid has in place governance and management policies, frameworks, and procedures that are generally aligned with common industry practice. However, we consider that the capital investment framework does not incorporate an effective portfolio optimisation process. Furthermore, in preparing its IT capex forecast, it does not yet appear to have applied its gating process.

Claims of an integrated risk assessment methodology were not well supported

123. TransGrid advised that the asset risk management methodology is used at multiple points in the capital investment framework and is linked to its corporate risk management framework. We did not see evidence of how this alignment was achieved or managed on an ongoing basis by TransGrid.

124. Through discussion at the onsite review meetings, and review of its documentation, TransGrid appears committed to continuing to develop its risk assessment

methodology and ensure this is better integrated into its capital investment framework and asset management approach.

Pre-investment risk assessment did not appear to be subjected to challenge

125. We consider that application of the risk-cost based assessment to optimisation of the capex portfolio, had it been applied, may have resulted in an effective challenge process and addressed the potential bias associated with the significantly over-stated level of risk claimed by TransGrid as its pre-investment base case.

The bias we observed in the risk cost assessment has led to overstating the capex forecast

126. We consider that the conservative approach to risk cost assessment, notwithstanding the inherent uncertainty with forecasting, is likely to have resulted in overstating the capex forecast for the areas we reviewed.

Application of TransGrid's risk assessment methodology in practice may lead to over-spending of its program

127. TransGrid's application of its risk assessment methodology appears to have been developed recently in readiness for the next RCP, and for some parts remains a work in progress. TransGrid applies the asset risk management methodology to projects as part of its business as usual decision processes.

128. In its current state of readiness, TransGrid's application of its risk cost methodology to BAU decision-making is likely to result in unwarranted spending in its works program unless the risk parameters are subject to robust challenge to remove the biases that we observed.

4 Assessment of forecasting methods

4.1 Introduction

130. In this section, we provide our findings in relation to the forecasting methods that TransGrid has applied to forecasting its capex requirements, that are relevant to the aspects of our review: augex projects that are driven by economic benefit, replacement, security & compliance, and IT.[47] We consider this in the following parts:

- TransGrid's expenditure categories;
- The methodologies used to forecast economic benefits-driven augex, repex, and IT capex activities;
- The methodologies used to estimate the costs of those activities;
- The methodologies used to ensure the work is delivered efficiently; and
- The methodology TransGrid uses to challenge its bottom-up activity forecast.

4.2 Capital expenditure forecasting approach

4.2.1 TransGrid's approach

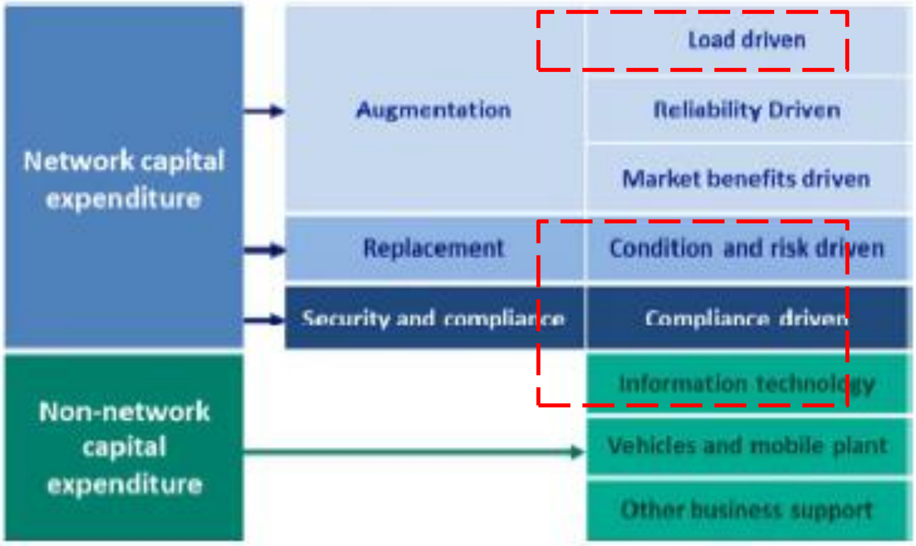
Expenditure categorisation

131. TransGrid has nominated its expenditure categories and key expenditure drivers as shown in Figure 11. Our review relates to aspects of those elements highlighted only.[48]

[47] *TransGrid Revenue Proposal 18/19 to 22/23 – January 2017*, page 63

[48] With regards to load-driven expenditure, our review is limited to the assessment of expenditure categories associated with projects driven by an economic benefit (16 projects) and providing dynamic voltage support (1 project) only.

Figure 11: Capital expenditure categories and drivers



Source: TransGrid Revenue Proposal 2018/19 to 2022/23, Figure 5.1 capital expenditure categories

Overview of TransGrid's forecasting methodology

132. TransGrid has determined its capital forecast from a bottom-up (zero-base) approach. Individual projects of work are identified from one or more expenditure drivers.[49] The primary drivers of its overall capex forecast are identified as:[50]

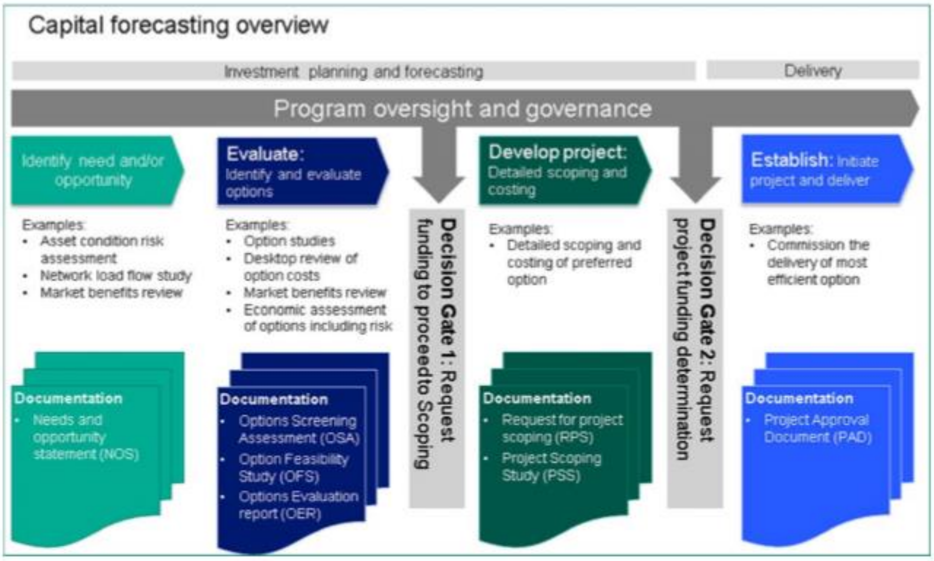
- The risk of asset failure and life cycle costs;
- Connecting distribution networks to the transmission grid;
- Non-compliance with regulations and standards;
- Inadequate network capacity to meet forecast customer demand; and
- Business support requirements.

133. As noted in section 3, TransGrid's proposed capital forecast has been developed based on project information components as illustrated in Figure 12 below, and which is the focus of our review.

[49] *TransGrid Approach to Forecasting Expenditure 2018/19 to 2022/23,* page 7

[50] *Ibid,* page 6

Figure 12: Overview of the components of TransGrid's capital forecasting approach



Source: TransGrid Revenue Proposal 2018/19 to 2022/23, page 63

Identify need and/or opportunity

134. The Need / Opportunity Statement (NOS) document content varies somewhat between expenditure categories, with a focus on:

- Identifying the need (e.g. to address an asset condition and/or performance issue, a compliance obligation, load growth, obsolescence, etc); and/or
- Identifying the opportunity to deliver a net economic benefit; and
- Translating need and opportunities into risks to be addressed, and monetising the risks according to the process described in section 3.

Options analysis and evaluation

135. The outcome of the evaluation step is a recommended option for addressing the need/opportunity in the corresponding project NOS. According to Figure 12 above, the evaluation includes the following components:

- Options screening assessment (OSA);
- Option feasibility study (OFS); and
- Options Evaluation Report (OER).

136. At the time of preparing this report, TransGrid had only provided OER documents to support its proposed expenditure for repex and IT projects. For augex projects, OFS documents were also provided for a number of projects. The OFS looks in more detail at the scope of work for the preferred option and the cost, time and delivery strategy to implement the work, accounting for such matters as outage requirements, environmental and other approvals, and delivery risk. The OER documents the options analysis for identified options, drawing on other documents (such as the NOS) and recommends the preferred option (scope, timing, cost). It also presents the annual risk cost for each of the identified options, including the Base Case.

137. The OER reports which options TransGrid considers to be technically feasible and for those options presents the results of commercial analysis using Discounted Cash Flow (DCF). The assessment of each technically feasible option includes annual benefits from the avoided risk cost (i.e. compared to the base case counterfactual).

In some cases, additional benefits (i.e. opex efficiency savings) have also been included. In cases where the assessed net present value of the preferred option was not positive, TransGrid extended the analysis to include an ALARP/SFAIRP assessment to help justify the project.

138. TransGrid has proposed investments in the next RCP if one or more of the following criteria are satisfied:[51]

- A positive NPV exists indicating there is value to consumers in investing;
- An ALARP regulatory requirement is to be met;
- A specific compliance requirement is mandated; or
- Strategic benefits can be obtained by investing.

4.2.2 Our assessment

There is typically a prima facie need for some form of action

139. In most cases, we have found that TransGrid's needs and opportunity analyses appropriately identify requirements to mitigate failure risks or opportunities, and progress to further evaluation. The drivers are typically well articulated and the 'base case' risks (i.e. before the proposed capex) from one or more of the six risk categories[52] are identified and monetised using its risk assessment methodology.

140. However, from our review of a sample of projects, we found some examples where we consider that:

- The identified need was not commensurate with TransGrid's obligations under the NER; and/or
- The identified 'base case' risk cost was grossly overstated due to issues with key underpinning assumptions, which lead us to question whether the need merited further evaluation.

Options identification does not include a reasonable range of credible options

141. The process for identifying options (risk treatments) is not clear in every case. TransGrid occasionally refer to the use of risk assessment tools such as bow-tie analysis,[53] however we identified cases where credible options exist (or at least options worthy of inclusion in the 'Evaluate' step) that were not discussed in the OER. Some options analysis considered only the 'chosen' option and a 'do nothing' base case. A comprehensive options analysis should demonstrate consideration of all credible capital investment solutions, operational solutions, and non-network solutions (including demand management) as well as scope variations (e.g. focus on only high risk, critical components).

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[51] TransGrid response to AER information request 026, Question 5 Reliance on Annual Risk Cost Assessment

[52] Reliability, safety & health, environmental, operational, financial, reputation

[53] For example, for substation unauthorised entry, TransGrid on-site presentation, *09 Session 9 – Security_AER,* slide 3

Treatment of benefits is inconsistent

142. The NPV analysis in some cases was undertaken for a combination of sub-projects, where the expenditure and benefits were aggregated. In these cases, it was not clear if the sub-projects also presented a positive NPV. In other cases, we found examples of the benefits being recycled, or re-used across multiple projects where the individual contribution from each of the identified projects was not clear.

143. TransGrid included the network safety risk reduction as shown in Figure 13 as the benefits associated with the chosen option.

Figure 13: Network safety risk reduction formulae

Network safety risk reduction benefit is calculated as:

$$Network\ Safety\ Risk\ Reduction\ (\$)$$

$$= R \times \Delta\$Reliability\ Risk + S \times \Delta\$Safety\ Risk + B \times \Delta\$Bushfire\ Risk$$

Where:

- Δ is the pre-investment risk minus the post-investment risk
- R, S and B are the Disproportionality Multipliers for reliability incident, safe risk and bushfire risk respectively

Source: Risk assessment framework presentation to AER, 8-9 May 2017

Application of the SFAIRP/ALARP test overstates the risk cost

144. TransGrid state that in accordance with its safety obligations in the *Electricity Safety Management Regulations* that it must demonstrate that the investment required to mitigate a risk is not grossly disproportionate. TransGrid states that it[54] "*is required to demonstrate that the cost 'grossly' exceeds the value of the safety and bushfire risk avoided as part of its regular ENSMS compliance audits. This is achieved systematically through the application of the disproportionality factors in the SFAIRP/ALARP tests as part of the risk and investment framework.*"

145. TransGrid uses an ALARP test as part of its project evaluation that adjusts the safety, bushfire and reliability risk costs by applying disproportionality multipliers to satisfy its regulatory obligations.

146. In Figure 13, the network safety risk equation also shows how TransGrid applies the disproportionality multipliers to determine the network safety risk avoided for use in its ALARP test.

147. The network safety risk avoided (the 'benefit') is then compared with the annualised capex required to avoid the risk, and if greater than the annualised capex the project is deemed to be required under the ALARP test.

148. The disproportionality multipliers used by TransGrid are shown in Figure 14.

[54] TransGrid response to AER information request 026, Question 19

Figure 14: TransGrid disproportionality multipliers

Risk	Consequence Severity	Disproportionality Multiplier
Safety (S)	Potential for single fatality (TransGrid staff) e.g. explosive failure of plant	3
Safety (S)	Potential for multiple fatalities (TransGrid staff and the public) e.g. conductor drop	6
Bushfire (B)	Potential for multiple fatalities (TransGrid staff and public) and extensive property damage.	6
Reliability (R)	Potential for multiple fatalities (public only) due to interruption to electricity supply.	0.1

Source: TransGrid onsite presentation to AER, 8-9 May 2017

149. TransGrid has provided its rationale for the use of the disproportionality multipliers, based primarily on work undertaken by the Health & Safety Executive (HSE) UK.[55] We consider that TransGrid has satisfactorily demonstrated that the disproportionality multipliers are appropriate for determining whether the cost of risk mitigation is disproportional to the benefit or not. However, we have not seen sufficient evidence to conclude these multipliers are not already considered in its selection of the worst-case consequence costs it has used in its analysis, and therefore are likely to result in a bias to over-state the level of risk.

Annualised capex calculation is understated for assessment

150. The annualised capex is derived by the division of the total capex by the remaining life of the asset in years. This calculation does not consider the cost of capital over the comparison period on a Discounted Cash Flow (DCF) basis, to then calculate the annual capital cost. For example, the recommended option (Option B) for Project 1555, Line 86 renewal, has a cost estimate of $66.2m and an economic life of 50 years. TransGrid calculate an annual capital cost of $1.3m for its ALARP test.[56] By including the cost of capital applying a discount rate of 10%, the annualised capex used for the analysis increases to $6.7m. In this case the network safety risk reduction proposed by TransGrid for Option B is $6.9m, and is only marginally passed.[57]

151. Reflecting a more reasonable estimate of the annualised capital cost to the ALARP test, where it has been relied upon to proceed with the project, is likely to change the outcome of the assessment.

Inclusion of sensitivity analysis

152. TransGrid advised that the ALARP test has been relied upon in five projects, for inclusion into the capital forecast. TransGrid stated that it applied Monte-Carlo analysis based on the probability distributions of a number of variables including the ALARP disproportionality multipliers, and determined that the P50 output value for the REPEX Portfolio Expenditure reduces by 1%. TransGrid concluded that[58] "*these*

[55] *TransGrid Asset Criticality Framework*, and TransGrid's response to AER information request 030, Question 4 VoSL

[56] By dividing the capital cost of $66.2m by a life of 50 years, equals $1.3m

[57] If the calculation of network risk reduction was also amended, the change would not have to be large for the economic justification for this project to be impacted

[58] TransGrid REPEX forecast overview presentation to AER, 8-9 May 2017

results indicate minimal change/sensitivity to the REPEX Portfolio Expenditure resulting from the adjustment of input parameters."

153. Whilst we consider the application of sensitivity analysis to be a reflection of good practice, the application of a sensitivity analysis does not address any underlying systemic bias in the assumptions and parameters.

Lack of justification of project timing

154. At a project level, TransGrid does not presented analysis to demonstrate the economic timing for its proposed expenditure, typically defaulting to undertaking the expenditure to address identified needs and opportunities within the next RCP.

155. Good industry practice now includes demonstrating that the timing of expenditure is economically optimised by comparing the annualised capital cost of the 'solution' against an increasing annual risk cost over time. The economically optimum project implementation time is when the annual risk cost exceeds the annualised cost of avoiding/mitigating the risk.

156. Furthermore, we have seen several examples in our sample project reviews where we consider that it is likely to be prudent and economically efficient for TransGrid to address some risks in the current RCP, and address some risks after 2022/23.

4.3 Activity level forecasting

4.3.1 TransGrid's approach

Economic benefits-driven augex activity forecasting[59]

157. Economic benefits-driven projects have been identified by TransGrid from its review of non-credible (very low probability) events, typically involving multiple contingencies and other coincident events or triggers (such as bushfires ignited during extreme weather). In each of the projects included in the forecast expenditure for the next RCP, TransGrid has identified technical solutions requiring relatively low-cost investments to deliver net economic benefits (i.e. from risk avoided).

Replacement capex activity forecasting

158. TransGrid identifies candidates for replacement/refurbishment activity based on its assessment of asset remaining life and asset performance. The remaining life is typically derived from a health index. If a project can be justified using risk-cost assessment, assets are scheduled for replacement or refurbishment in the next RCP.

159. TransGrid's asset health indices are derived from a uniform method within each asset class based on conditional indicators: "*The health index, with the calculated remaining life of each asset, provides an estimated time frame in which renewal*

[59] Other augex-related activity forecasts are not within the scope of our review

options for the asset should be considered." Assets assessed to be approaching end of life are earmarked for action in the next RCP. [60]

160. To assess the risk posed by an individual asset, for its major asset classes, TransGrid develops an effective asset age from the remaining life of the asset by modelling the relationship between the remaining asset life and the health index.

161. TransGrid has used a selection of data points from which to determine the relationship between effective age and health index, where TransGrid had a high level of confidence in the data[61] "*Sample points were chosen for a selection of assets that represent a range of chronological ages, a mixture of conditions, including those with type issues, assets approaching their end of life and installed assets expected to continue in normal operation. These representative assets were reviewed individually to forecast the remaining life with consideration given to the conditional drivers and their normal age.*" [62]

162. TransGrid summarises the key criteria for selection of the sample points for determining the effective age as:[63]

- *"Being able to represent the overall condition of the population groups.*
- *The dataset shall contain a high portion of assets with poor condition to help in determining the statistical distribution;*
- *The asset must contain sufficient conditional information to assist with achieving a higher accuracy of remaining life estimation."*

163. TransGrid describe the selection of the remaining life values[64] as providing sufficient time to address condition issues in a timely matter, and recognising that the health index methodology adopted does not account for all types of condition issues.

164. TransGrid describe the general process for selection of substation assets into the repex portfolio as follows:[65]

- *"Asset portfolio ranked using the health index system.*
- *An effective age was estimated for each asset in the population*
- *For transformers, each asset with 15 or less years of remaining life was looked at in detail and its asset strategy was developed and included in the next regulatory period proposal as appropriate (refer to Current Strategy column within the Transformer HI spreadsheet). For circuit breakers, assets with 10 or less years of remaining life were considered.*
- *Based on the PoF curve developed for the asset class, the PoF for the individual asset is obtained using the asset's effective age.*

[60] TransGrid response to AER information request 026, Question 24 Sample Points and Data Adjustment, page 3

[61] *Ibid,* page 4

[62] *Ibid,* page 3

[63] *Ibid,* pages 4-5

[64] Transformer 15 years, CB 10 years, instrument transformers 10 years

[65] TransGrid's response to AER information request 030, Question 20 Substation Projects Methodology

- *The relevant risks (network, environmental, safety and financial) were considered and quantified for each transformer and circuit breaker.*
- *The PoF and location factors are used to calculate the total risk posed by each asset.*
- *The total risk is then used as an input to the NPV calculation and ALARP assessment.*
- *The NPV analysis was then completed on each available option for each asset."*

165. The process described above result in the development of an effective asset age which is then the key determinant of: (i) a PoF for each asset class; and (ii) consideration for inclusion into the capex forecast. As discussed in section 3, the PoF for transmission lines and secondary systems differs slightly from that described above, whilst an assessment of asset condition is retained for determining the PoF.

Security and Compliance activity forecasting

166. TransGrid identifies security and compliance activity by considering asset condition, asset performance and asset age. Where applicable, technical obsolescence is also taken into account to identify candidates for replacement or refurbishment. This leads TransGrid to estimate the effective asset end of life. Risk-cost analysis is used to compare options and to demonstrate the extent of activity required within the next RCP.

IT capex activity forecasting

167. TransGrid advised that each of its IT programs of work have been developed based on needs analysis undertaken jointly by TransGrid's IT Group and TransGrid's external IT advisor. This included consideration of asset lives and new business requirements.

4.3.2 Our assessment

Activity-based forecasting appears to bias projects for inclusion into the forecast

168. TransGrid's activity-based forecasting methodology lacks a rigorous approach to confirm that the timing of expenditure is optimal:

- Of the sample of programs and projects we reviewed, the required by date - typically recorded in the NOS - was designated as 2023 (corresponding with the end of the next RCP).
- As indicated elsewhere in this document, we are not convinced that, among other things, TransGrid has applied sufficient scrutiny to the proposed timing of the network and non-network activities that we have reviewed.

Approach to determining the effective age is reasonable

169. TransGrid's modelling of the relationships between effective age and the Health Index is based on five data points. TransGrid undertook additional analysis at our request to include further sample points. The results were very similar.

170. We therefore consider that the approach taken by TransGrid to determine effective age is reasonable. This is supported by the observation that the calculated effective age is, in general, younger than the natural age.

4.4 Cost estimation

4.4.1 TransGrid's approach

171. TransGrid developed the network project cost estimates to an accuracy of ±25% for the purposes of options evaluation.[66] TransGrid's approach to developing the cost estimates for options comparison and input into its Revenue Proposal, relevant to the capital projects within the scope of our review, include:[67]

- Using the Success Enterprise estimating system to generate the most likely (P50) costs using 'standard market costs'; where
- The standard market costs are derived from competitive tender and historical work for labour, equipment, materials, design, and commissioning. An allowance for uncertainties is also included based on "*unexpected scope costs derived from actual data from past projects.*"

172. TransGrid commissioned Evans & Peck to review and test its cost estimation process for the last reset and found it to be "*in accordance with what they consider best practice estimating*".[68]

173. TransGrid has based its cost estimates for IT projects on a combination of actual costs for recent IT investments and advice from its external IT adviser.

4.4.2 Our assessment

Network cost estimates are likely to be reasonable

174. We have not observed any material issues in the information we reviewed regarding TransGrid's network cost estimating methodology. However, we expressed concern at an on-site meeting that the bulk of the forecast expenditure was based on estimates at a project/program level of only ±25% accuracy.

175. In response to our information request, TransGrid provided analysis of a subset of the completed projects from its last Revenue Proposal that shows a net variance of -3% from the original estimates.[69] The original estimates for those projects were also to ±25% level of accuracy.

176. Whilst TransGrid's new information is not, by itself, conclusive, the combination of this analysis and the other evidence of good cost estimating practices it has provided is sufficient for us to conclude that, in aggregate, the cost estimates are likely to be reasonable (for the scopes of work proposed).

IT cost estimates are of indeterminate accuracy

177. The IT projects are not yet at 'DG1-ready' level of development. TransGrid has provided insufficient evidence to demonstrate that the costs it has incurred historically for IT assets are a good basis for forecasting future costs without adjustments. Similarly, at this stage of the project development lifecycle, we are not

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66 Should the projects satisfy the DG1 requirements, detailed scoping and costing of the preferred option is undertaken.

67 *TransGrid Approach to Forecasting Expenditure,* page 10

68 *Ibid*

69 Approximately 40% by value; source: *TransGrid-IR030-Q8 Cost Estimation-20170605-PUBLIC*

convinced that cost estimates provided by vendors are sufficient for a reasonable basis for the expenditure forecast for the next RCP given the stated uncertainties regarding technology, scope, and integration effort required.

4.5 Delivery strategy and risk

4.5.1 TransGrid's approach[70]

178. TransGrid presents the delivery strategies in its project documentation for individual projects/program of work.[71] The delivery models that TransGrid selects from include alliance, early contractor involvement, design and construction, external construct and in-house delivery.

179. At a portfolio level TransGrid has identified risks to the timely delivery of design services and construction services and has advised its responses to those risks.

180. TransGrid has processes for monitoring project/program implementation against KPIs (including volume versus expenditure).

4.5.2 Our assessment

Project level delivery risk is adequately addressed for economic benefits-driven projects

181. Given the position in the project development lifecycle, the extent of analysis that TransGrid undertakes at the project level is reasonable, as demonstrated by the analysis reported in the OFS documents provided.

182. Project delivery risk for repex and IT projects is indeterminate. We have not been provided with sufficient information to form a view about whether there is a material risk to the efficient delivery of repex and IT projects in the next RCP.

183. We note, however, that TransGrid has in place a typical governance structure for monitoring on a monthly basis delivery of the works program. Whilst we have not assessed the quality of the monthly reports, provided the data is an accurate reflection of progress, we would expect that the level of governance is adequate given the volume and complexity of work.

4.6 Investment planning and portfolio management

4.6.1 TransGrid's approach

184. TransGrid states that it[72] "*has prioritised the portfolio of projects to develop the forecast expenditure, as follows:*

[70] TransGrid response to AER information request 030, Question 14 Capex Deliverability

[71] Based on our sample review of economic benefits driven augex projects only

[72] TransGrid response to AER information request 026, Question 2 Capital governance framework

- *For repex, TransGrid applied a risk assessment approach to identify assets with the highest risk of failure based on asset health information.*
- *For augex, TransGrid modelled load growth, changes in load flows reliability, and market benefits. The need for and/or opportunity arising from augmentation is identified through modelling or requirements of reliability standards and licence conditions ..."*

185. TransGrid also add that it prioritises on[73] "*an annual basis within multiple equipment replacement projects, to take account of updated condition and planning information. This ensures that consumers benefit by the highest value replacements occurring first, subject to outage availability and any delivery efficiencies in the works program.*"

186. TransGrid advised that 88% of its capex program was justified on the basis of NPV as shown in Figure 15 below.

Figure 15: Justification category for the forecast expenditure

Justification Category	% Value of Portfolio
Positive NPV	73%
Positive NPV + ALARP	15%
ALARP Only	7%
Compliance Requirements	3%
Strategic Benefits	2%

Source: TransGrid onsite presentation to AER, 8-9 May 2017

4.6.2 Our assessment

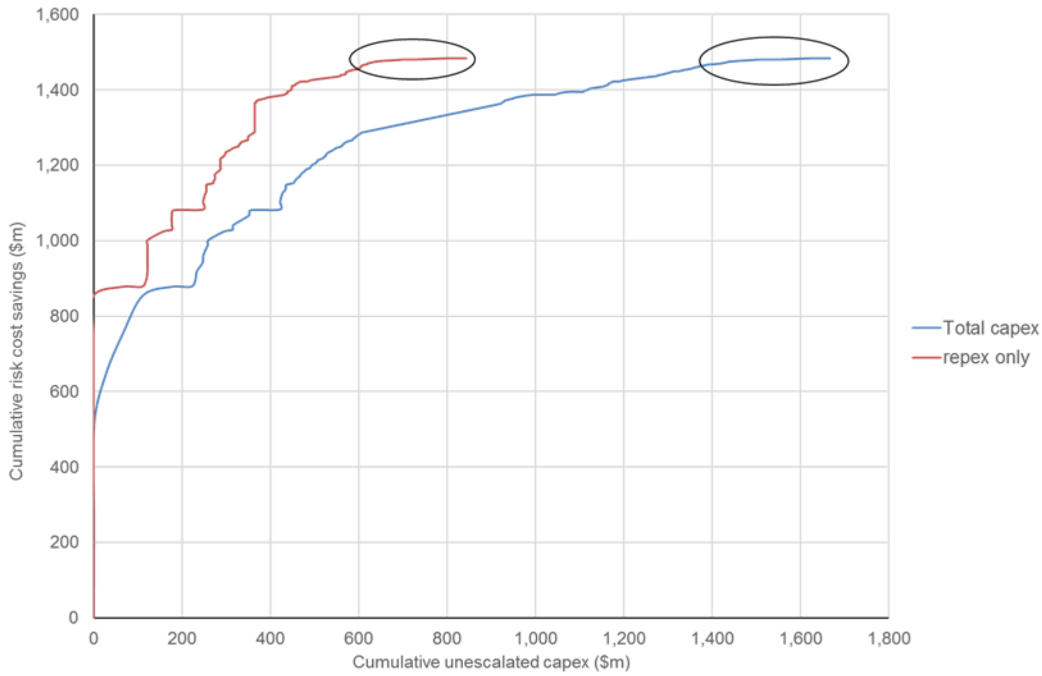
TransGrid does not appear to rigorously challenge its bottom-up forecast

187. TransGrid includes a step for portfolio optimisation in its capital governance framework as shown in section 3. From the description provided by TransGrid during the onsite meeting, and our review of the available information, TransGrid's reference to optimisation is directed to managing the scope and timing impact of changes once the project has commenced. There is no reference to optimisation or management of the portfolio prior to approval to proceed.

188. As shown in Figure 16, the cumulative risk cost savings flattens for increasing capex for both repex and total capex. Whilst it is not possible to draw conclusions from this chart alone, the general shape of the relationship suggests that there may be an opportunity to test that the level of capex is optimised. We have not seen evidence of this form of analysis or any other 'top-down challenge' approach applied.

[73] TransGrid response to AER information request 026, Question 2 Capital governance framework

Figure 16: Areas of low incremental benefit



Source: TransGrid response to information request 026, question 2

Lack of adequate justification for parts of forecast

189. In our review of a sample of TransGrid's proposed projects and programs we found issues pertaining to the level of justification provided, where the option was selected for reasons other than a positive NPV.

TransGrid appear to be managing within a RCP constraint

190. Start and finish times for projects and programs of work within the current RCP, and the small component of work that rolls-in from the current RCP to the next RCP[74] are indicative of TransGrid constraining expenditure unnecessarily within RCP time limits. Not only would we have expected a larger proportion of the work program to be continuing from the current RCP into the next RCP, the lack of rigour regarding the timing of work evidenced from TransGrid's evaluation process prior to DG1 reinforces our concerns.

4.7 Implications for proposed expenditure forecast

TransGrid has generally demonstrated a prima facie case for the need to act

191. We consider that TransGrid's needs assessment typically identifies emerging or existing risks of sufficient level that corrective action of some sort is required in the next RCP. However, we consider the needs assessment and evaluation phase biases the work to occur within the next RCP.

[74] comprising 5 repex projects and an ICT project totalling approximately $11.1m for the capex categories under review

At a project level, TransGrid's expenditure forecasting methodology is biased towards overstating the expenditure required in the next RCP

192. We have seen evidence of insufficient rigour in the development of TransGrid's expenditure forecasts at the project/program level. In particular:

- There is a lack of consideration of the timing of the work, with options for deferring some work to a later RCP apparently not considered;
- Lack of evidence of rigorous challenge at a project level of input assumptions and parameters; and
- There is evidence of overstating risk costs and understating the capital cost of solutions in the NPV analyses.

193. We consider that this indicates a bias to overestimating the expenditure required either because it is likely that not all the work is required to be undertaken in the next RCP.

At the portfolio level, the summation of individual projects is likely to overstate the expenditure required in the next RCP

194. In our experience, expenditure forecasts based on bottom-up aggregation of the activity at the project/program level without rigorous 'top-down challenge' overstate the actual expenditure required.

195. We have seen insufficient evidence that TransGrid has applied a rigorous top-down challenge to its portfolio, and where such a top-down review was applied, is likely to reduce the proposed capex forecast. Based on our analysis we consider there is a prima facie case for reducing the proposed expenditure forecast.

196. The relatively small proportion of expenditure in the next RCP attributed to continuation of work programs commenced in the current RCP indicates that TransGrid constrains its work to occur within RCP boundaries. This also means that a very high proportion of the forecast expenditure for the next RCP is based on projects that have not yet been subject to DG1 scrutiny.

5 Assessment of economic benefits-driven augex

5.1 Introduction

197. In this section, we provide our assessment of certain aspects of TransGrid's forecast capex in the augmentation expenditure category, specifically the projects driven by economic benefits and to provide dynamic voltage support to the network.

5.2 Expenditure summary

198. TransGrid has proposed a forecast of $61.9m in augex projects driven by economic benefits for the next RCP, as shown in Table 6.

Table 6: Forecast economic benefits driven augmentation expenditure ($m, real June 2018)

Project name / grouping	2018/19	2019/20	2020/21	2021/22	2022/23	Total RCP
Projects that deliver economic benefits	1.49	7.79	11.84	7.17	9.86	38.14
Dynamic Voltage Support	1.53	7.37	14.88	0.00	0.00	23.78
Total	3.02	15.16	26.72	7.17	9.86	61.92

Source: EMCa analysis of TransGrid's Capital Accumulation Model

199. From Table 6, we note that the annual expenditure varies significantly over the RCP due to (i) the bottom-up, discrete project-driven nature of the forecast, and (ii) the relatively high expenditure in two years assigned to providing dynamic voltage support. We have not included a historical profile of expenditure for this category, as the expenditure drivers are not recurring and therefore any trend, should we have been provided with one, is unlikely to be provide assistance in reviewing the forecast.

200. TransGrid has identified 16 projects for which its proposed solutions result in net economic benefits from one of five sources:[75]

- Improved power quality;
- Reduction in load restoration time;
- Improved network resilience;
- Improved operational efficiency; and
- Improved response to grid emergencies.

201. TransGrid has applied risk-based cost-benefit analysis as the basis for its justification of the net economic benefit of the solutions. We have considered a sample of the projects, as discussed below.

5.3 Summary of sample projects

Smart Grid Control projects

202. There are seven smart grid control projects representing forecast expenditure of $21.1m. TransGrid has identified non-credible, concurrent transmission line contingencies at the time of maximum system demand at seven locations in the network that may give rise to cascading network failures, leading to significant loss of load. Bushfires are designated as the likely cause of the multiple contingencies.[76]

203. In each case, TransGrid has considered two options to reduce the load at risk: (A) install fast-acting SCADA/protection-based Hybrid Special Protection Systems (SPS) to rapidly trip pre-selected feeders, or (B) build a new transmission line to prevent overloads on other circuits. Option A was selected in each case, with load at risk of being shed reduced by more than 50% (but not reduced to zero). TransGrid derived a net economic benefit in each case by comparing the capital cost of Option A with the avoided risk cost of unserved energy according to the following equation:

$$Unserved\ energy\ =\ (MW\ at\ risk\ x\ 0.5\ x\ failure\ duration)\ x\ overall\ failure\ rate$$ [77]

(Equation 1)

$$Risk\ cost\ =\ Unserved\ energy\ x\ VCR \quad (Equation\ 2)$$

204. TransGrid's key assumptions (common to each project), are as follows:

- *MW at risk*: TransGrid assumes that the NSW load will be at maximum demand if the lines trip – TransGrid qualitatively links bushfires, extreme weather events (in this case a heat wave), and maximum system demand, but does not provide analysis to support its assumption.

[75] *TransGrid Revenue Proposal 18/19 to 22/23 – January 2017*, Appendix G, page 7

[76] In 2001 and 2002 various combinations of three, four and five concurrent line outages occurred in various locations (see for example, *TransGrid NOS 1472 Yass_Marulan_Bannaby330kV SmartGrid Ctl-0117).* During bushfires, phase-to-phase faults can occur (insulation breakdown between phases is induced by a critical mass of smoke particles, leading to protection systems tripping the affected line circuits. Cascading tripping can result from other lines being overloaded.

[77] TransGrid expects that demand will reduce over time during the outage duration as load is progressively restored – it uses a factor of 0.5 to account for this.

- *0.5 * failure duration*: TransGrid has assumed that full load restoration will take 8 hours with 50% restored within four hours, citing Control Room experience and a past black start event as the basis for this assumption.
- *Overall failure rate*: the probability of the multiple contingency event occurring and resulting in widespread loss of load in the identified cut-set is 1:100. TransGrid provides bushfire examples from 2001 and 2002 to demonstrate that multiple contingency events do occur, however, we note that the events did not result in system voltage collapse (although it was narrowly avoided by operator action in the 2001 case).
- *VCR* – the Value of Customer Reliability (VCR) reflects the cost of consequence value of $38,350 / MWh is sourced from AEMO for mixed residential/industrial customers.
- *Impact of remedial action* – TransGrid claims that the 'smart grid control' solution (Option A) will operate as intended, preventing the unplanned load shedding by quickly tripping pre-selected line circuits. In each case, the residual load shed is assumed to be less than 50% with the SPS in place in each case. Whilst TransGrid do not confirm whether this form of SPS has been applied successfully in other locations, given that the solution is based on a protection grade scheme, is likely to be robust.

Project 1399 Yass 330kV Bus CB Capacity Augmentation

205. TransGrid has determined that if there is a double 330kV busbar outage at Yass terminal station when load flow is above a certain limit in a certain direction occurs, there is the *potential* for 8,000 MW of load to be shed due to voltage instability.

206. TransGrid determines the likelihood of the consequence via the following equation:[78]

$$P_{unplanned\ outage\ of\ one\ 330kV\ bus}\ x\ P_{failure\ of\ one\ 330kV\ bus}\ x\ \mathrm{P}_{cut-set\ flow\ exceeds\ the\ secure\ limits}$$

(Equation 3)

207. As there are five circuit breakers (CB) that could fail and result in unplanned busbar outages, TransGrid multiplies the outage rate of a 330kV bay CB (0.079 p.a.)[79] by 5 to determine the first factor in the equation above. Similarly, it multiplies the 330kV CB failure rate (0.024 p.a.) by 5 to determine the second factor. The third factor is based on the percentage time p.a. that the load through the Yass-Canberra cut-set exceeds 1,150MW, which is 1.3%.

Project 1416 Tomago 330kV bus capacity augmentation

208. TransGrid's review of the reliability of supply at Tomago Aluminium Company (TAC) identified that a certain, double contingency event will interrupt a TAC potline causing loss of 300MW to TAC. TransGrid appears to count this failure event as an Energy Not Supplied Event (ENS) under the Service Target Performance Incentive Scheme, and "*affecting generation dispatch, interconnector flows and market price.*"[80]

[78] *TransGrid-NOS 1399 Yass 330kV Bus CB Capacity Augmentation-0117*, page 5

[79] *Ibid, page 4*

[80] *TransGrid-NOS 1416 Tomago 330kV Bus Capacity Augmentation-0117*, page 3

209. TransGrid's cost-benefit analysis is based on determining the value of unserved energy to TAC should the double contingency event occur. It applies a VCR of $44,720 (for industrial loads) to determine the cost of unserved energy.

Project 1460 Transposition of line 87 and 8C/8E

210. TransGrid has identified a violation of the negative phase sequence (NPS) limit.[81] TransGrid's estimates the voltage limit violation occurs for 1 hour per year (0.011%).[82, 83] TransGrid has determined that to comply with the NER, the base case would require it to restrict southerly flow on the QNI to zero and northerly flow on the QNI from NSW to 200MW. According to TransGrid, the restrictions would apply 83% of the time. TransGrid determines the risk cost to be $12.3m per year from the following equation:[84]

$$Risk\ cost = \left(P_{import\ unavailable} + P_{export\ constrained}\right) x\ VCR \qquad (Equation\ 4)$$

Project 1480 Travelling wave fault locators

211. TransGrid identified 12 transmission lines for which installation of travelling wave fault locators at a total capital cost of $2.3m ±25% could reduce the operational cost of locating faults from $4.1m p.a. to $0.2m p.a.

Project 1650 Dynamic voltage support

212. TransGrid has undertaken system studies which identify possible voltage stability issues due to the combined effect of:

- Forecast connection of renewable generation in excess of threshold levels at particular, electrically weak[85] parts of the transmission system in NSW[86], and
- Displacement of some conventional high inertia synchronous machine thermal units by renewable generation.[87]

213. TransGrid proposes installing dynamic reactive power compensation in at least two locations to provide sufficient voltage control to mitigate the following risks:[88, 89]

[81] Per Schedule S5.1a.7 of the National Electricity Rules

[82] *TransGrid-NOS 1460 Armidale and Dumaresq QNI Transposition-0117*

[83] We assume that this accounts for the loading pattern at Coffs Harbour substation for which the 'maximum loading condition occurs about 1.7% of the time' – if not then the likelihood of the consequence is overstated by a factor of 60

[84] *TransGrid-OER 1460 Armidale and Dumaresq QNI transposition-0117, where P = probability*

[85] The strength of the power system reflects the sensitivity of system variables to various disturbances. In a weak system, a small disturbance (such as a line outage) can cause large deviations in voltages and other variables in the network to the extent that the security of the system can be jeopardised. A measure of system strength at the point of connection of generator(s) is the Short Circuit Ratio (SCR).

[86] At the 'edge of the grid' at specified 'renewable energy hubs' in the South West, Central West and North areas of the NSW grid as identified in the Connections Opportunity report (see also Table 2, Appendix G to TransGrid's RFP 2018-2022)

[87] *TransGrid-NOS 1650 Various Locations Dynamic V Support-0117*, section 1.2

[88] *TransGrid-OER 1650 Various Locations Dynamic V Support-0117*, page 3

[89] TransGrid has also identified in NOS 1650 that certain substation plant ratings may also limit the capacity of generation that can be connected at the identified 'renewable generation hubs' per its NSW Connections Opportunities report.

- Renewable generation uptake is constrained, creating a barrier to implementing the state and federal government committed renewable generation target in New South Wales, and/or
- Voltage instability causing frequent load shedding.

214. TransGrid has assumed that 5% (300 MW) of the proposed renewable generation by 2020 will not be built or will be constrained off (in the absence of its proposed solution).

215. TransGrid assumes that the unavailable renewable energy generation will be solar PV (currently the most expensive generation but with the lowest capacity factor) and that it will be replaced by gas-fired generation.

216. TransGrid has determined that there is an avoided risk benefit of $108.9m p.a. for a capital investment of $38.9m by calculating the annual cost of constraining renewable generation from the NEM.[90] Given the uncertainties described above, TransGrid estimates there is a 60% likelihood that 2 x SVCs will be required in the next RCP, with expenditure of $23.8m.

5.4 Our assessment of the proposed expenditure

TransGrid has typically identified events where action should be considered

217. From our review of the sample projects, TransGrid has generally demonstrated a prima facie case for further evaluation of the risk posed by the low-probability, high consequence contingent events.

218. However, for Project 1416 Tomago 330kV bus capacity augmentation. TransGrid has not provided evidence that the temporary loss of a TAC potline will lead to cascading network failure. TransGrid cites the requirements of NER clause S5.1.8 as the cornerstone of its justification for the project, which relates to "*minimising disruption to the transmission network and to significantly reduce the probability of cascading failure*."[91] Our interpretation of NER clause S5.1.8 is that it is not designed to result in all customers subsidising an increase in supply reliability to a single customer.[92]

TransGrid has selected appropriate technical solutions for its evaluation

219. Based on the information provided, we consider that TransGrid has identified the appropriate technical solutions to address the need/opportunity, however in our view the proposed work activity in the next RCP has not been adequately justified in every case.

TransGrid has not adequately justified parameters relied on in its risk-cost analysis

220. We consider that TransGrid has not adequately justified each of its parameters and/or key assumptions to support its proposed forecast capex. Each of these

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[90] *TransGrid-OER 1650 Various Locations Dynamic V Support-0117*, pages 3, 4

[91] Ibid, page 2

[92] Noting that, in addition to our assessment that the reasoning for the project need is flawed, we do not agree with TransGrid's determination of the cost of unserved energy

parameters have a material impact on TransGrid's risk-cost analyses used to demonstrate the economic merit of undertaking the work.

221. Examples of our concerns from the sample projects we considered include:

- In its smart grid control projects, whilst we consider that it is reasonable to assume that system demand will be high when severe bushfires occur, the load may not be at the peak in the areas assumed to be affected, and a moderating factor should be applied to the load. TransGrid's approach to moderating the duration for which the load is at risk is appropriate, however TransGrid provides no supporting analysis to demonstrate that the two assumptions are reasonable;

- In Project 1460 Travelling wave fault locators, we consider that the parameters used in determining the avoided operating costs were overstated, despite TransGrid's reference to historical data and experience;[93]

- In Project 1399 Yass 330kV Bus CB Capacity Augmentation, the difference between an 'outage rate of a 330kV bay CB' and a '330kV CB failure rate' is not clear and the reason for the former being more than three times higher than the latter is also not clear. We note that in at least one other project, TransGrid only uses the lower failure rate of 0.024 /unit/year; and

- In Project 1650 Dynamic voltage support, our reading of AEMO's 2016 Statement of Opportunities (SOO) document contradicts statements made by TransGrid,[94] and the discrepancies are not adequately explained. Furthermore, assumptions surrounding the level of installed generation, and resulting generation that may be constrained, including its 5% assumption, is similarly not explained. Even if 150MW (5% of 3,000 MW) of renewable generation is not available, this may not be a material constraint at a national level. The appropriate pricing signals should be provided to prospective generators to ensure that they are aware of the potential for contribution to network augmentation costs at the designated renewable generation hubs.

222. As it is inherently challenging to 'accurately' determine some of the parameters TransGrid uses in its economic benefit calculations, we consider that TransGrid should have undertaken sensitivity analyses to demonstrate that the analysis is robust and the proposed expenditure forecast reasonable.

The risk-cost analysis is flawed in some cases

223. In our review of the sample projects we have material concerns with the approach TransGrid has taken to determine the risk-cost in two cases:

- Project 1399 Yass 330kV Bus CB Capacity Augmentation: we consider that TransGrid's methodology for determining the LoC overestimates the risk of unserved energy because TransGrid does not account for the fact that the CBs in question are repairable. We believe that the determination of the probability that both components are concurrently out of service should account for the relatively small CB mean time to repair.

[93] TransGrid has subsequently reviewed its assumptions and its analysis and has concluded that this project has a negative NPV (*TransGrid-IR030-Q23_24 Project 1486 & 1480-20170526-PUBLIC*)

[94] We found two examples, (i) no shortfall in NSW frequency control ancillary services, inertia and rate of change of frequency is forecast in the next ten years, and (ii) of the proposed 4,935MW of renewable energy generation, only 212 MW was solar generation (at that time) rather than TransGrid's assumption that 'the renewable energy source most likely to connect will be solar PV.'

- Project 1650 Dynamic voltage support: based on our assessment of the assumptions and parameters used by TransGrid in its economic analysis, we consider its approach to be fundamentally flawed.

TransGrid has not adequately justified the timing of the work

224. For economic-benefits driven projects, TransGrid has nominated that all projects should be delivered within the next RCP. However:

- It is not clear from the information provided whether TransGrid has been in breach of the NPS limits described in Project 1460 (Transposition of line 87 and 8C/8E) since 2016 (or even earlier). If it is in breach now, there may be a legitimate case for undertaking this relatively small project in the current RCP; and

- In the case of the dynamic voltage support project, TransGrid has clearly identified the triggers that would lead to the requirement of reactive compensation. However, whilst it is possible dynamic voltage support may be required by 2023, the timing and location(s) at which it may be required (if any) are speculative. Our concerns regarding the amount of renewable energy generation assumed to be installed by 2020 in NSW discussed above reinforce the uncertainty regarding the need for this work in the next RCP.[95] TransGrid estimate a 60% likelihood that 2 x SVCs will be required in the next RCP, but in the absence of analysis to support this conclusion,[96] we consider that there is a stronger likelihood that the work may be reasonably deferred or be undertaken at a lower cost.

5.5 Implications for proposed expenditure forecast

225. We found that TransGrid has generally identified events for which the multiple concurrent outages will lead to high risk costs. However, based on our review of a sample of projects, we consider that:

- There is insufficient justification for the need to take any action in response to the identified issue with project 1416;

- Risk-cost parameters (e.g. PoF, LoC, and CoF) and associated assumptions (e.g. moderation factors) are inadequately justified and appear to be biased towards overstating likelihood and consequence (particularly in the absence of adequate moderating factors) of the event; and

- TransGrid's approach to the risk cost calculation appears to be flawed in projects 1399 and 1650.

226. For these reasons, we consider the expenditure forecast for the next RCP for the economic benefits-driven category is overstated.

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95 *TransGrid-OER 1650 Various Locations Dynamic V Support-0117*, page 2

96 *TransGrid Revenue Proposal 18/19 to 22/23 – January 2017, Appendix G,* page 8

6 Assessment of repex including security & compliance capex

6.1 Introduction

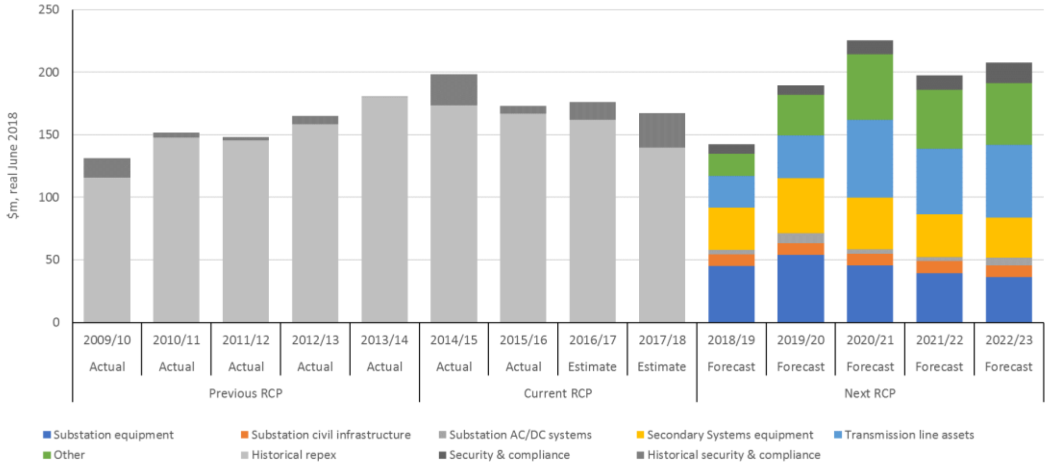
227. In this section, we provide our assessment of TransGrid’s forecast capex in the repex category (condition and risk driven) and the security and compliance expenditure category.

6.2 Expenditure summary

228. TransGrid has proposed a forecast expenditure of $961.8m for asset replacement, including security and compliance, for the next RCP.

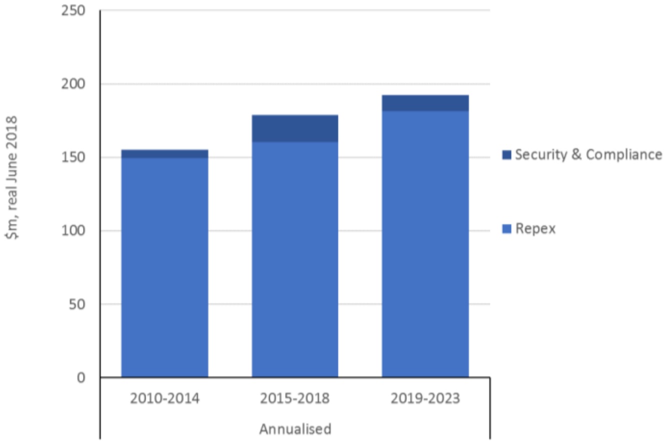
229. In Figure 17, we show the actual and forecast asset replacement and security and compliance capex over three RCPs. In Figure 18 we show the annual average expenditure for each RCP. The trend of the annual average expenditure is increasing between periods. However, the profile within the current RCP is declining from a high level in the first year. This decline is forecast to continue into the first year of the next RCP before increasing again.

Figure 17: Actual and forecast capex ($m, real June 2018)



Source: EMCa analysis of TransGrid Revenue Proposal 18/19 to 22/23, Table 5.13

Figure 18: Annualised actual and forecast capex ($m, real June 2018)



Source: EMCa analysis of TransGrid Revenue Proposal 18/19 to 22/23, Table 5.13

230. TransGrid has not provided a detailed explanation of the trend between periods, other than to point to changes in its collection of asset condition information and analysis using its newly adopted risk model. TransGrid state that[97] "*the same asset management system and risk methodology has been used to develop the Repex required over the next RCP that also resulted in the reduction in Repex in the current RCP*" and therefore it asserts that the forecast is reflective of actual practices and associated efficiencies in delivery.

Forecast replacement expenditure

231. TransGrid proposes $907.8m repex (including overheads) for the next RCP.

[97] TransGrid response to AER information request 030, question 13

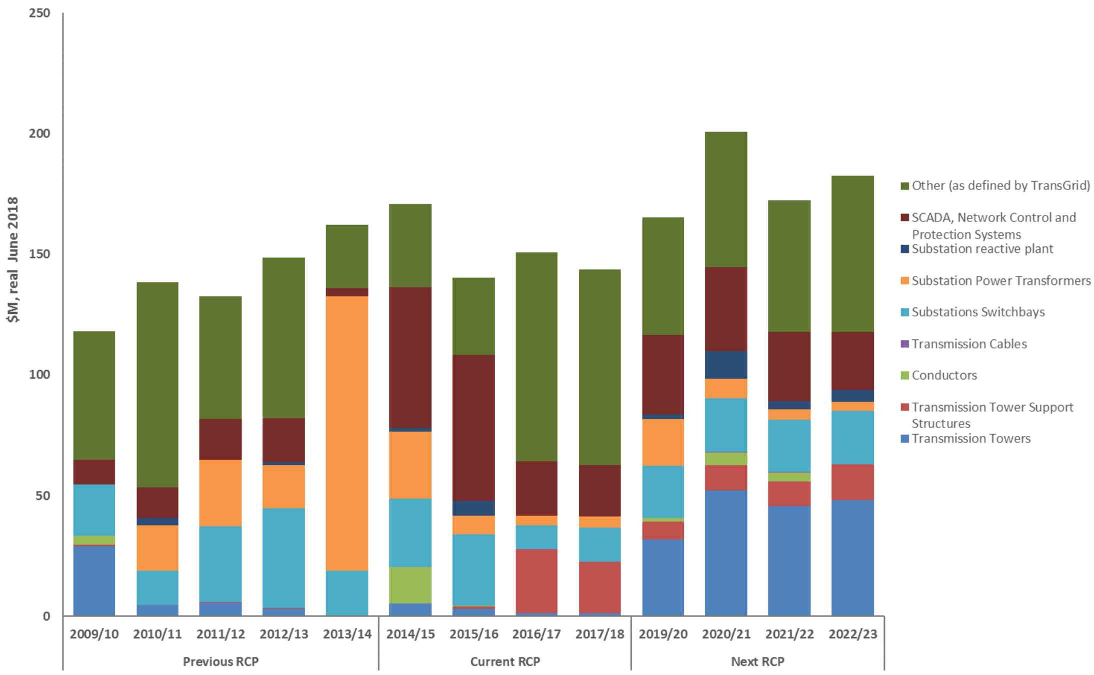
Table 7: Forecast replacement expenditure grouping by RIN category ($m, real June 2018)

Expenditure grouping	2018/19	2019/20	2020/21	2021/22	2022/23	Total RCP
Transmission Lines	22.38	40.87	68.17	59.73	62.97	254.13
Substations Switchbays	20.48	21.54	22.07	21.82	22.23	108.14
Substation Power Transformers	4.36	19.37	8.09	4.23	3.71	39.76
Substation reactive plant	0.61	1.81	11.54	3.46	5.01	22.44
SCADA, Network Control and Protection Systems	20.74	33.04	34.90	28.64	23.76	141.08
Other (as defined by TransGrid)	50.59	48.75	55.82	54.46	64.85	274.48
Total (excl overheads)	**119.17**	**165.39**	**200.60**	**172.33**	**182.54**	**840.03**
Overheads	15.69	16.25	13.72	13.31	8.77	67.76
Total (incl overheads)	**134.86**	**181.65**	**214.32**	**185.64**	**191.31**	**907.79**

Source: EMCa analysis of TransGrid RIN

232. In our review of the expenditure trend analysis, we have relied on TransGrid's RIN data (excluding overheads). From Figure 19, we observe that the composition of the repex forecast has changed substantially between RCPs. The forecast increases in most categories of expenditure from the current RCP. The expenditure associated with the 'Other' repex category[98] forms the largest component of the repex for the next RCP.

Figure 19: Replacement expenditure grouping by RIN category – direct costs only ($m, June 2018)



Source: EMCa analysis of TransGrid RIN

233. To assist our assessment, we have re-allocated the major projects included in the 'Other' repex category into the respective project groupings, as shown in Table 8. We have undertaken this allocation based on our understanding of the scope of the proposed expenditure. We have not made any retrospective adjustments to the RIN data or charts generated from the RIN data provided by TransGrid.

[98] We understand that TransGrid has isolated some expenditure in its 'Other' category to remove these from their own repex model analysis. We have not, nor have we been asked to review any elements of TransGrid's repex model

Table 8: Repex project groupings used for our assessment ($m, real June 2018)

Project category	2018/19	2019/20	2020/21	2021/22	2022/23	Total RCP
Total Transmission lines	37.55	55.65	87.34	77.25	84.82	342.61
Total Substations	58.58	72.51	67.55	52.58	57.29	308.51
Total Secondary systems	30.78	43.97	43.52	39.97	32.73	190.98
Total Communications	5.38	6.93	13.33	13.26	13.90	52.80
Total Uncategorised	2.58	2.58	2.58	2.58	2.58	12.90
Total	**134.86**	**181.65**	**214.32**	**185.64**	**191.31**	**907.79**

Source: EMCa analysis of TransGrid Capital Accumulation Model

234. From Table 8, we see that the largest expenditure groupings proposed for the next RCP are transmission lines and substations.

Forecast security and compliance expenditure

235. TransGrid has forecast $54.1m in security and compliance expenditure (including overheads) for the next RCP.

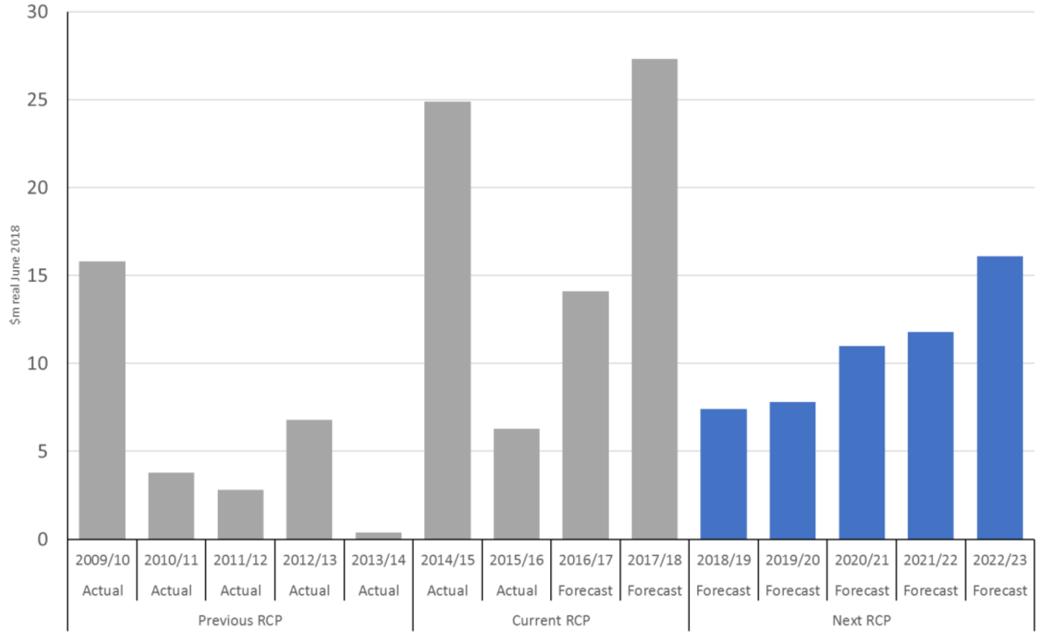
Table 9: Security & compliance project groupings used for our assessment ($m, real June 2018)

Expenditure category	2018/19	2019/20	2020/21	2021/22	2022/23	Total RCP
Security / Compliance	7.40	7.80	11.00	11.80	16.10	54.10
Total	**7.40**	**7.80**	**11.00**	**11.80**	**16.10**	**54.10**

Source: EMCa analysis of TransGrid Capital Accumulation Model

236. In Figure 20 we show the profile of security and compliance capex.

Figure 20: Security & compliance actual and forecast expenditure ($m, real June 18)



Source: TransGrid's Revenue Proposal

237. From Figure 20, we observe an increasing trend of security and compliance expenditure in the next RCP. The average annual expenditure is lower than the current RCP. There is no discernible trend from the current or previous RCPs.

6.3 Transmission lines and cables

6.3.1 Overview

Asset management strategy

238. TransGrid's *Transmission Lines Renewal and Maintenance Strategy* and *Cables Renewal and Maintenance Strategy* documents form part of its asset management framework. They provide an overview of the asset population, identify emerging issues with the asset class, review historical renewal strategies and outline the renewal and maintenance initiatives to be implemented in the next RCP. The outcome of the strategy documents is the program of works.

239. In its RP, TransGrid highlights[99] that recent detailed inspections and analysis have identified a number of condition issues with steel and wood pole transmission lines, and these have been used as the basis for the preparation of projects included in the capex forecast. We looked for evidence concerning this analysis in the sample projects and programs.

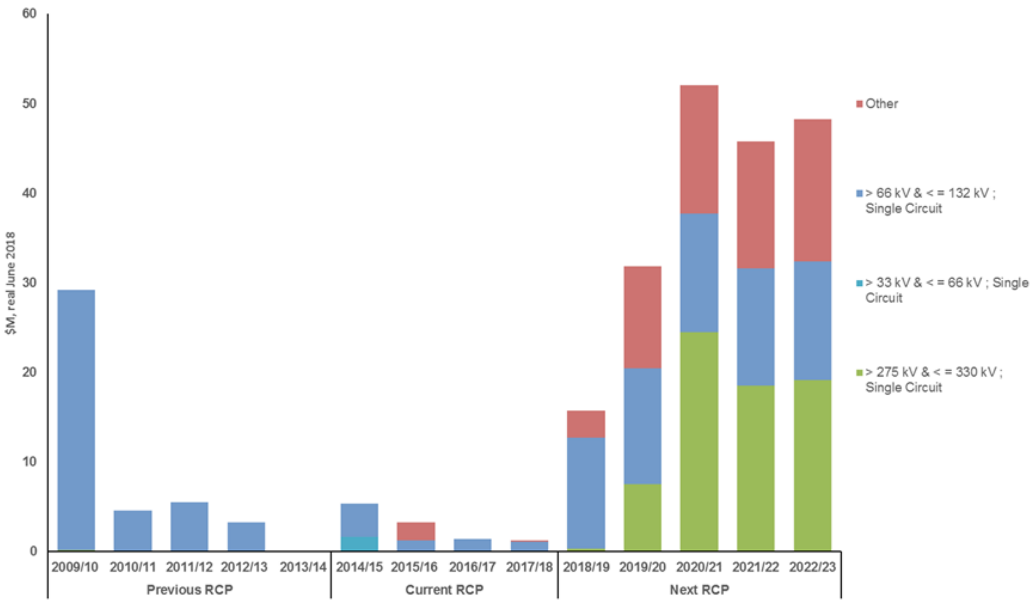
RIN expenditure analysis

240. The transmission lines and cables expenditure category comprises the asset categories of: (i) transmission towers, (ii) transmission support structures, (iii) conductors and (iv) cables. The historical and forecast expenditure profiles are shown in Figure 21 and Figure 22.

241. According to the RIN, forecast expenditure on conductors is $10.8m and cables is $0.2m over the next RCP. Being substantially lower than the expenditure on transmission towers, this has not been shown graphically.

[99] *TransGrid Revenue Proposal 18/19 to 22/23 – January 2017,* pages 102-103

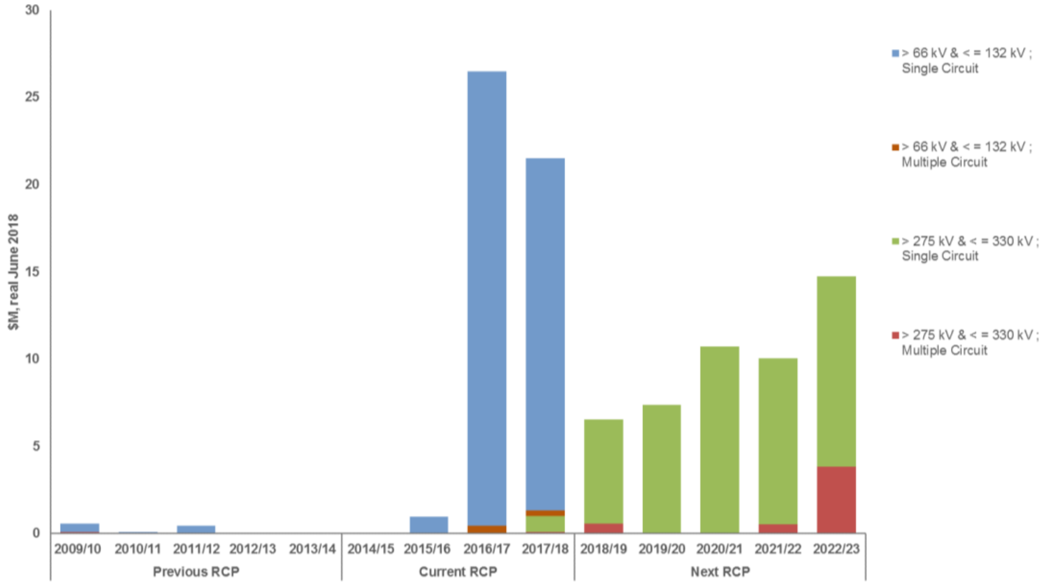
Figure 21: Transmission towers RIN expenditure grouping – direct cost only ($m, June 2018)



Source: EMCa analysis of TransGrid RIN

242. In Figure 21, we observe an increasing expenditure trend for transmission tower related expenditure over the next RCP, with a significant step increase from the expenditure incurred in the current RCP across all voltage classes.

Figure 22: Transmission support structures RIN expenditure grouping – direct cost only ($m, June 2018)



Source: EMCa analysis of TransGrid RIN

243. In Figure 22 we observe a significant step increase during the current RCP from a period of negligible expenditure in prior years, before reducing to a lower level at the commencement of the next RCP, then increasing over time. According to TransGrid's lines renewal strategy, it commenced a number of 132kV wood pole

replacement projects to be completed by 2018,[100] which are described as[101] "*wood pole line with high defect rate. Line well beyond end of life*" and which a strategic initiative to "*replace all wood pole structures with concrete pole design*" is assigned. In the absence of better information, we consider this may explain the increase in expenditure evident in years 2016/17 and 2017/18.

244. We observe a high level of the proposed forecast expenditure is associated with 330kV renewal projects, and other categories of repex. We have reviewed the major project groupings from TransGrid's CAM to understand how the forecast has been prepared, as shown in Table 10 and that we have relied on in our assessment. We have included three transmission lines related projects that TransGrid had categorised in its 'Other' repex category.[102]

Table 10: Forecast of major project groupings for Transmission lines ($m, June 2018)

Project name / grouping	2018/19	2019/20	2020/21	2021/22	2022/23	Total RCP
Various 132kV Lines Wood Pole Replacement	14.78	14.87	14.90	14.98	15.07	74.59
Line 86 renewal	0.49	10.56	33.61	25.60	-	70.25
Asset Replacement - End of Life - TL Renewal*	3.66	13.04	16.20	16.35	18.08	67.33
330kV line renewal	10.13	8.54	13.57	11.06	17.35	60.65
Transmission Line Asbestos Removal*	8.48	8.54	8.56	8.62	8.67	42.87
Line 11 Suspension Structure Renewal	-	0.06	0.31	0.56	21.77	22.71
TL Silmalec Fitting Condition Phase 2	-	-	-	0.06	3.88	3.94
Cable 41 Tunnels Condition*	0.01	0.05	0.19	0.02	-	0.26
Total Transmission lines	**37.55**	**55.65**	**87.34**	**77.25**	**84.82**	**342.61**

Source: EMCa analysis of TransGrid's Capital Accumulation Model

6.3.2 Summary of sample transmission lines & cables projects

Various 132kV Lines Wood Pole replacement

245. TransGrid has identified project 1558 for replacement of 996 132kV wood poles at a cost of $74.6m with a corresponding annual risk cost of $3.03m. TransGrid states that the project is required by 2023, and is included to satisfy the organisation's ALARP obligations.

246. The targeted wood pole replacement is expected to extend the life of the line asset by 10 years with the defect rate remaining constant over the 10-year period. The existing yearly defect rates for the lines identified in this project vary across a wide range of between 0.16% to 2.67%.[103]

247. The risk cost determination relies on a PoF of 0.27% for a single pole failure. With a population of 966 poles, TransGrid calculate the PoF for the 966 poles identified for replacement as over 261% (or 2.6 failures per year).

[100] Including line 99F, line 970 and line 96H

[101] *TransGrid Transmission Lines Renewal and Maintenance Strategy*, page 13, 14

[102] Projects included in the 'Other' repex category by TransGrid are identified in the table with an asterix

[103] Sourced from OER 1558 132kV TL Wood Pole Replacement, however for Line 97L the defect rate is recorded as 7.82% in the NOS, whereas it is 2.67% in the OER. This difference is not explained. The proposed quantity of poles proposed for replacement is unchanged.

248. The highest component of the base case risk cost is associated with environmental risk. The calculation is based on a combination of inputs, the highest of which is the risk of bushfire event from a conductor drop. TransGrid identify the worst-case consequence cost of $400m from bushfire damage, add further consequence costs,[104] and when multiplied by a LoC of 0.202%, arrive at an annual risk cost of $0.82m. This is repeated for personal injury risk and repair cost within the conductor drop scenario. A further scenario of an unplanned outage is added to the risk consequence cost, and this total is multiplied by the PoF to arrive at the total risk cost of $3.0m per year.

249. A single option has been selected (option A – wood pole replacement with concrete pole). The option of replacing with wood poles was not considered as TransGrid has adopted a strategy to replace wood poles with concrete poles due to their higher reliability. In addition, savings of $0.083m p.a. for inspections and $0.047m p.a. for defect maintenance (totalling $46.23m over the assessment period) are included in the analysis.

Line 86 renewal

250. TransGrid has identified project 1555 for replacement of Line 86, a 330kV transmission line which runs between Tamworth and Armidale comprising of 416 structures.[105] TransGrid has identified that wood rot beneath composite pole joint sleeves is prevalent throughout the line, and in 2011, 22 structures required replacement (with concrete poles) due to condition related issues, and a further 14 poles required remediation.[106] No further reports of defects or replacement of wood poles on Line 86 have been provided in the analysis.

251. TransGrid has proposed inclusion of this project in the forecast at a cost of $70.25m, against a risk cost of $1.92m per annum. TransGrid state that the project is required by 2023, and is included to satisfy the organisation's ALARP obligations.

252. The risk cost determination assumes a PoF of 0.0596% for a single structure failure. With a population of 391 composite wood poles, TransGrid calculate a 23% probability of a failure in the population of 391 poles identified for replacement per year. TransGrid apply similar risk cost assumptions to those identified for project 1558 above.

253. Two options were considered in the options analysis, with both replacing all remaining wood poles on the line with concrete poles, with the variation being whether the conductor is re-used (option A), or installed as new (option B). The recommended option was to replace the conductor (option B).

254. Under option B, TransGrid proposes to install a new conductor to improve the security of the connection to the QNI, and reinforcement for future connection of renewable generation in the region. TransGrid also acknowledges that a RIT-T analysis is required, and is scheduled for completion by December 2019.

[104] Associated with litigation, media coverage, legislation breach and investigation costs

[105] Comprising composite wood, concrete and steel structures

[106] TransGrid do not elaborate on the required remediation of the additional 14 poles

330kV line renewal

255. TransGrid has proposed inclusion of 25 projects[107] relating to the renewal of 330kV transmission towers, with the project costs ranging from $349k for Line 20 to $9.5m for Line 22. The highest risk cost is associated with 'environmental risk', driven by the assessment of a bushfire consequence resulting from conductor drop.

256. TransGrid has assessed a single option that addresses the nominated asset condition issues, design and type issues associated with each transmission line. The condition issues are captured in a Network Asset Condition Assessment (NACA), and vary between project. However, at the time of preparing our report, copies of these documents were not provided to support the proposed expenditure forecast.

End of life – TL – Renewal

257. Project 1523 includes the treatment of grillage foundations[108] at a project cost of $67.33m, against an annual risk cost of $15.84 per annum. The project has been included based on a positive project NPV and it also satisfies the organisation's ALARP obligations. TransGrid states that the project is required by 2023.

258. Two options were reviewed in the analysis: Option A comprising anode replacement and foundation concrete encasement; and Option B comprising anode replacement and structure replacement. The technical solutions considered for the project include analysis of soil conditions to target the identified renewal strategies.

6.3.3 Our assessment of transmission lines & cables projects

Evidence that the expenditure forecast and management strategy do not appear aligned in all areas

259. In its *Renewal and Maintenance Strategy* TransGrid explains that the number of poles included for replacement has been forecast based on the historical defect rates.[109] Whilst it could be inferred, TransGrid does not provide evidence to confirm that the definition of a defect, to which the defect rate applies, is one where the pole is no longer serviceable and the pole must be replaced. For example, TransGrid advised that it had undertaken a pole staking trial and determined that it was suitable to apply to 25% of the defective poles.[110] In its options analysis we expected that TransGrid would have assessed the viability of staking poles for which staking was likely to be suitable, and replacing the remainder.

260. The expenditure profile evident from the RIN analysis suggests that wood pole replacement projects appear to have included replacement of all poles.[111] It is not clear how to us, how entire pole replacement and the proposed strategy of targeted

[107] Projects 1427A, 1268A, 1269A, 1271A, 1272A, 1273A, 1274A, 1275A, 1276A, 1278A, 1280A, 1317A, 1333A, 1341A, 1346B, 1347A, 1348A, 1349A, 1350A, 1351A, 1352B, 1353A, 1407A, 1408A, 1411A

[108] footings are constructed from hot-dip galvanised steel members extending from the tower body above ground as a continuous member below ground, formed into a grill and direct buried.

[109] *TransGrid Transmission Lines Renewal and Maintenance Strategy*, page 65

[110] Determined from a sample of 4,000 poles which had 41 suspect or condemned wood poles of which 10 were identified as suitable for staking

[111] Wood pole replacement projects undertaken in 2016/17 and 2017/18 as indicated from TransGrid's RIN

pole replacement based on condition is evidence of uniform application of its asset management approach.[112]

261. In the absence of this explanation, we do not consider that TransGrid has demonstrated that it proposes a prudent level of pole replacements and pole reinforcements.[113]

Analysis provided to support forecast pole replacement is not compelling

262. We did not find compelling evidence to support:

- The stated decline in asset condition as the basis for inclusion of the assets identified in the respective projects, nor adequate consideration of the optimal timing of expenditure. For example, whilst the proposed replacement of 993 132kV wood poles in project 1558 is lower than the 1,163 wood poles forecast to exceed the nominal design life in the next RCP, the determination of a prudent level of expenditure for the next RCP is not clear;
- The savings claimed following pole replacement, which are significant. We would expect to see the basis for the savings documented and reflected in the operating expenditure forecast, which we have not been asked to review; and
- The basis for replacement of the remaining 391 structures for Line 86. We would expect to see an increasing defect rate, or elevated failure history[114] to drive a change in replacement strategy.

The risk cost analysis is likely to overstate the benefits

263. We found evidence of a bias in the risk cost analysis that is likely to overstate the benefits associated with projects:

- The selection of the worst-case consequence cost of $400m based on the Black Saturday bushfire in Victoria is likely to inflate the estimate of risk cost for TransGrid. Whilst TransGrid seeks to moderate the selection of this consequence cost by using a LoC factor to account for conditions in NSW, the consequence cost fails to recognise other conditions that differ for a transmission network or its operating environment, as discussed in section 3;
- TransGrid's assessment of residual risk is often understated, which in turn leads to an over-estimation of the benefit of the option – for example, in project 1558, the bushfire risk posed by failure of the proposed new concrete poles is close to zero, whereas the risk from the remaining wood poles is greater than zero;
- Similarly, whilst not a major driver of risk cost in the line repex projects considered, TransGrid has calculated the safety risk using a VSL of $10m and legal consequence costs totalling a further $10m, and a LoC based on the likelihood a member of the public may be in proximity to the line. This assumes that if the structure fails, and the person is in the vicinity at the time of the failure, then they will suffer fatal injuries. It is more likely that other moderating factors exist that further reduce the likelihood of a fatality in these conditions, as discussed in section 3.

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112 TransGrid's response to AER information request 030, Question 13

113 TransGrid identify that 1,163 wood pole structures will exceed the nominal design life in the next RCP, and a further 2,110 wood pole structures will do so in the following RCP, requiring an estimated 1,800 replacements in each 5-year period.

114 One structure failure incident on Line 86 since its construction [1982] due to extreme weather conditions.

- Where the ALARP test has been applied, the annualised capex calculation is flawed as discussed in section 4. When adjusted for the cost of capital in the calculation, the ALARP test is marginal for some projects and when considered with other biases, is likely to result in changing the scope of the proposed expenditure.

Incorrect categorisation of expectation as asset replacement

264. The basis for inclusion of the Line 86 project into the repex forecast is not evident. In addition to the concerns raised above, TransGrid acknowledges that the project (at least in part) is subject to a RIT-T analysis for augmentation-related expenditure.

6.4 Transmission substations

6.4.1 Overview

Asset management strategy

265. In its *Transmission Substations Renewal and Maintenance Strategy* TransGrid stated that the existing Renewal and Maintenance Initiatives has targeted the high risk assets for replacement with modern equipment which typically deliver higher reliability, and contributed to maintaining low levels of substation asset failures and outages.[115]

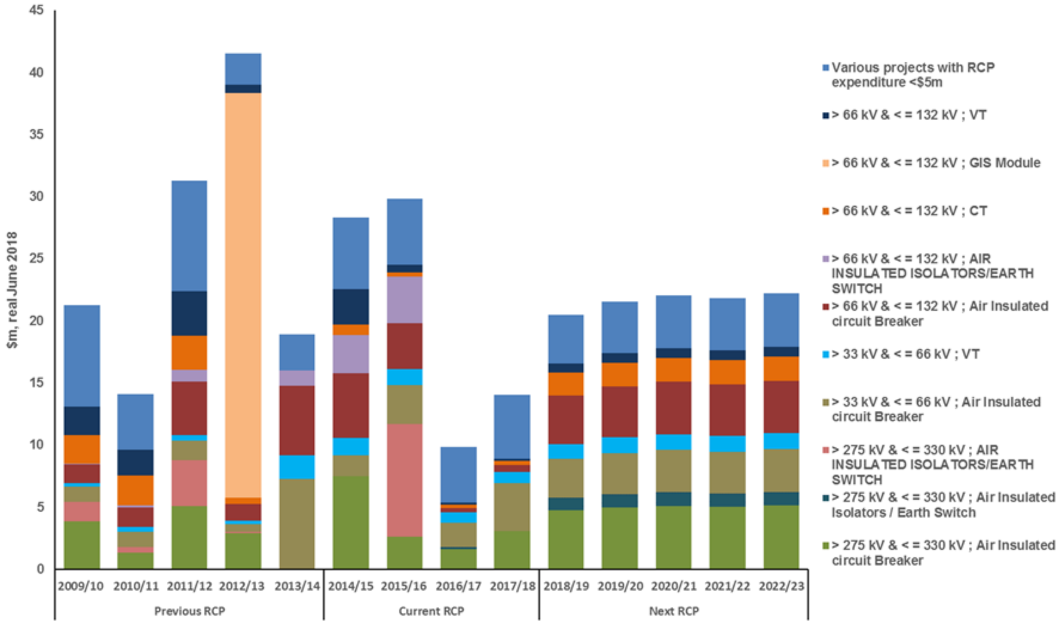
266. TransGrid has identified a number of key emergent issues with each asset category and assigns corresponding initiatives. The issues driving the expenditure forecast are described in more detail in subsequent sections.

RIN expenditure analysis

267. The transmission substations expenditure category comprises the asset categories of (i) substation equipment, (ii) substation AC/DC systems, and (iii) substation civil structures. The historical and forecast expenditure profiles are shown in the figures below.

[115] *Transmission Substations Renewal and Maintenance Strategy*, page 9

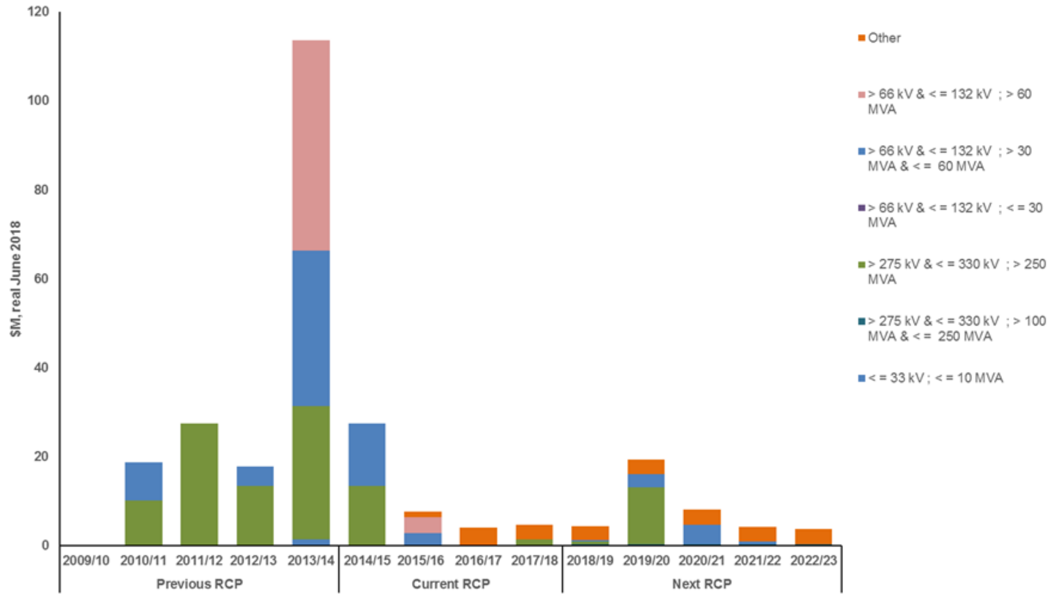
Figure 23: Substation switchbays RIN expenditure grouping – direct cost only ($m, June 2018)



Source: EMCa analysis of TransGrid RIN

268. From Figure 23, we observe a volatile expenditure profile in the current RCP and the previous RCP. By contrast, the forecast for the next RCP is for a virtually flat expenditure profile at a much higher level than the last two years of the current RCP.

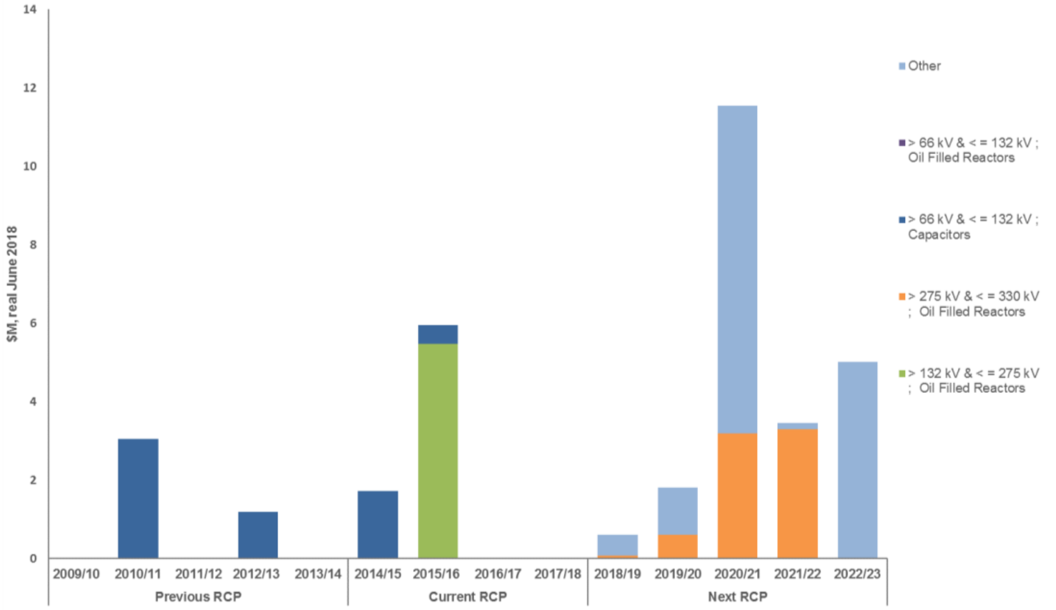
Figure 24: Substation power transformers RIN expenditure grouping – direct cost only ($m, June 2018)



Source: EMCa analysis of TransGrid RIN

269. From Figure 24, we observe a similar level of expenditure across the next RCP as incurred in the current RCP with a small spike in 2019/20 associated with 330kV transformer asset category.

Figure 25: Substation reactive plant RIN expenditure grouping – direct cost only ($m, June 2018)



Source: EMCa analysis of TransGrid RIN

270. From Figure 25, we observe a proposed increase in forecast expenditure in the next RCP associated with reactive plant, associated with a classification of 'Other'.

271. In our review of the projects and programs, we have looked for evidence of projects that support the expenditure trends we observe in the RIN data.

Major project and programs

272. For substations, TransGrid has proposed forecast repex of $308.5m, as shown in Table 11 further broken down into (i) substation equipment (including SVC replacement categorised under 'Other' repex by TransGrid), (ii) substation AC/DC systems, and (iii) substation civil structures. We have reviewed each of these major project groupings in the subsequent sections.

Table 11: Forecast of major project groupings for substation equipment *($m, 2018)*

Project name / grouping	2018/19	2019/20	2020/21	2021/22	2022/23	Total RCP
Substation equipment	45.94	55.27	54.74	39.66	41.67	237.28
Substation AC/DC systems	3.46	7.99	3.51	3.53	6.14	24.63
Substation civil structure	9.17	9.25	9.30	9.39	9.48	46.59
Total Substations	**58.58**	**72.51**	**67.55**	**52.58**	**57.29**	**308.51**

Source: EMCa analysis of TransGrid CAM

6.4.2 Summary of substation equipment projects

Breakdown of major project and programs

273. For substation equipment, TransGrid has proposed forecast repex of $220.0m. We have reviewed the major project groupings sourced from TransGrid's Capital Accumulation Model to understand how the forecast has been prepared, as shown in Table 12 (which we have relied on in our assessment). We have included as

substation equipment the SVC refurbishment project ($17.3m) that TransGrid had categorised in its 'Other' repex category.[116]

Table 12: Forecast of major project groupings for substation equipment ($m, 2018)

Project name / grouping	2018/19	2019/20	2020/21	2021/22	2022/23	Total RCP
Replacement of various circuit breakers	13.81	13.93	14.00	14.12	14.24	70.11
Repalcement of various Transformer / reactors	1.57	19.14	10.28	4.82	0.40	36.21
Transformer - Reactor Expected Failure	5.81	5.83	5.81	5.81	5.81	29.09
Various Locations CT Renewal Program	4.17	4.20	4.23	4.27	4.31	21.17
Various Locations VT Renewal Program	3.60	3.64	3.66	3.71	3.75	18.36
SVC refurbishment*	0.64	1.39	9.36	0.19	5.69	17.26
Transformer Renewal 2018/19 - 2023/24	2.61	2.62	2.63	2.63	2.64	13.14
Various Location Disconnector Renewal	2.25	2.28	2.29	2.32	2.34	11.48
Substation rebuild	9.64	-	-	-	-	9.64
Various location bushing renewal	1.17	1.17	1.17	1.17	1.17	5.85
Substation Capital Spares	0.62	0.79	0.67	0.62	1.31	4.02
Substation - use of non-conventional	0.04	0.27	0.63	0.00	-	0.95
Total Substation equipment	**45.94**	**55.27**	**54.74**	**39.66**	**41.67**	**237.28**

Source: EMCa analysis of TransGrid Capital Accumulation Model

Inclusion of committed projects

274. TransGrid has included four 'substation rebuild' projects[117] that are committed in the current RCP, with expenditure totalling $9.6m in the next RCP.

Replacement of various circuit breakers

275. TransGrid has over 1,500 Circuit Breakers (CBs) over a range of voltages and technologies installed across its network. It has determined that 237 CBs[118] are approaching end of life in the next RCP based on its Health Index and risk review.

276. TransGrid has identified 77 CBs for retirement in the 2015/16 to 2017/18 period, at an average annual rate of approximately 25 per year which is increasing to an average annual rate of approximately 47 per year in the next RCP at a project cost of $70.1m.

277. TransGrid has separated its assessment of CB replacement into two groups: Group A and Group B. Group A includes replacement of both the circuit breaker and its associated CTs using a Dead Tank CB (DTCB)[119] for 69 units. Group B includes like for like replacement with a conventional circuit breaker for 168 units.

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[116] Projects included in the 'Other' repex category by TransGrid are identified in the table with an asterix

[117] Vales Point Substation Rebuild, Munmorah Substation Rebuild, Wagga 132/66kV Substation rebuild, and Orange 132/66kV Substation rebuild

[118] We noticed a small inconsistency in documentation provided by TransGrid that also referred to 236 circuit breakers for replacement

[119] TransGrid has developed a policy to replace circuit breakers with dead tank type when circuit breaker replacement is required and the risk associated with the adjacent current transformers is sufficient to justify the increased capital costs. TransGrid claim this is justified on the basis of the maintenance cost saving, reduction in future outages and reduced operational risk. We have not been provided a copy of this justification

278. TransGrid assessed its CB failure data to develop a PoF distribution, as described in section 3. We note that a single PoF distribution was developed for all CB voltages from 11kV to 500kV and across all technologies.

279. TransGrid developed its relationship between asset age and Health index as described in section 4, against a technical life of 40 years. We note that the effective age of the CB population is generally younger than its natural age, indicating that the population is in better condition than indicated by its natural age. TransGrid then determined a remaining life, which was the technical life of 40 years, minus the effective age.

280. The initial list of assets reviewed for renewal were those where the remaining life was less than or equal to 10 years. TransGrid states that it[120] "*then evaluated to determine the most efficient solution, relative to the associated economic risk reduction benefit. Only those assets that were justified on the basis of a positive NPV or ALARP/SFAIRP obligations were included in the repex portfolio*" and excluded CBs that were due for replacement in the current period. We observed CBs removed from the program, however we did not see evidence of consideration of options other than replacement for Group A and Group B in its evaluation.

281. In its NOS, whilst TransGrid states that overhaul is less relevant to older CBs, it has not provided any evidence that this has been evaluated in its analysis.

282. TransGrid has undertaken sensitivity analysis, where the threshold of the number of operations was increased from 7,000 to 10,000 operations which led to a small reduction[121] in the CBs identified for renewal consideration. TransGrid considers that an increased operating limit of 10,000 is not operationally practical, and did not alter the limit used in its calculation.

Transformer renewal 2018/19 – 2023/24

283. TransGrid's power transformer population is comprised of 221 individual units. TransGrid identified 18 units for refurbishment comprising 14 transformers[122] at a cost of $13.1m, identified as project 1354.

284. TransGrid developed its relationship between age and Health index as described in section 3, against a technical life of 40 years. We note that the effective age of the transformer population is generally younger than its natural age, indicating that the population is in better condition than indicated by its natural age. TransGrid then determined a remaining life for each transformer, as described for CBs.

285. Transformers that had a remaining life less than 15 years were included in the analysis for renewal and replacement. Based upon the individual transformer condition and risk, candidates for refurbishment were selected and economic analysis undertaken.

286. There is evidence that TransGrid has adopted a monitoring strategy for some units within this review envelope, and decided not to proceed to refurbishment or replacement. Similarly, based on its own experience with similar units, treatment of

[120] TransGrid response to AER information request 026

[121] 8 fewer circuit breakers, or 0.5% of the CB population, were identified for renewal consideration

[122] At Kemps Creek, the two 500/330/33KV transformers comprised a total of 6 single phase units

some transformers has been brought forward where the condition was considered at higher risk, or where TransGrid observed similar degradation patterns to other replaced units.

Replacement of various transformers / reactors

287. Based on the above analysis for refurbishment of transformers, transformers were also identified for replacement over refurbishment. This project grouping comprises six projects[123] totalling $36.2m. In these instances, TransGrid proposes that refurbishment is no longer an option. The largest project is Sydney East No.1, 2, 3 Transformer Condition, at $15.3m (Project DCN548).

288. The Sydney East Substation has four 330/132 kV transformers. Transformers No. 1, 2 and 3 are assessed by TransGrid as approaching the end of their serviceable lives. The NOS indicates that Transformer No. 3 has already been taken out of service. Condition assessments have identified issues with insulation, leaks, diverter switch and bushings, and carbonisation of the main oil tank due to a leaky diverter switch. TransGrid has determined that this presents an unacceptable risk, and an increasing risk of failure that requires rectification.

289. The total pre-investment risk at Sydney East Substation was calculated as $5.20m pa for transformers 1, 2 and 3. Five options were considered in its analysis with the preferred option being to replace transformers 2 and 3, and the associated secondary systems, and to decommission transformer 1 at a capital cost of $15.5m,[124] almost entirely mitigating the identified risks and resulting in a positive NPV of $33.3m.

290. A similar process for assessment has been undertaken from the remainder of the transformers (and reactors) in this expenditure grouping.

Expected transformer and reactor failure

291. TransGrid has proposed a further program to replace transformers and reactors upon failure over the next RCP at a cost of $27.7m.

292. TransGrid has aggregated the annual failure probability for each transformer and reactor class over the 5 years of the next RCP to estimate the number of failures expected, and applied this to the replacement cost by voltage class. Whilst we were not provided with the analysis relied upon for the proposed expenditure, we understand that TransGrid has used the same failure probability data relied upon in the development of the transformer renewal and replacement programs.

Various locations CT renewal

293. TransGrid has included Project 1338 to replace a subset of its CT population. The total risk associated with this subset of the CT population is estimated at $4.8m per annum at a cost of $19.6m.

[123] Projects 1607, DCN276, 1219, 1367, DCN548, 1282

[124] The value of $15.5m is sourced from the OER, whereas the value of $15.3m is sourced from the Capital Accumulation Model.

294. Only the option of replacement of the CTs was considered. TransGrid prepared a detailed model where the NPV analysis for 357 CTs was prepared.[125,126] A total of 305 CTs were deemed to pass the economic NPV evaluation, including some CTs based on the combined NPV of all phases within a bay,[127] and are included in this project. The remaining CTs were deemed not to pass the positive NPV selection criterion, and were excluded from the forecast.

6.4.3 Assessment of substation equipment projects

Inadequate assessment of a prudent level of expenditure

295. The modelling of the substation equipment projects included detailed assessment of risk cost, and selection of projects for inclusion into the expenditure forecast. However, we did not find compelling justification for the proposed expenditure increase for this asset category over the previous and current RCPs. For example, whilst the population of CTs are generally assessed to have an effective age to be younger than their natural age, which can be above 60 years, the selection of 10 years remaining life for inclusion into the expenditure forecast has not been justified.

296. The inclusion of the proposed expenditure for expected failures of transformers appears to be in addition to the transformer renewal and replacement programs based upon assessment of risk and asset health. TransGrid has not provided compelling evidence as to the reasons that this program is required in addition to the aforementioned program to manage its transformer and reactor population.

297. We did not see adequate analysis that the need addresses an identified risk. In its options analysis documents, TransGrid state that:[128] "*Options to reduce the network safety risk as per the risk treatment hierarchy have been considered in other lifecycle stages of the asset, and it has been determined that no reasonably practicable options exist to reduce the risk further than those capital investment options listed in Table 1."* Whilst we consider that the assessment of all appropriate risk treatments is reflective of good practice, we did not see evidence of how these were assessed and decision not to progress these had been evaluated.

High probability of failure rates not adequately supported

298. In the transformer renewal project, we note that the PoF analysis was based on bushing failure for three transformers[129] rather than transformer failure as used for the remainder of the population. The selection of an alternate failure model and corresponding higher PoF may be reasonable for these units, however we did not see evidence to justify this decision. We would expect that the refurbishment costs would be reflective of renewal of the bushings, rather than what appears to be a cost similar to the other units in the project. We note that if the transformer PoF had been applied, the analysis was likely to result in a negative NPV for the economic

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[125] CTs associated with the DTCB replacements under project 1337 have been removed from the analysis.

[126] TransGrid include reference to 570 current transformers (just under 30% of the oil insulated CT population) as being considered in the Need statement for Project 1338, however the relationship to the 357 CTs included in the analysis is not clear.

[127] For example if two phases are positive and one is negative and the total for that project is positive, refer *TransGrid OER 1338* page 6.

[128] A general statement that was identified in multiple OER documents

[129] Murray No.1 (SWSMUR1A2) Sydney North No. 3 (CMSSYN1C2) and No. 4 (CMSSYN1D2)

assessment of these three transformers, suggesting they may reasonably be excluded from the program.

299. For CBs, we consider that there is evidence of different failure rates being applied across voltage levels (i.e. Cigre data collected across the industry) and we have observed other utilities recognising these differences in their cost-risk analyses to more accurately represent the CB population. We did not see this undertaken by TransGrid.

Derivation of reliability risk costs are likely to be over-stated

300. The reliability risk cost is the dominant driver of risk cost for all substation related expenditure. Adequate justification for the selection of input assumptions for the calculation of reliability risk costs has not been provided.

301. TransGrid apply a $/hour assumption to calculate the reliability consequence of load at risk for loss of a major substation element (i.e. line, transformer etc). It is not clear how the analysis considers the moderation of the 'effective' outage duration by load restoration activities and is likely to overstate the reliability impact. For example:

- For the CB renewal project, the assumption of 5 days (120 hours) interruption duration and LoC of 100% contribute to a very high reliability cost, and is likely to be much lower; and
- For the transformer renewal project, the load at risk appears to be based on the requirement to replace the transformer, at the current level of demand and with a load interruption duration of 30 days (720 hours). The LoC value is the multiple of a ratio of mean demand to peak of 0.65 and a redundancy factor of less than or equal to 1.0. We understand that inclusion of the redundancy factor has the effect of lessoning the consequence cost due to ability to transfer load to other transformers. However, this also assumes that TransGrid has no other option to supply this load over this time, and inflates the reliability consequence.

Modelling of benefits casts doubt over robustness of NPV analysis

302. Projects are included in the expenditure forecast if the project NPV assessment is positive. The NPV analysis assumes an increasing level of benefit (associated with avoided risk cost) over the 25-year assessment period. However, we found examples that cast a level of doubt on the robustness of this analysis:

- In the analysis of CB renewal Group 1, a 132kV bus section CB at Muswellbrook 330kV substation includes a reliability risk cost saving of $1.0m pa.[130] When factoring in the 132kV CB replacement cost of $267,000, the NPV analysis results in a positive NPV of $9.6m, resulting in a payback within 1 year. Within the CB renewal project a total of 64 sub-projects have a payback period within 1 year. This casts a level of doubt on the assessment of reliability risk cost, as a reasonable estimate of benefits (avoided risk costs) and therefore the robustness of the NPV model;
- For transformer renewal projects, the NPV analysis for individual sites includes a large amount of expenditure modelled in the last year of the next RCP which suggests that the economic analysis is sensitive to the timing. We note that

[130] TransGrid response to IR 026, Q3 NPV calculations 1337 – Circuit Breaker Replacement Program, Sheet Group 1 (DTCB) Option A NPV

when aggregated, the expenditure forecast for this project over the next RCP is flat, which suggests that there may be scope for deferral of some projects; and

- The modelled benefit (avoided risk cost) increases with the increasing PoF value over the assessment period of 25 years. This may have the result of over-estimating the benefit, as many of the transformers are approaching end of life, and the planned refurbishment provides a life extension only of between 4 and 10 years (post investment). After which time, further expenditure is likely to be required and which does not appear to be correctly represented over the assessment period.

303. We also observed that in some instances, such as for the transformer renewal project, the reliability consequence cost also includes the failure of the availability incentive scheme. The inclusion of the availability incentive scheme does not appear to be consistent with an investment test for consumers.

6.4.4 Summary of substation AC/DC systems projects

Breakdown of major project and programs

304. For substation AC/DC systems, TransGrid has proposed forecast repex of $24.6m. We have reviewed the major project groupings sourced from TransGrid's Capital Accumulation Model to understand how the forecast has been prepared, as shown in Table 13.

Table 13: Forecast of major project groupings for substation AC/DC systems ($m, 2018)

Project name / grouping	2018/19	2019/20	2020/21	2021/22	2022/23	Total RCP
415 AC Distribution replacement	0.80	5.30	0.82	0.82	3.41	11.15
Replacement of 50V RPS	1.71	1.72	1.72	1.74	1.75	8.64
50V and 110V NiCad Battery	0.51	0.52	0.52	0.52	0.53	2.60
Replacement of 110V Chargers	0.44	0.45	0.45	0.45	0.46	2.25
Total Substation AC/DC	**3.46**	**7.99**	**3.51**	**3.53**	**6.14**	**24.63**

Source: EMCa analysis of TransGrid Capital Accumulation Model

415V AC Distribution replacement

305. TransGrid has identified 7 projects associated with replacement of its 415V AC distribution systems with project costs that range from $46.9k to $3.8m. TransGrid state that it[131] "*has experienced an increase in the number of safety incidents related to the 415V AC systems across all substation sites over the past two years. The investigation into these incidents has highlighted the poor condition of aging 415V AC distribution infrastructure as a major contributing factor to these incidents.*"

306. Project 1478 includes replacement of the 415V AC distribution system at Armidale substation. Armidale Substation was originally constructed in 1969 and expanded in 1972 with the addition of a 330kV switchyard. It is a critical point of interconnection for the supply to the NSW North East Region and connects to Essential Energy at 66kV. It has been identified as among those with a high proportion of the AC/DC distribution system defects in the network and will be over 50 years old by 2023. The project cost is estimated at $2.7m with a corresponding risk cost of $609k per annum. TransGrid advised that the risk cost will increase due to the PoF increasing as the assets move further past their technical life.

[131] *TransGrid OER 1513 Koolkhan substation*

307. Project 1516 includes replacement of the 415V AC distribution system at Sydney East substation. TransGrid advised that the Sydney East site has 20% of all 415V AC distribution defects across the network. The system will be over 45 years old by the end of the next RCP. The project cost is estimated at $3.2m with a corresponding risk cost of $23.7m pa.

308. The dominant driver of the risk cost is the reliability consequence associated with an unplanned outage of the substation. TransGrid advise that the risk costs are based on 2015/16 probabilities of failure as extrapolated from the 415V Safety Survey conducted in 2015.

309. TransGrid explained that the current management of defects does not address the "*structural deficiencies in the infrastructure and a more holistic approach to bring systems up to current requirements as per AS3000 will likely achieve better safety outcomes.*"[132]

Replacement of 50V RPS

310. Project 1361 includes replacement of the 50V Rack Power Supply (RPS) systems that are used to provide a continuous supply of power to communications equipment during a loss of primary supply across the majority of high voltage (HV) sites and all Radio Repeater Sites (RRS). The project has a positive NPV of $25.4m for a project cost of $8.1m.

311. There are currently 213 RPS systems installed within TransGrid's network with installation dates between 2002 and 2016. Based on the installation dates advised by TransGrid, the age of RPS systems will range from 7 years-old to over 20 years-old at the end of the next RCP.

312. TransGrid consider that 130 of the RPS systems have reached the end of their technical life by the end of the RCP resulting in reduced capabilities to meet backup supply performance requirements, and should be replaced on a like for like basis.

6.4.5 Assessment of substations AC/DC systems projects

Need and options analysis is not complete

313. TransGrid has considered a single option in its analysis to replace individual systems without adequate evidence or supporting information to justify this option. We would typically expect to see defect analysis and condition assessments, and evaluation of targeted risk mitigation strategies and increasing risk or observed failures. The options analysis would then consider, partial replacement options, packaging with other works or both. For example, TransGrid is proposing to replace over 60% of its RPS systems in the next RCP, and has not adequately established this as a prudent level of replacement based on age or condition.

314. Whilst we expect that TransGrid has included projects to mitigate a material risk, and it is likely that expenditure is able to be readily justified for this work, TransGrid has not adequately supported the proposed scope of works as being a prudent and efficient forecast.

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[132] *TransGrid OER 1516 Sydney East 415V AC Dist Replacement*, page 2

Reliability risk cost is overstated

315. Reliability risk cost is the dominant driver of the analysis. For example, the analysis of the 50V RPS replacement includes a base case risk cost of $19.1m pa (including a reliability risk cost of $17.1m) which appears overly conservative for the failure of a 50V power supply, particularly where the probability of coincident failure across multiple sites, as assumed in its analysis, would be extremely low. Similarly, the base case reliability risk cost for the 415V AC Distribution replacement at Sydney East appears similarly overstated at $23.7m pa.

316. The input assumptions surrounding the load at risk calculation also appear to be overstated. The likelihood of a 415V AC distribution system failure causing complete loss of supply from the substation has not been justified and appears to be unreasonably high. Notwithstanding that the reliability impact of loss of a substation may be large, and a catastrophic failure such as a substation fire may result from failure of the AC distribution system, the likelihood that a non-critical system[133] will result in a complete loss of a substation is extremely low. TransGrid has not provided evidence from its own experience or broader industry experience to support its assumptions.

6.4.6 Summary of substations civil structures projects

Breakdown of major project and programs

317. For substation civil structures, we have reviewed the major project groupings from TransGrid's CAM to understand how the forecast has been prepared, as shown in Table 14.

Table 14: Forecast of major project groupings for substation civil structures ($m, 2018)

Project name / grouping	2018/19	2019/20	2020/21	2021/22	2022/23	Total RCP
Various Location Steelwork Renewal	9.17	9.25	9.30	9.39	9.48	46.59
Total Substation civil structure	**9.17**	**9.25**	**9.30**	**9.39**	**9.48**	**46.59**

Source: EMCa analysis of TransGrid Capital Accumulation Model

Various location steelwork renewal

318. TransGrid has nominated a single project for this category, project 1358 Steelwork treatment comprising the steelwork treatment in-situ and remediation of hold-down bolts across 9 substation sites. TransGrid has identified that corrosion of substation gantry steelwork is an emerging issue and investigations (including condition assessments) have been undertaken to quantify the work required and the hazards associated with corroded steelwork approaching its end of life.

6.4.7 Assessment of substations civil structures projects

Risk cost is likely to be overstated

319. The risk cost analysis includes an elevated and overly conservative assessment of reliability risk cost. For example, at Sydney South substation, TransGrid has included a $11.1m pa risk cost associated with failure of the holding down bolts plus

133 The AC distribution system powers all non-critical systems at a substation site including GPOs, lighting, air conditioners, security and transformer cooling

a further $6.2m pa risk cost for a member failure, associated with loss of 1,307MW. The analysis assumes that failure of the steelwork will result in the catastrophic failure of the gantry structure and loss of the entire substation for 720hrs (30 days). TransGrid allocate a 2% LoC, based on its assessment that the whole substation will lose this level of load for this period of time, which is comparable to a 1 in 50 years event.

320. The corresponding reliability consequence cost applied in this analysis is $72 billion pa for this site, and this value is used for both the failure of the holding down bolts and failure of a steel member. We consider the analysis over-states the LoC, and that TransGrid has not provided evidence that supports the estimate of reliability consequence cost as being reasonable.

321. In the NPV analysis, the risk costs have been assumed to be constant for each year, rather than continuing to increase due to continued deterioration. TransGrid advised that it has taken this approach due to the assumptions and the level of detail achieved within the modelling of steelwork failure probability and calculated yearly risk costs. We consider this assumption is insufficient to offset the conservative estimate of input assumptions noted above, resulting in a NPV of $95m for a project cost of $10.9m for Sydney South.

322. The selection of work across these substation projects has not been adequately justified in the documents we have been provided, and when considered with the risk-cost assumptions described above, we consider that the expenditure forecast is likely to be over-stated.

6.5 Secondary Systems

6.5.1 Overview

Asset management strategy

323. TransGrid has provided a copy of its *Automation Systems Renewal and Maintenance Strategy* that forms part of the asset management framework, and provides an overview of the asset population, identifies emerging issues with the asset class, reviews historical renewal strategies and outlines the renewal and maintenance initiatives to be implemented in the next RCP. The outcome of the strategy documents is the asset management program of works.

324. TransGrid stated that the existing Renewal and Maintenance Initiatives has had the effect of lowering the average age of secondary systems assets, and introduced increased functionality associated with modern protection and control systems.

325. In its Automation Systems Renewal and Maintenance Strategy, TransGrid describes its asset health categorization for secondary systems as comprising three levels;[134]

- *OK - assets not requiring any actions at this time as there are no know issues, and a failure of a unit can be addressed immediately.*

[134] *TransGrid Automation Systems Renewal and Maintenance Strategy*, page 21

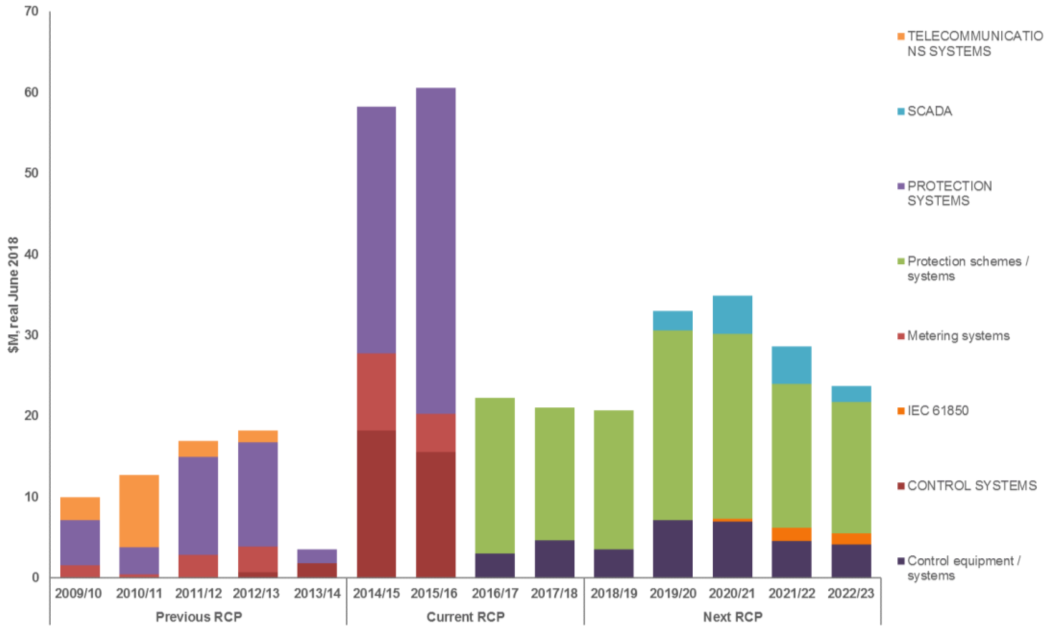
- *Investigate - assets where should an asset fail, it may not be addressed adequately to meet legislative requirements under the current configuration and therefore either replacement or acquisition of spares holdings.*
- *Replace - assets where immediate replacement is recommended due to the lack of ability for TransGrid to address asset failures within a reasonable timeframe to return an asset to service.*

326. TransGrid has identified a number of systemic issues relating to the fleet of secondary systems assets, resulting in increasing replacement activity for protection relays and DC supplies for the next RCP. For analysis equipment,[135] TransGrid has adopted a replace on failure strategy as required for those assets that form part of AEMO requirements.

RIN expenditure analysis

327. The historical and forecast expenditure profiles are shown in Figure 26 below.

Figure 26: Secondary systems RIN expenditure grouping – direct cost only ($m, June 2018)



Source: TransGrid RIN

328. From Figure 26, the historical expenditure levels evident in 2014/15 and 2015/16 are not supported by statements in the *Automation Systems Renewal and Maintenance strategy*,[136] which suggests that this expenditure was either unplanned or associated with other replacement projects. TransGrid forecasts a continuing focus on protection system replacement/renewal in the next RCP.

[135] Such as disturbance recorders and quality of supply monitors

[136] Renewal initiative historical expenditure, Table 4 which shows less than $10m pa for these two years

6.5.2 Summary of Secondary Systems projects

Breakdown of major project and programs

329. For secondary systems, TransGrid has proposed forecast repex of $191m. We have reviewed the major project groupings sourced from TransGrid's Capital Accumulation Model to understand how the forecast has been prepared, as shown in Table 15, which is what we have relied on in our assessment. We have included a further two secondary systems projects that TransGrid had categorised in its 'Other' repex category.[137]

Inclusion of committed projects

330. TransGrid has included a single secondary systems renewal project (Sydney North Secondary System Replacement) that is committed in the current RCP, totalling $1.3m in the next RCP.

Table 15: Forecast of major project groupings for secondary systems ($m, 2018)

Project name / grouping	2018/19	2019/20	2020/21	2021/22	2022/23	Total RCP
Secondary systems renewal / replacement	19.11	29.29	26.11	18.90	16.67	110.07
Protection relay replacement	11.57	11.71	11.84	12.02	12.20	59.33
SCADA Replacement*	-	2.82	5.31	5.31	2.28	15.73
Substation Security Zone (SSZ) Condition*	-	-	-	3.52	1.26	4.77
Protection-Time Domain Development	-	0.04	0.16	0.11	0.21	0.53
Substation Based PC Condition	0.11	0.11	0.11	0.11	0.11	0.54
Total Secondary systems	**30.78**	**43.97**	**43.52**	**39.97**	**32.73**	**190.98**

Source EMCa analysis of TransGrid Capital Accumulation Model

Secondary systems renewal

331. TransGrid has identified 21 projects for renewal of its secondary systems due the assets reaching the end of their technical life. The end-of-life assessment is based on one or more of technological obsolescence, spares unavailability, manufacturer non-support, and component deterioration. In each case, the Base Case risk cost for each site is deemed sufficiently high to warrant further evaluation.

332. For each substation site, a number of options were reviewed including replacement with secondary systems buildings (SSBs), in-situ replacement, strategic replacement (partial replacement), and IEC61850 replacement.

333. For a large number of projects, the complete in-situ replacement option was selected above the strategic replacement option on the basis of positive NPV, despite the significantly higher capital cost. The NPV was in some cases marginally positive, meaning that a small downward adjustment to the benefits assessment is likely to result in a negative NPV. TransGrid claim that these projects are generally also justified based on satisfying its ALARP obligations.

334. Project 1193, Broken Hill secondary systems renewal, is included in the forecast at a project cost of $11.3m. TransGrid recommended the highest cost option associated with a combination of installing new SSBs and new 22kV metalclad switchgear, which has a positive NPV. The risk-cost analysis includes 22kV switchgear risks in

[137] Projects included in the 'Other' repex category by TransGrid are identified in the table with an asterix

addition to the risks associated with secondary systems failure. The basis for managing this work as a package is not made clear, and whilst the reasons may include potential cost efficiency or delivery efficiency, it is less clear if these would be separately justified.

Protection replacement

335. TransGrid has identified 12 projects that relate to replacement of specific protection relay types and schemes based on condition. In most cases, the options analysis considers replacement of all individual units (strategic replacement) alongside prioritised replacement based on load and voltage.

336. Project 1379 GE Multilin is the largest project totalling $38.9m in which TransGrid proposes replacing all the identified assets. There is a discrepancy between the NOS and OER regarding the population of assets that are covered by this need, with the latter increasing the population by 35 units. TransGrid recognises that the population is reduced by 131 assets to account for the secondary systems renewal projects or those that are used on negotiated services, however the resulting population for replacement is not included. A major driver appears to be the age of the units as[138] "*approximately 46.9% of these relays were installed prior to 2008, and will have reached the end of their estimated life by 2023.*"

337. TransGrid has identified an increasing defect rate over the period 2013/14 to 2015/16. The forecast defect rate and, more specifically, the effect of the corrective actions currently being implemented to manage this risk (if any), do not appear to have been described. The total risk per annum is estimated at $26m.

338. TransGrid identified options to prioritise the replacement by criticality (load, voltage) however opted to progress the entire program. The project was justified on the basis of meeting ALARP obligations (the NPV was marginally negative).

SCADA replacement

339. Project 1254 involves replacement of TransGrid's EMS. The options analysis included replacement only at a cost of $15m, against a Base Case annual risk cost of $1.8m, to meet its compliance obligations.

340. TransGrid state that[139] "*Although the Net Present Value (NPV) analysis is negative, this option is still preferred over the Base Case because this option will maintain TransGrid's compliance with the NER requirement of remote monitoring and control capabilities and to continue with the supply of status system points as determined by AEMO to maintain the security and reliability of the network*."

6.5.3 Assessment of Secondary Systems projects

Insufficient assessment of the need and options has been undertaken

341. Whilst the *Automation Systems Renewal and Maintenance strategy* identified increasing defect rates across the population, we did not find quantitative evidence of how the individual projects were selected for inclusion in the forecast.

[138] *TransGrid NOS 1379*, page 2

[139] *TransGrid OER 1254*, page 5

342. The secondary systems renewal projects and other projects in this category are inter-dependant. TransGrid has adjusted replacement volumes based on other works being included in the expenditure forecast for this asset category. However, the basis for inclusion of the entire remaining population of assets in the preferred option not evident.

343. For the SCADA replacement project, TransGrid states that other factors justify the selected option but were not included in the NPV analysis (including time to deliver, and difficulty in modelling failure modes). We consider that additional options could have been reasonably assessed, including life extension for the SCADA system. Details such as installation date, failure modes, defect and risk analysis, renewal and maintenance expenditure history would have assisted with demonstrating that the project is justified.

ALARP test is flawed

344. As discussed in section 3, we consider that the annualised capex cost calculation relied upon in TransGrid's ALARP test is flawed. When correctly accounting for the cost of capital, the ALARP test, as it is applied by TransGrid, is not satisfied in some cases for secondary systems projects.

345. When we recalculated the annualised capex for the protection replacement project, it does not pass TransGrid's ALARP test.

Reliance on the IRT raises concern

346. For secondary systems, TransGrid has captured the risk information in the IRT. We were advised during onsite that the load at risk and interruption duration values used as the basis for calculating reliability risk in the IRT are not real, rather they represent back-calculated values from an external source to make the IRT operate correctly. We remain concerned with TransGrid's reliance on the IRT, given the number of calculations that are performed external to the tool. We have requested explanation of these values, and the supporting external calculations. At the time of preparing this report, this had not been received from TransGrid. We are therefore unable to comment on the reasonableness of these input values.

347. The high risk costs included in the IRT are driven by the reliability cost, and appear to assume a reliability consequence of[140] "*black start for assets protecting primary plant at 330kV and above with "N-1" redundancy. The restoration time has been set as 8 hours with an assumed 1,296MW of load interrupted to mixed customers (residential, commercial, and agricultural) to model a number of potential network scenarios based on this consequence*." As discussed in section 3, these assumptions suggest an inflated consequence due to the summed load interrupted, and duration of event included in these calculations.

Proposed volume of work is not adequately supported

348. It is not clear how the optimal timing of this expenditure was investigated, nor was there evidence of whether undertaking this program over a longer period was investigated by TransGrid. Whilst we expect that TransGrid has included projects to mitigate a clear and identified risk, and it is likely that expenditure is able to be

[140] TransGrid OER1379 Protection GE Multilin Condition, and repeated in similar OER documents

readily justified for this work, TransGrid has not adequately supported the proposed scope of works as being a prudent and efficient forecast.

6.6 Communications

6.6.1 Overview

Asset management strategy

349. TransGrid has provided a copy of its *Telecom Infrastructure Development and Renewal Strategy and Objectives* that forms part of the asset management framework, and provides an overview of the asset population, identifies emerging issues with the asset class, reviews historical renewal strategies and outlines the renewal and maintenance initiatives to be implemented in the next RCP. The outcome of the strategy documents is the program of works in this asset category.

350. The management strategy includes three primary development plans that are fundamental to ensuring the communications network holds the capability and capacity to support the changing business services, namely:

- Preparedness for Increasing Capacity Demands;
- Establish Network Protected Rings; and
- Establish IP-Based Service Delivery Platforms.

RIN expenditure analysis

351. The supplied RIN categories do not include communications as a separate reportable expenditure category.

6.6.2 Summary of communications projects

Breakdown of major project and programs

352. For communications, we have reviewed the major project groupings from TransGrid's CAM to understand how the forecast has been prepared, as shown in Table 16.

Table 16: Forecast of major project groupings for communications ($m, 2018)

Project name / grouping	2018/19	2019/20	2020/21	2021/22	2022/23	Total RCP
Installation of Fibre Networks - Phase 2	2.37	3.90	10.28	10.18	10.78	37.52
Telecommunications SDH Network Condition	3.00	3.03	3.05	3.08	3.11	15.28
Total Communications	**5.38**	**6.93**	**13.33**	**13.26**	**13.90**	**52.80**

Source EMCa analysis of TransGrid Capital Accumulation Model

Installation of fibre networks – phase 2

353. TransGrid has included project 1355 to continue the installation of fibre networks via aerial Optical Ground Wire (OPGW). We note that TransGrid has included replacement of 1,222km of OPGW in RP1 and proposes a further 690.3km in RP2 with a further unknown quantity in RP3.

354. In its OER, TransGrid states that[141] "*TransGrid's Telecommunications Infrastructure Renewal and Development Strategy details the organisational requirement to roll out protected fibre rings as the new basis for the telecommunications network structure. The initial rollout of this strategy occurred under Need 669, and phase two covers the work to be completed across the entire High Voltage (HV) Network in the 5 to 10 year timeframe of the strategy.*"

355. The benefits calculated for this project appear to be based on those identified as part of the initial fibre rollout project under Need 699. The benefits equate to $1.21m per annum for the proposed program, as well as a one-off capital disposal benefit of $10.21m in 2024. We have not been provided justification of the calculation of these benefits, or the basis for inclusion of a capital disposal benefit associated with this project should this reflect an end of life asset replacement decision.

356. TransGrid has included this project due to the additional benefits realised from improved security and capacity of the fibre optic network, and not on the basis of avoided risk cost.

Telecommunications SDH Network Condition

357. Project 1365 includes replacement of the fleet of Synchronous Digital Hierarchy (SDH) assets by 2023. TransGrid states that the fleet of assets will reach their end of life by 2023. Manufacturer support for all models currently installed ceased as of June 2016.

358. TransGrid advised that it currently has sufficient spares to manage equipment failures through to 2021, assuming current failure rates remain steady.

359. In TransGrid's options analysis, it determined that none of the identified options provided a positive NPV or passed its own ALARP test, however it recommended inclusion of a staged replacement option on the basis of a compliance obligation under the NER, specifically clauses 4.3.4 and 4.11.1. TransGrid propose to progress replacement of its 'A' system during the next RCP, with spares recovered from its network to manage the remainder of the population, prior to replacement of its 'B' system in the subsequent RCP. TransGrid's sensitivity analysis of the NPV shows a marginally positive NPV at a discount rate of WACC.

6.6.3 Assessment of communications projects

Network expansion strategy appears the dominant driver

360. The TransGrid's *Telecom Infrastructure Development and Renewal Strategy and Objectives* describes the communications network as[142] "*the supporting delivery platform and is the fundamental enabler from which both information technology (IT) and Operational Technology (OT) services are delivered. Failure to advance the development of the communications network in alignment with IT and OT business service requirements will result in the business benefits not being realised from the services being deployed.*"

[141] *TransGrid OER 1355 Installation of Fibre Networks Phase 2*

[142] *TransGrid Telecom Infrastructure Development and Renewal Strategy and Objectives*, page 20

361. We have not seen sufficient evidence to support the calculation of benefits from the proposed expenditure, and there is suggestion that the[143] "*benefits of increased communications capabilities to remote sites that more modern equipment will provide were identified in the OPGW business case*" which suggests that these may have been claimed across multiple projects. Notwithstanding that the installation of fibre networks is a program commenced in the current RCP, we did not see evidence to support the proposed forecast expenditure, including where the benefits have been included in the capex and opex forecast.[144]

362. We are unconvinced that the expenditure forecast for phase 2 of the fibre rollout, as currently presented, meets the requirements of an asset replacement project or that the input assumptions relating to benefits are reasonable despite this being a continuing project from the current period. In the absence of this information, the degree of expenditure required to prudently manage the asset versus providing additional capacity and functionality to the business is not evident.

363. For its SDH replacement project, TransGrid has not detailed its selection of the components of its 'A' and 'B' systems. It is not clear whether[145] "*the opportunity also exists to redesign the architecture of the telecommunications network to utilise current technology that is native for Ethernet protocols, to further leverage TransGrid's investment in optical fibre and to align the communications network with the projected future requirements for data transfer with the deployment of IEC61850 across the high voltage system*," may provide further opportunities to optimise the delivery of this project or to deploy more efficient technologies or solutions.

Conservative risk assessment applied

364. The allocation of a reliability risk cost based on an estimate that 16 hours will be required to recover any loss of load after an unplanned outage from the communications network once spares become exhausted, appears overly conservative and likely to lead to significantly overstating the risk cost.

6.7 Unallocated repex

365. As noted above, TransGrid nominated a large list of projects as part of an 'Other' category of repex. We have reallocated these projects to a primary asset class grouping for the purposes of our assessment. The exceptions are identified in Table 17.

[143] *TransGrid OER 1365*, page 3

[144] We did not, nor were we asked to specifically review any parts of TransGrid's proposed opex forecast.

[145] *TransGrid NOS 1365*, page 2

Table 17: Forecast of major project groupings for unallocated expenditure ($m, 2018)

Project name / grouping	2018/19	2019/20	2020/21	2021/22	2022/23	Total RCP
Test Equipment & Tools	2.01	2.02	2.01	2.01	2.01	10.06
Additional cost of Replacement due to expected RIT-T rule change	0.57	0.57	0.57	0.57	0.57	2.83
Total uncategorised	**2.58**	**2.58**	**2.58**	**2.58**	**2.58**	**12.90**

Source EMCa analysis of TransGrid Capital Accumulation Model

366. We consider that the proposed expenditure is more typically associated with non-network capex and have not undertaken a project based review of this expenditure category. We note that the expenditure is not supported by a risk cost analysis, but rather a trend based forecast.

6.8 Security & compliance capex

6.8.1 Overview

Expenditure summary

367. TransGrid has proposed forecast capex of $54m on ten security & compliance projects, as shown in Table 18.

368. At substations that TransGrid identify as high and critical risk, TransGrid deploys perimeter patrols and the following physical deterrents to mitigate the risk of unauthorised entry: high security fencing, card access control, restricted locking and keying system, and substation lighting. If there is unauthorised entry, TransGrid relies on motion detection and CCTV to initiate a security response.[146] TransGrid proposes replacing these systems in the next RCP and adding a number of new initiatives, namely: quad-lens cameras and infra-red cameras.

[146] *TransGrid presentation on-site session 9 – Security_AER,* page 3, 5

Table 18: TransGrid's security and compliance projects

Project category	2018/19	2019/20	2020/21	2021/22	2022/23	Total RCP
CCTV System Renewal	2.24	2.26	2.26	2.27	2.28	11.31
Access Card and Intrusion Detection System Replacement	-	0.97	3.64	3.68	2.57	10.86
Substation Lighting Replacement	1.62	1.63	1.63	1.64	1.64	8.16
Substation Noise Non-Compliance Program - Install noise walls	1.30	1.30	1.30	1.31	1.31	6.53
Motion Detector Replacement	0.83	0.83	0.83	0.84	0.85	4.18
Electric Fence Topping Replacement	0.82	0.82	0.83	0.83	0.84	4.14
Substation Noise Non-Compliance Program - Replace Molong Tx	-	-	0.15	0.56	3.32	4.04
TL Low Spans Stage 2	-	0.00	0.26	0.49	2.26	3.01
Physical Security of Comms Equipment	-	-	0.07	0.19	0.99	1.24
Yanco Sub Low 33kV Busbar Clearance	0.56	0.01	-	-	-	0.57
Total Security & compliance	7.36	7.83	10.98	11.81	16.06	54.04

Source EMCa analysis of TransGrid Capital Accumulation Model

6.8.2 Summary of security & compliance projects

Substation security related projects

369. TransGrid has sought to justify the need for each of the six projects[147] on one or more of four grounds: [148]

- Alignment with its Security Standard, which is based on the ENA *'National Guidelines for Prevention of Unauthorised Access to Electricity Infrastructure';*
- Compliance with its safety obligation to '*eliminate or minimise risk to health & safety of workers and members of the public So Far As is Reasonably Practicable or As Low As is Reasonably Practicable'*;
- Protect the electricity infrastructure from malicious attacks or acts of terrorism (including cyber-attacks); and/or
- Keeping operating costs down.

370. In each project TransGrid uses risk-cost analysis in support of its proposed work program. It estimates the key parameters for its base case as follows:

- PoF:[149]
  - where existing systems are in place it uses actual performance (unavailability) data as the basis for the PoF;
  - where a device/system is not currently installed, it assumes that they fail to perform their function 100% of the time; and/or
  - it uses other assumptions (such as the probability for any electronic device aged over 10 years may fail is 70%).

[147] CCTV System Renewal, Access Card and Intrusion Detection System Replacement, Substation Lighting Replacement, Motion Detection Replacement, Electric Fence Topping Replacement, and Physical Security of Comms Equipment

[148] *Ibid, slides 4, 6*

[149] See for example *Transgrid NOS-1398 CCTV System Renewal-0117-CONFIDENTIAL,* page 6 and *TransGrid OER-1398 CCTV System Renewal-0117,* page 3

- CoF - TransGrid assigns costs to one or more of the following material categories of CoF: personal injury (electrocution); service interruption, repair cost, and [lost] productivity.
- LoC:[150]
  - *electrocution of unauthorised personnel* - TransGrid determines the LoC by combining its historical unauthorised entry rate of 4% per site p.a. with an estimated risk of electrocution of 1% giving an LoC of 0.04% per site p.a. It then adds a LoC of 0.02% to account for the increased risk of undetected entry from failed motion detectors to arrive at a total LoC of 0.06% per site per annum;
  - *service interruption caused by unauthorised personnel* – TransGrid has recorded one such incident in the last 10-years at approximately 100 substations; based on this TransGrid applies a LoC of 1%;
  - *repair cost*: TransGrid applies the full cost of repair of assumed damage; and
  - *lost productivity*: TransGrid applies the full estimated cost of 'inconvenience to staff'.

Substation noise compliance

371. TransGrid is required to comply with noise standards[151] and has determined from desktop modelling that four of its substations are at high risk[152] of non-compliance and three other substations are at moderate/high risk[153] of non-compliance. Noise complaints received by TransGrid relate to one of the seven substations (Muswellbrook).[154]

372. TransGrid assesses the base case risk cost to be $9.36m p.a. by aggregating the financial risk, environmental risk and reputation risk at each substation.

373. Although TransGrid states that it has assumed for the purposes of its expenditure forecast that '*up to four of these [seven] sites will be identified as having actual existing noise nuisance issues that will require mitigation'*,[155] it has in fact based its expenditure forecast on corrective action at six of the seven substations.[156] It proposes replacing a transformer at Molong and installing noise walls at the other five sites at a total cost of $10.6m.

Non-compliant clearances

374. TransGrid proposes two projects involving correction of non-compliant electrical clearances: (i) Project 1556 being for the rectification of high risk low conductor spans, and (ii) Project 1606 being for the rectification of low 33kV busbar clearance at Yanco substation.

375. In both cases, TransGrid has assessed the compliance requirements against industry standards and its own internal design requirements. The line clearance

[150] *TransGrid presentation on-site session 9 – Security_AER,* page 9

[151] Noise pollution is regulated by the NSW Environmental Protection Authority under the Protection of the Environment Operations Act 1997, with provision for work orders and fines

[152] Modelled noise levels >10dB above the limit

[153] Modelled noise levels 5-10dB above the limit

[154] *TransGrid-IR030-Q27 Noise Compliance-20170526-PUBLIC,* page 1

[155] *TransGrid-NOS 1454 Substation Noise Non_Compliance Program-0117,* page 3

[156] Canberra is to be addressed as part of a capital project in the current period

project has been assessed as providing a positive NPV, and the busbar clearance is included to meet the business ALARP obligations. The dominant driver of the risk cost analysis is safety for both projects.

6.8.3 Assessment of safety & compliance expenditure forecast

Derivation of PoF has not been supported

376. With respect to TransGrid's derivation of PoF parameters, we consider that its use of relevant historical data (which it does when it is available in sufficient quantity) is a reasonable approach. However, applying a 100% failure rate to devices that are not installed and then attributing the devices' 'absence' to unauthorised entry, electrocution and service interruption is not adequately justified by TransGrid. TransGrid has not provided sufficient evidence to support its assumption regarding the PoF for electronic devices.

Examples where the application of LoC is flawed

377. We consider that both TransGrid's derivation of, and application of, the LoC parameters in its substation security projects are flawed. For example, TransGrid applies the LoC parameters to determine the risk cost in each of the six projects and, in the case of the project 1398, twice within the project. In our view, TransGrid's approach overstates the risk cost, as it effectively assumes that the deterrent and detection systems operate independently. Rather, these systems act together as a deterrent to unauthorised entry and, if there is unauthorised entry, some systems also act to mitigate the risk of electrocution and/or service interruption.

378. We consider that TransGrid should compare the risk cost avoided from the proposed suite of substation security measures[157] against the combined capital cost of those measures ($39.9m). We consider it likely that an ALARP evaluation will be required to justify the proposed investment.

379. In other examples, TransGrid has not provided sufficient evidence to support the addition of 0.02% to the LoC (electrocution) due to the predicted unavailability of motion detectors; and based on its own data, the service interruption LoC should be 0.1%, not 1%.[158]

380. In summary, we consider that TransGrid's approach to determining the risk costs for the individual substation security projects is likely to significantly overstate the annual safety and service interruption risk cost.

Additional functionality proposed not supported

381. TransGrid has provided insufficient justification for the additional functionality it proposes in some projects (e.g. quad lens cameras and infra-red cameras).[159] The incremental value of these initiatives on a risk avoided basis appears to be too small to justify the expenditure.[160]

[157] That is applying the LoC once, not multiple times

[158] One service interruption from an unauthorised person in 1000 substation operational years

[159] The thermal imaging camera is an asset management tool, not a security or compliance initiative

[160] For example, the avoided risk from the Quad Lens Camera is estimated to be $2.9k p.a. per site, which may not be sufficient to justify the capital cost (refer to TransGrid, *Riskrpt_1398_BaseCase_Part3)*

TransGrid's information indicates action may be required earlier than the next RCP

382. In general, the substation security options selected by TransGrid are aligned to its Security Standards and with good industry practice. Based on the information provided, we consider that it is possible that the security measures deployed at some substations require immediate attention, however we have not reviewed TransGrid's work plan for the current RCP.

383. The absence of consideration of works in the current RCP, casts a level of doubt on the claims made in the supporting information, and in the risk cost analysis provided to support the proposed expenditure.

Some of the proposed activity may be able to be prudently deferred

384. TransGrid advises that it has undertaken '*a detailed noise assessment*' at Molong substation and now predicts potential for limit exceedance of between 0.6-3.3dB.[161,162] In our view, this is indicative of the potential for material variances between desktop modelling and actual measurements. We consider that TransGrid should confirm whether there are significant noise compliance breaches by taking measurements in accordance with the applicable international or jurisdictional standard.

385. We consider that a prudent operator would, after it has determined through measurement the extent, if any, of noise non-compliance:

- Develop a work plan to progress towards noise compliance that balances impact, risk and cost;[163] and
- Agree the work plan with the environmental regulator, on the understanding that provided TransGrid implemented the work plan, it would not be fined for non-compliance.

386. Until such measures are taken, we do not consider that TransGrid has adequately justified the proposed expenditure.

6.9 Implications for proposed expenditure forecast

387. TransGrid has proposed an increase in replacement expenditure (including security and compliance) for the next RCP to reflect the asset condition, obsolescence, security and compliance related risks. TransGrid has generally demonstrated a prima facie case for the need for some activities of the types described in its proposal, to be undertaken in the next RCP.

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161 *TransGrid-OER 1454 Substation Noise Non_Compliance Program-0117,* page 3

162 Which we interpret to be above the +5dB limit, but the result is still much less than the initial modelling result of 12dB.

163 For example, taking into account the number of complaints at each substation, the extent of noise non-compliance, the tonality of the noise, the duration of the breach, and the potential number of customers that may be exposed to excessive noise

Systemic Issues leading to over-estimation

388. We consider that the systemic issues identified in our review reflect a bias towards the over-estimation of forecast expenditure. The impact of this bias is demonstrated in the replacement and security & compliance expenditure projects that we reviewed, where we find that the proposed level of expenditure for the next RCP:

- Has not been adequately linked to a prudent needs-driven analysis, including efficient timing of expenditure;
- Has not been adequately supported by robust options analysis, including inadequate justification of additional functionality, strategic benefit or inclusion in the forecast for reasons other than condition and risk drivers; and/or
- Includes inflated risk parameters used in the evaluation of projects that have led to a higher level of proposed expenditure than may be required.

Assessment of prudent and efficient level of expenditure

389. Our assessment of the impact of this bias on the sample of project expenditure included a number of aspects:

- We considered opportunities for optimisation across the portfolio where proposed expenditure did not adequately reflect prudent needs driven or risk based analysis, or where the timing of the proposed expenditure did not reflect an efficient level. Of the projects we reviewed, we found examples where TransGrid:
  - Has not demonstrated that the proposed level of expenditure was required to be incurred in the next RCP, and/or
  - Included expenditure that appeared to address a risk that was already addressed by other parts of its portfolio.

  To the extent that TransGrid has not at this stage justified the need for certain projects, or justified certain programs to the level proposed within the next RCP, we consider that TransGrid will find that its prudent requirement is in the order of 10% less than it has currently forecast.

- We considered opportunities where alternate options might reasonably exist to mitigate the identified risk and where, once examined, they may lead to less expenditure being required. Of the projects we reviewed, we found examples where:
  - Staged or partial replacement options and operational measures were not adequately considered, with a bias for completing projects within the RCP boundaries;
  - Additional functionality and scope was included in projects without sufficient justification to support the additional expenditure; and
  - Insufficient justification was provided for projects included to deliver strategic benefit, or other drivers other than condition and risk.

  To the extent that TransGrid has not yet adequately considered feasible options where they exist for certain projects, we consider that TransGrid will find that its prudent requirement is in the order of 5% less than it has currently forecast.

- We also considered opportunities to adjust for the impact of bias from inflated risk parameters used in the evaluation steps, that exist in addition to the above issues, and lead to over-stating the forecast expenditure. We consider that TransGrid will find that once it applies more rigorous challenge to these risk parameters, it will find that its prudent requirement is in the order of 5% less than it has currently forecast.

Summary impact of prudent and efficient level of expenditure

390. We consider that the systemic issues identified reflect a bias towards cost and risk overestimation that is likely to exist across TransGrid's replacement including security and compliance expenditure forecast. We reviewed a sample of projects to find supporting evidence of the systemic issues identified in our review. Taking account of uncertainty and possible overlap in the factors described above we estimate the aggregate impact of these systemic issues on proposed replacement expenditure including security and compliance to be in the order of 15% to 25%.

391. Accordingly, we consider that TransGrid's forecast replacement including security and compliance expenditure, reduced by this amount, would more reasonably reflect that of a prudent and efficient service operator.

7 Assessment of IT capex

7.1 Introduction

392. In this section, we provide our assessment of TransGrid's forecast IT capex in the non-network capex category.

7.2 Expenditure summary

7.2.1 Overview of forecast expenditure

393. TransGrid has proposed IT capex of $102.7m for the next RCP at an annual average of $20.5m as shown in Table 19.

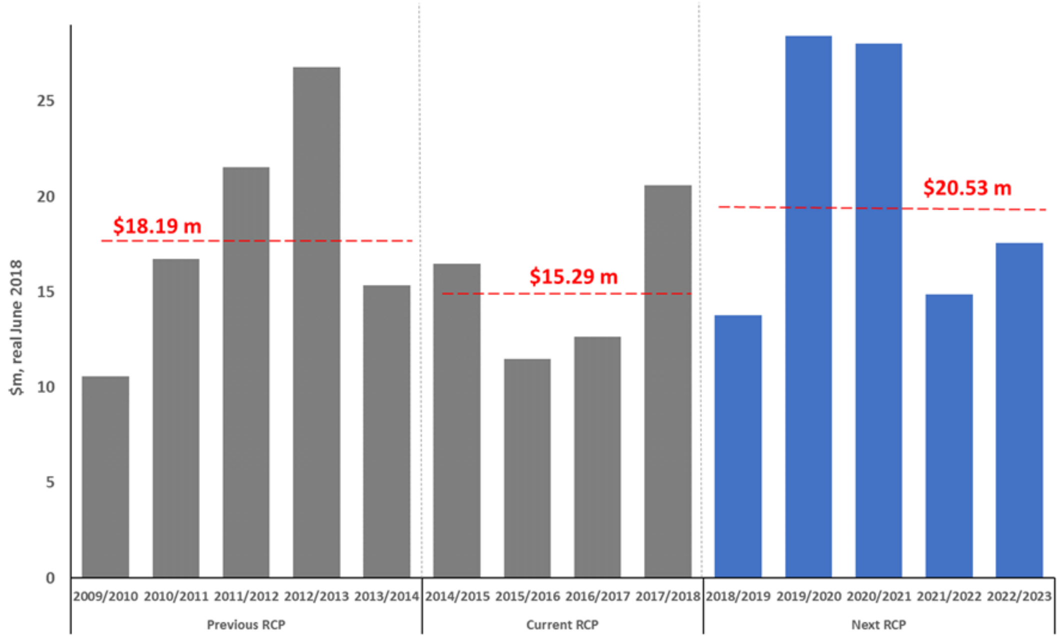
Table 19: TransGrid's forecast IT Capex ($m, June 2018)

	2018/19	2019/20	2020/21	2021/22	2022/23	Total	Average p.a.
RIN (Including overheads)	13.79	28.42	28.01	14.88	17.57	**102.67**	**20.53**

Source: TransGrid's response to Information Request 004

394. In Figure 27 below we show TransGrid's IT capex for the previous RCP, current RCP, and the next RCP. Despite being quite variable from year to year, the annual average expenditure has not increased over the previous and current RCPs.

Figure 27: TransGrid's actual and forecast IT capex ($m, June 2018)



Source: Transgrid RIN for 0910 to 15/16, Capital Accumulation Model for 16/17 & 17/18, TransGrid's response to Information Request 004 for 18/19 to 22/23

395. TransGrid explained that the primary driver for its IT forecast is end of life asset replacement to manage business risk, because the performance of IT assets decline at the end of their useful life, risking service failure that could impact TransGrid's operations. For example, TransGrid advised[164] that at the end of the service life for software, the level of vendor support reduces, but increases in price. Also changes in both the internal and external environment, including software updates and hardware replacements, increase the risk of compatibility related failure.

396. TransGrid explained[165] that its IT program will also enhance TransGrid's existing capabilities with up to date technology solutions that build required capabilities to meet future business requirements and customer expectations. These programs are designed to improve reliability, quality and security of supply, enhance productivity both in the office and in the field, improve the efficiency and quality of asset design, and protect TransGrid from cyber threat.

397. TransGrid's proposed IT capex consists of 8 programs as shown in Table 20 below, each of which consist of many inter-related projects.

[164] *TransGrid's onsite IT Presentation to AER*, 10 May 2017

[165] *TransGrid's onsite IT Presentation to AER*, 10 May 2017

Table 20: TransGrid's proposed ICT programs ($m, real June 2018)

ICT Program	Cost
Pervasive Security	7.6
Infrastructure Enablement	15.6
Enterprise Analytics Platform	8.4
Intelligent Asset Design	3.2
Intelligent Operations Centre	11
Digital Field Force	8.6
Digital Enterprise	36.6
Corporate Data Network	11.6
TOTAL	**102.60**

Source: TransGrid's reponse to Information Request 004, page 5

398. TransGrid advised that each of these programs has been developed based on needs analysis undertaken jointly by TransGrid's IT Group and TransGrid's external IT advisor. This included consideration of asset lives and new business requirements. During the onsite meeting, TransGrid advised that given the rapid rate of change in IT solutions, these programs have not yet been prepared for DG1 in accordance with TransGrid's capital investment framework.

399. The largest of TransGrid's IT programs is the Digital Enterprise program at $36.6m, which comprises applications that provide financial services, office productivity, asset management, works management, warehousing functions, system planning, and integrated service delivery. TransGrid's proposed IT forecast is based on its assumption that each of these applications will be progressively replaced or upgraded over the regulatory period. Upgrade of the current enterprise resource planning (ERP) application, Ellipse, was cancelled in the current RCP and measures were taken to extend the life of the existing version of Ellipse instead. TransGrid is assessing alternate ERPs as a replacement for Ellipse in the next RCP.

400. Several of the programs, including Enterprise Analytics Platform, Intelligent Asset Design, Intelligent Operations Centre, and Digital Field Force, focus on building TransGrid's capabilities by investing in new technologies which TransGrid says will enable it to operate its business more efficiently and safely.

7.2.2 Observations on historical expenditure

401. TransGrid forecasts underspending its IT capex allowance[166] by approximately 25%. TransGrid explained that this is primarily due to reductions in two projects:[167]

- Firstly, TransGrid decided not to proceed with its planned upgrade to its ERP system. TransGrid was in the process of being privatised by the NSW Government, and TransGrid considered it prudent to defer any expenditure on the ERP to enable the new owners to make the decision, given that the new owners are likely to have their own ERP application and associated systems. TransGrid spent $1.5m in 2016 to prolong the life of Ellipse and as a result now

[166] The AER does not approve a specific IT capex allowance. TransGrid referred to 'allowance' as being equal to the IT capex forecast for the current RCP that was accepted by the AER in its Final Decision.

[167] *TransGrid's onsite IT Presentation to AER*, 10 May 2017

expects to not require $13m of previously-forecast capex across 2017 and 2018. TransGrid has also dropped to a lower level of vendor maintenance and support.

- Secondly, an underspend in infrastructure of $9m less than forecast. TransGrid explained that this was made possible due to a significant reduction in the price of storage hardware.[168]

402. TransGrid forecasts spending $2.7m more than originally expected for the current RCP on cyber security. TransGrid explained that this expenditure is necessary to provide protection for its systems appropriate for its current risk assessment of cyber-attack.[169]

7.3 Assessment of proposed expenditure

Adoption of end of life replacement

403. For most programs, end of life for existing solutions is the primary rationale for the proposed expenditure. TransGrid explained that risk cost escalates at end of life as warranties and product support deceases and the risk of failure increases substantially. The cost of support also often increases at end of life.

404. TransGrid reports the useful lives of its IT assets in its IT Asset Management Framework.[170] We understand that TransGrid has largely adopted the standard solution lives advised by vendors for its proposed IT capex forecast (that generally align with vendor warranty and support periods) and has assumed that each system will be replaced at this time. TransGrid has provided little evidence to support the reasonableness of this assumption. We did not see evidence that TransGrid had explored the viability of extending solution lives when preparing its proposed IT capex forecast.

405. We note that during the current RCP, TransGrid was able to extend the life of its Ellipse system, delivering the financial benefits of deferred investment and enabling TransGrid to defer any replacement decision until modern Enterprise Resource Planning (ERP) systems gain maturity.

406. We would expect that in practice TransGrid will likely consider options to defer items in its IT capex programs when conducting its options analysis, including delaying projects to enable adoption of new functionality offered as technology solutions mature. Upon closer review of the risk costs over the IT asset life-cycle, further opportunities to optimise the timing of replacement decisions may be explored, at a point prior to elevated performance degradation. Where IT assets are replaced at end of service life, evidence of the actual/forecast performance degradation should support the decisions to justify this expenditure.

407. We consider that TransGrid's IT capex proposal may be overstated as a result of the inclusion of projects for IT solution upgrades/replacements that a prudent TNSP would continue to operate beyond the standard service life.

[168] *TransGrid's onsite IT Presentation to AER*, 10 May 2017

[169] *TransGrid's onsite IT Presentation to AER*, 10 May 2017

[170] Which range from 2 years for smartphones to 10 years for data centre UPS and air-conditioning

Inadequate options analysis undertaken

408. For each program, TransGrid has only assessed its preferred solution against a base case option of running the existing IT service to failure (i.e. no further capital investment). TransGrid has not considered any other alternative.

409. At our onsite review meeting, TransGrid explained that *'Due to the changing solution landscape it would be premature to fully develop options at this time.'*[171] We understand that TransGrid consider that available IT solutions and applicable prices can change considerably in a short period of time and as such a comprehensive options analysis would be invalid by the time of DG1.

410. We are concerned that the lack of options analysis by TransGrid may have resulted in over estimation of IT capex forecast. An options analysis has the potential to identify lower cost solutions to meet TransGrid's business requirements, and where there is known volatility in pricing this should form part of the assessment of available options. We note that option evaluation forms a primary input to the DG1 approval step in TransGrid's own capital investment framework.

411. An options analysis also has the potential to identify opportunities to defer part of, or all of, an IT program to future years. This may involve some immediate term expenditure to extend a system's useful life and to maintain an adequate level of support. It may also involve accepting a higher (though still acceptable) level of risk of some form of failure. This was demonstrated effectively by TransGrid in the current RCP through the deferral of the planned upgrade to Ellipse to the next RCP, saving $11.5m capex this period.[172] In addition to the benefit of the deferred expenditure, TransGrid has also allowed time for superior solutions to be developed.

Limited risk assessment undertaken

412. Risk cost avoidance is the main benefit (and in some cases only benefit) modelled in the NPV analysis for each IT program. TransGrid's modelling assumes that risk cost escalates rapidly at end of the standard service life, but TransGrid has provided little evidence (such as failure rate data) in support of this assumption.

413. The PoF is a major determinant of the risk cost calculation, as described in previous sections of this report. TransGrid explained that it has determined the IT PoF rates as follows:

> *"<u>Enterprise Class Software Failure</u>*
>
> *Software systems have several modes of failure:*
>
> 1. *Defects arise which were previously unknown because of data issues or a part of the system is being used for the first time;*
> 2. *Vulnerabilities are discovered and exploited by people seeking to cause damage;*
> 3. *Changes in the surrounding ecosystem (operating system, upstream or downstream integration points etc) cause failure;*

171 *TransGrid onsite presentation to AER*, 10 May 2017, page 28

172 *TransGrid onsite presentation to AER*, 10 May 2017, page 19

Based on these factors TransGrid has assigned an asset life of five years to enterprise class application software and a probability of failure of 20%.

<u>Infrastructure Failure</u>

Probability of failure is estimated at 50% based on the rate of change of the external environment specified by vendors. This includes infrastructure software version updates and hardware replacements to enable compatibility across the network."[173]

414. TransGrid has not provided compelling evidence to support its selection of the PoF rates. It seems unrealistic to model, what is in some cases, a very large step change in an asset's reliability at end of life (e.g. 50% PoF in years 1 to 5 for Corporate Data Network Refresh compared to 0% the year before).[174] We would expect to see the PoF increase over time as risk determinants increase (e.g. such as the decline in vendor support). For example, for the Intelligent Asset Design program, PoF escalates from 20% in 2023/24, to 30% in 2024/25, to 50% in 2025/26. [175]

415. Also, we found little evidence that TransGrid considered the post investment PoF[176] for the majority of its IT capex proposal (i.e. PoF is zero throughout the asset's useful life). It does not seem reasonable to assume a 0% PoF in any year of an asset's life, and if considered in the analysis, the NPV for some programs is likely to be overstated.

416. TransGrid has also not provided evidence to support its assumptions for its selection of LoC and CoF, and as such, it is difficult to determine that these are reasonable. For example, for the Information Infrastructure Refresh project, TransGrid has:

- modelled a worst-case scenario of failure affecting 1,000 users for 150 hours. We have assumed that the reference to 150 hours represents business hours as TransGrid appears to have used 'business hours' costs to calculate its CoF.
- included the consequence cost for both 'IT Service Degraded' and 'IT Service Interruption' in its CoF calculation, whereas we would have expected to see the CoF calculation include just one of these costs given an IT service can be either degraded or interrupted (but not both at the same time).
- tripled the risk cost by assuming the same risk consequence cost for three failure mechanisms (software failure, component failure, and hardware failure) with the same PoF.

Inclusion of other opex benefits in the analysis

417. We note that some IT programs provide additional functionality that will deliver opex efficiency savings in other areas of TransGrid's operations. TransGrid estimates these benefits will add to $8.8m per annum. We would expect to see these opex efficiency savings identified in TransGrid's opex forecast, with a plan outlining how

[173] TransGrid response to AER information request 004, page 7.

[174] The NPV model uses a constant risk cost for years 1 to 5, which implied PoF does not change over this period. However, we note that this seems to be inconsistent with Investment Risk Tool in which reports that the PoF escalates over the life of the investment.

[175] Sourced from the OER & NPV model, however we note that the Investment Risk Tool seems to report a different escalation rate for PoF.

[176] We note that TransGrid assumed a post investment PoF of 1% for Pervasive Security

the savings will be delivered. We have not undertaken, nor have we been requested to, a review of TransGrid's opex forecast.

7.4 Implications for proposed expenditure forecast

418. TransGrid has proposed an increase in IT capex for the next RCP compared to its actual/estimated costs for the current RCP. TransGrid has not provided compelling evidence to support the proposed increase.

419. In reviewing the proposed projects and programs, we consider that the IT capex forecast is over-stated, based on evidence of:

- Insufficient justification for the estimated PoF, during operation, at end of life and post investment;
- Inadequate justification for the LoC parameters and what appear to be high CoF assumptions; and
- Inadequate option analyses, including unrealistic base case options and lack of consideration of IT asset life extension strategies.

420. We reviewed the historical expenditure incurred by TransGrid for its IT capex and consider that, on balance, the average expenditure over the current RCP and previous RCP is a better indicator of a prudent level of required expenditure. We conclude that over-stated risk has resulted in an over-estimation of the expenditure forecast of between 15% and 20%. Accordingly, we consider that TransGrid's forecast replacement capital expenditure for IT capex, reduced by this amount, would more reasonably reflect that of a prudent and efficient service operator.

8 Assessment of cable unavailability for Powering Sydney's Future project

8.1 Introduction

421. In this section, we describe our assessment of the methodology and the input parameters used by Ausgrid to determine cable unavailability for the Ausgrid cables that supply inner Sydney and the CBD, and that TransGrid has used in its assessment of time for the PSF project.

8.2 Overview of Ausgrid's approach

422. The Ausgrid cables within the scope of this review are eight 132kV oil-filled cables that supply the inner Sydney area, including the CBD. The cables range in age from 28 – 50 years (average age of 43 years). Ausgrid consider that these cables are prone to leaking oil through a large range of failure modes.

423. Ausgrid's approach to predicting future cable unavailability rates is based on a combination of '*interactive condition and failure prognosis*', which has been assessed by an independent expert to be an improvement over the 'standard' level of industry practices and that the modelling technique is "*valid and credible for forecasting failures and prioritising feeders based on historic cable failures and condition*."[177]

424. Ausgrid has applied the Crow-AMSAA methodology to model the oil-filled cable failure rate (or intensity) at a given cable age for Ausgrid's oil-filled cable population. The model generates output values of β and λ that define the failure rate

[177] *CutlerMerz, Oil filled cable failure model Independent validation report, September 2016,* pages 1 - 3

characteristic. The oil-filled cable population failure intensity model has been developed from all failures[178] of the population of oil-filled cables during the period 2009 - 2015.[179]

425. The output values for the oil-filled cable population as a whole are then adjusted to produce output values of β and λ for individual cables. The adjustments are based on an assessment of the condition of the individual cables by assigning an equivalent number of significant oil leaks (which is estimated from a combination of normalised oil leaks and insulation resistance test results).

426. Ausgrid has provided an independent verification report[180] of its oil filled cable failure modelling technique. Among other things, the report illustrates the individual steps in the model, as briefly described above, and reproduced in Figure 28.

427. The failure rate (failures per year), *f*, is determined using the derived output values of β and λ according to the following equation:[181]

$$f = L\,\lambda\,(t_2^{\beta} - t_1^{\beta}) \qquad \textit{(Equation 5)}$$

where:

L = *the length of the cable segment (km)*

t_1 = *the age of the cable segment at the start of the year (in years)*

t_2 = *the age of the cable segment at the end of the same year (in years)*

β = *shape parameter*

λ = *scale parameter.*

428. Ausgrid has determined cable unavailability (expressed as percentage time per year) according to the following equation:

$$U = f\ x\ MTTR/(52 + f\ x\ MTTR) \qquad \textit{(Equation 6)}$$

where:

f = *failure rate (from Equation 5)*

$MTTR$ = *mean time to repair (weeks)*

429. Figure 29 shows the Crow-AMSAA log-log cumulative failures versus cumulative age plot with the line of best fit (red line) established by simple linear regression. The slope of the line is the β parameter in Equation 5 and λ is the y-axis intercept. The 95% confidence intervals (dotted green lines) are used by Ausgrid as bounds for estimating the range of β values for individual cables and cable sections.

8.3 Our assessment of cable unavailability

430. We consider Ausgrid's development of the cable unavailability for the oil-filled cables in question by considering:

[178] Cable Risk Model REV2_TRANSGRID v1_3 - FINAL (6yr Failure Data)

[179] Ausgrid response to AER Information request 025 - Supply to inner Sydney and CBD v1.1

[180] *CutlerMerz, Oil filled cable failure model Independent validation report, September 2016*

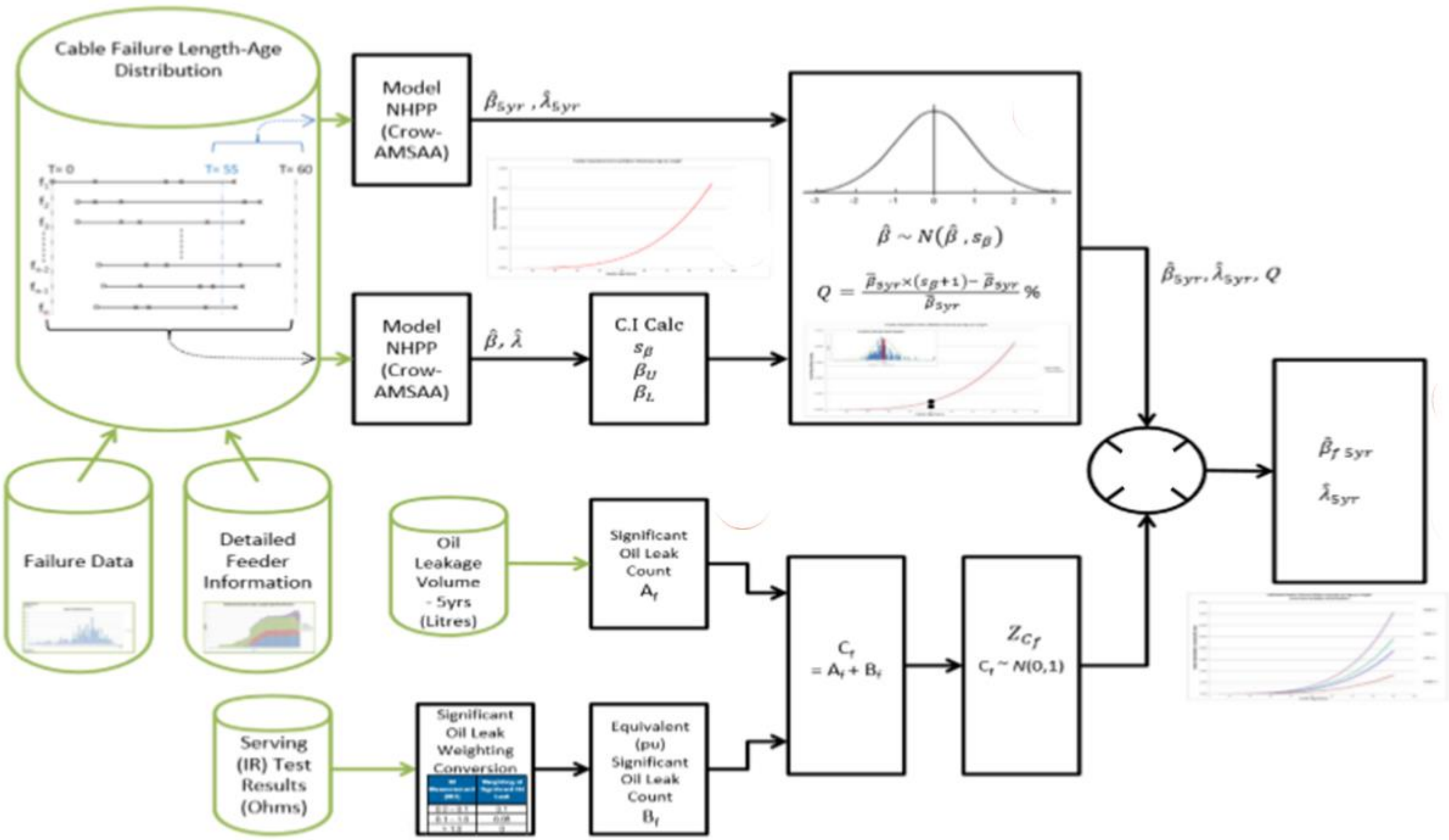
[181] Source of Equations 5 and 6: *Ausgrid response - AER Information request 25 - Supply to inner Sydney and CBD v1.1*

(i) the appropriateness of the predictive failure methodology;

(ii) the key steps and assumptions Ausgrid apply in deriving the frequency of failure; and

(iii) the derivation of cable unavailability, examining both the methodology and the key assumptions.

Figure 28: Flow diagram representation of Ausgrid's oil-filled cable model



Source: CultlerMerz report, page 4, adapted by EMCa

Figure 29: Crow-AMSAA plot of Ausgrid oil-filled cable failures (full population)[182]

Source: Ausgrid response - AER Information request 25 - Supply to inner Sydney and CBD v1.1, page 4

8.3.1 Predictive failure methodology

Applicability of the model

431. We have reviewed the suitability of Crow-AMSAA reliability growth plots for predictive failure modelling of Ausgrid's cables. Crow-AMSAA plots are suitable for predicting future failures for mixed failure modes in linear systems, whereas another common tool, Weibull probability methodology, is a powerful tool for single mode failures. The Crow-AMSAA technique involves plotting cumulative failures over time (log-log), with a line of best fit described by the equation $n(t) = \lambda * t^{\beta}$, where β is the line slope, λ is a 'scale factor', and n(t) is the failure event at time t. A β value >1 indicates that the failure rate is increasing, β = 1 indicates a constant failure rate, and β <1 indicates a declining failure rate.[183, 184, 185]

432. Whilst the appropriateness of using the Crow-AMSAA approach was not central to its assessment, TransGrid's consultant CutlerMerz observed that: (i) the Ausgrid model is closely related to the Crow-AMSAA method and '*provides a general correlation technique*', and (ii) there is an opportunity for improvement through better utilisation of available data.[186]

433. We consider that Ausgrid's use of the Crow-AMSAA method is suitable, noting that it has, through the steps indicated in Figure 28 above, employed its own approach to determining the failure rates for individual cables.

[182] The reference to cable 91X/2 is to illustrate a point in the source document; the blue-dotted lines represent a β standard deviation of 3

[183] P. O'Connor and A. Kleyner, *Practical Reliability Engineering*, 5th Ed, Wiley, 2012, page 37

[184] N. Comerford, *Crow/AMSAA Reliability Growth Plots, 2005,* pages 1-22

[185] P.E. Barringer, *Predict Failures: Crow-AMSAA 101 and Weibull 101, 2004*, pages 1-14

[186] CutlerMerz, *op. cit.* pages 3, 5

8.3.2 Key steps and assumptions in deriving cable failure rate

434. In this section, we consider the key steps in the development of the failure rate for individual cables.

Ausgrid's definition of cable failure

435. Ausgrid has identified multiple failure modes and causes.[187] Rather than deal with over 60 individual failure modes in its failure rate modelling, Ausgrid defines cable failures in three mode types (or groups): corrective (M2), breakdown (M3), or third party (M5). A fourth failure mode type, M1, is used in its cable failure spreadsheet,[188] however we were unable to identify a definition in the information provided by Ausgrid.

436. M2 cable repairs can be planned or unplanned and are typically associated with defects identified through inspection, testing and monitoring of cables. M3 and M5 failures are unplanned events.

Source of cable failure data

437. Ausgrid's cable failures data used to derive the oil-filled cable population failure/defect intensity model includes over 1,200 lines of information, one entry for each failure/defect event. The failure data is used to determine the oil-filled cable population failure rate (i.e. using all 1,200 failures). A subset of the dataset corresponding with each of the M2, or M3 or M5 classifications is used to determine separate failure rates for each of the corresponding failure mode types.

Ausgrid has advised that its historical data is not 100% complete,[189]: *"…due to differences in how planned vs unplanned outages were historically defined and captured in System Operations, compared to how this delineation would be made for contemporary asset management purposes…*"[190] There are also apparent inconsistencies between cable failure data spreadsheets.[191] Ausgrid advises that it has sought to account for these issues with historical data by relying on SAP notification/defect data as the basis for defect intensity.[192]

438. It is not within the scope of our review to undertake an audit of Ausgrid's data. However, we consider that Ausgrid should confirm that it has appropriately classified the failure events in its input data. Reclassification of some M2 failures to M1 failures would have the effect of altering the data points used in the Crow-AMSAA-based modelling to derive β and λ parameters for M2 failures. However, because the

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[187] Refer to parts and failure modes in *TransGrid-IR030-Ausgrid-Q34 Ausgrid Oil Cable_Failure Tree_MTTR May 2017-20170526-CONFIDENTIAL*

[188] Ausgrid, *Cable Risk Model REV2_TRANSGRID v1_3 - FINAL (6yr Failure Data)*

[189] For example, in *Ausgrid, 20170512 - Outage data for PSF cables v1.0.xls*, the 'Work' column in Sheet1 is incomplete

[190] *Ausgrid response (2) - AER Information request 25 - Supply to inner Sydney and CBD - Cable Outage Data V1.0*

[191] For example, it is not possible to reconcile the failure data for cable 91X/02 in *Cable Risk Model REV2_TRANSGRID v1_3 - FINAL (6yr Failure Data).xls* and in *20170512 - Outage data for PSF cables v1.0.xls*

[192] *Ausgrid response (2), op. cit.*

number of potential misclassified failures is likely to be less than 10% of the total M2 failure events, the effect *is unlikely* to be material.

Establish population failure intensity model

439. Ausgrid normalises the failure event data against age and to the total population length of oil cable as it varies over time to remove the potential for bias to long feeders. We consider this to be an appropriate step.

440. Ausgrid applies the normalised historical defect and cable population information to populate a Crow-AMSAA based probability 'plot',[193] as described above, resulting in β and λ parameters for the oil filled cable population. Ausgrid has used seven years of data (2009-2015) in its analysis (the 1200 failure events referred to above).[194] The use of the 'recent data' is primarily because the leakage volume over the period 2009-2015 was significantly less than the prior years (due to improved maintenance strategies and replacement of some poorly performing cables). The resultant β parameter in the failure rate equation (Equation 5) is therefore more representative of current practices and the state of the oil-filled cable network. The Simple Linear Regression approach for curve-fitting was selected and, based on the information provided,[195] we consider this is appropriate for this purpose.

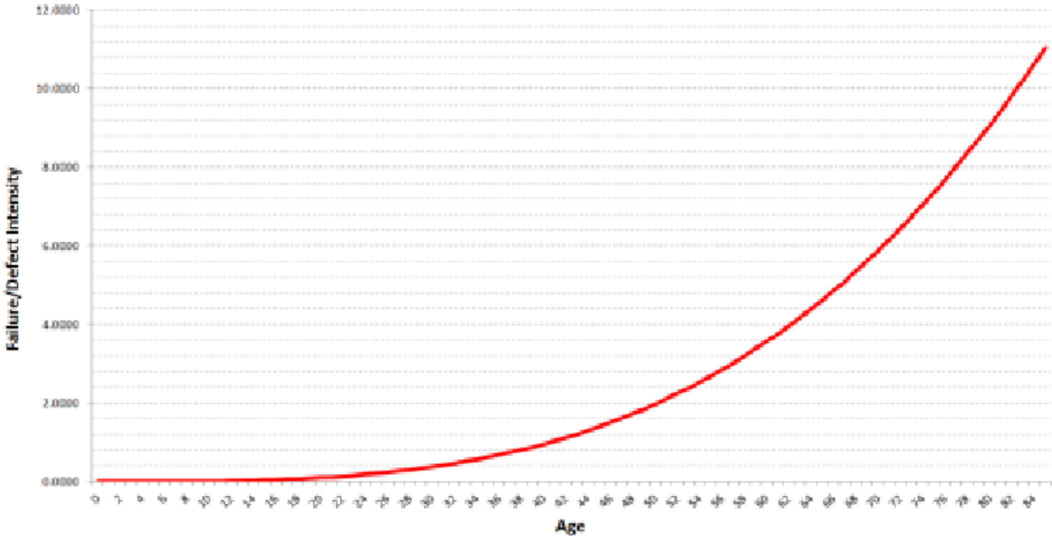
441. The oil-filled cable population $\beta = 4.2465$ and $\lambda = 1.4163\text{x}10^{-7}$, indicates a relatively high failure rate, which is to be expected given the broad base of failures/defects included in the modelling and the age of the oil-filled cables. We do not have access to the model in which the parameters are derived. The resulting failure curve for the oil-filled cable population is shown in Figure 30.

[193] We assume that Ausgrid uses a software package to convert the data into the Crow-AMSAA plots and to generate the λ and β parameters

[194] Ausgrid refer to the use of the last 6 years of data. We consider that this difference is unlikely to have a material effect on the derived population β and λ parameters

[195] Including CutlerMerz' assessment, *op. cit.* page 12

Figure 30: Ausgrid's oil-filled cable population failure intensity model



Source: Ausgrid response - AER Information request 25 - Supply to inner Sydney and CBD v1.1

IR & Oil leak condition factor and Z-score

442. As the first step in deriving adjustment factors to account for individual cable condition, Ausgrid has translated oil leakage over the period 2010-2015 for each cable into a normalised value for significant leaks per feeder (A_f).[196]

443. Ausgrid uses measurements taken from serving insulation tests (insulation resistance, IR)[197] to establish an IR condition factor (B_f). The IR test results are converted into predicted significant oil leaks[198] by using a 'weighting' or conversion factor related to IR test result ranges.[199] Loss of serving insulation resistance is known to be a leading indicator of cable failure. Ausgrid has presented analysis showing the correlation between serving IR test results, oil leak data, and conversion factors, demonstrating that the conversion factors are reasonable.

444. The asset condition factors A_f and B_f are added to give a condition factor, C_f, of per unit equivalent oil leaks (per cable). The individual cable condition factors are assumed to be independent and identically distributed. Ausgrid has converted them into a standard normal distribution z-score (Z_{CF}), which represents the number of standard deviations each Z_{CF} score is from the population mean.

445. This approach allows Ausgrid to determine β and λ for individual cables, rather than apply the β and λ calculated for the overall oil-filled cable population.

446. The adjustments are constrained within 3 standard deviations of the population mean. The β standard deviation of three incorporates 95% of the likely values of the population beta gradient and allows for meaningful differentiation between the individual cable results.

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[196] Normalisation is against the volume of oil leak per annum which is deemed to be significant (1825 litres)

[197] Serving tests: serving is the insulation around the cable core

[198] More than 5 liters per day or 1,825 liters of oil per annum – this is based on the accuracy of the measurement/alarm system and is agreed as the threshold with the EPA

[199] The time period over which the IR results have been measured is not clear

447. Importantly, Ausgrid applies this approach to M2, M3, M5 failure data to derive M2, M3 and M5 population β and λ parameters and then, by applying the Z factors, determine M2 β, M3 β, and M5 β parameter values for each cable.[200]

448. By applying Equation 5, Ausgrid has calculated:[201]

- The M2 corrective defect failure rate for each oil-filled cable;
- The M3 breakdown failure rate for each oil-filled cable; and
- The M5 third party failure rate for each oil-filled cable.

449. Whilst Ausgrid has provided a description of the steps involved to achieve the individual cable β and λ parameters for each cable and for M2, M3, and M5 failure mode categories and the results of its analysis, we have not been provided with the model that Ausgrid used to derive them. However, based on our review of: (i) the description of the approach undertaken by Ausgrid; (ii) the independent verification of the approach (but not the data) by CutlerMerz;[202] and (iii) Ausgrid's responses to our information requests, we are satisfied that Ausgrid's method for deriving β and λ parameters is reasonable for the purposes of predicting individual cable failure rates for M2, M3 and M5 categories of failure.

8.3.3 Key steps in deriving cable unavailability

Methodology

450. Cable unavailability is determined by Ausgrid based on Equation 6, above. It determines total cable unavailability for individual cables by combining the predicted unavailability due to M2, M3 and M5 repair times according to the union of the three unavailability rates:[203]

$$U_{Total} = U_{M2} \; U \; U_{M3} U \; U_{M5} \qquad \textit{(Equation 7)}$$

where:

U_{M2} is the cable unavailability from M2 (corrective) failures

U_{M3} is the cable unavailability from M3 (breakdown) failures and

U_{M5} is the cable unavailability from M5 (3rd party) failures

451. We consider both Equation 6 and its extension, Equation 7, are fit for the intended purpose.

Source of cable outage and repair data

452. The duration for which the cable was out of service (if at all) is not included in Ausgrid's cable risk model.[204] The 1,200 failures/defects include a significant number

[200] The λ parameter for each individual cable is the same as the λ value for the M2, M3, or M5 population

[201] *Ausgrid Subtransmission Feeder Unavailability Analysis 20170309*

[202] CutlerMerz, *op.cit.* page 13

[203] *Ausgrid response - AER Information request 25 - Supply to inner Sydney and CBD v1.1,* page 10

[204] Ausgrid, *Cable Risk Model REV2_TRANSGRID v1_3 - FINAL (6yr Failure Data)*

of events which appear not to require a cable outage to rectify.[205] As Ausgrid is required to remove cables from service to complete a repair, some corrective and all significant leaks/breakdowns,[206] require an outage to complete the works. Cable unavailability is not just affected by physical damage to the cable, but also by significant oil leaks and many other failure causes.

453. In Ausgrid's definition of events, (i) 'planned' events do not include a cable outage (i.e. non-zero repair time) and occur during scheduled maintenance outage windows, and (ii) 'unplanned' events require an outage, and occur between scheduled maintenance outages.[207]

454. As discussed below, Ausgrid has not relied on this data for calculation of cable unavailability.

Derivation of Mean Time to Repair (MTTR)

455. Rather than use actual failure repair times to determine the MTTR for M2, M3 and M5 failure modes, Ausgrid has used an "*FMEA process and workshops to assess likely average repair times and cross-checked the results with SCADA/OMS data to validate the workshop outcomes.*"[208] [209] We understand that this 'hybrid' approach was because of issues with the quality of the cable failure information (as discussed above).

456. The results used in Equation 6 are MTTR (M2) = 1.06 weeks, MTTR (M3) = 7.0 weeks and MTTR (M5) = 5.5 weeks.

457. In reviewing the reasonableness of Ausgrid's average MTTR values, we used three cross-checks, as discussed below.

Confirmation of definitions of the failure modes relevant to the unavailability model

458. As discussed above, Ausgrid's determination of MTTR results for M3 and M5 failure mode types are based on unplanned outages. Breakdown failures "*generally lead to unplanned outages of the cable.'*"[210] Ausgrid's defines corrective failures as conditional failures (or defects). The repairs may be planned or unplanned, with Ausgrid assigning zero repair time to planned repairs.

459. Based on these definitions, we would expect Ausgrid's failure statistics dominated by failures which it classifies as M2 failures, with much less M3 failures and very few

[205] For example, approximately 10% of the recorded failures are due to spurious alarms and pressure gauge and switch errors which are unlikely to require a cable outage to rectify

[206] For example, Ausgrid defines a significant oil leak as being the loss of more than 5 litres of oil per day

[207] *TransGrid-IR030-Ausgrid-Q34 Ausgrid Oil Cable_Failure Tree_MTTR May 2017-20170526-CONFIDENTIAL*

[208] Ausgrid, onsite meeting presentation *10A 20170509 - Ausgrid Oil Cable Risk Model v3.1*

[209] *TransGrid-IR030-Ausgrid-Q34 Ausgrid Oil Cable_Failure Tree_MTTR May 2017-20170526-CONFIDENTIAL*

[210] *Ausgrid response – op. cit.,* page 11

M5 events. This is what we see in Ausgrid's cable failure data list[211] and in Ausgrid's classification of failure causes.[212]

460. If, as we suspect, the failure rates for the M2 failure mode are derived from data that includes corrective failures for which there was no cable unavailability (i.e. no cable outage), the derivation of the MTTR for the M2 failure mode should also account for events for which no outage of the cable is required. In its spreadsheet delineating its derivation of the M2 MTTR, Ausgrid *has* included zero duration outages.[213]

Engineering judgement regarding the practical aspects of repairing cable faults

461. We note that the route of the eight 132kV Ausgrid cables that we understand are integral to the PSF project traverse the inner Sydney and CBD areas. They are therefore likely to have a higher than average proportion of their total route length in locations with access constraints. We consider that as M3 and M5 cable failures (by Ausgrid's definition) require immediate de-energisation of the affected cable section, the proposed M3 and M5 mean times to repair of 7.0 weeks and 5.5 weeks respectively are likely to be reasonable.[214] As noted above, Ausgrid's use of its own cable specialists (whom we assume have collectively been involved in the cable fault and defect repair process for many years) plus their cross-check against actual outage data in deriving the MTTR values, [215] adds confidence in the results.

The average repair time in Ausgrid's oil-filled cable fault database

462. Ausgrid has provided a spreadsheet with failure data for the 'PSF cables' only.[216] It does not include descriptions of all failures, but it does include the outage times for the failures included in the spreadsheet. The accuracy of this data is uncertain. However, the average outage time for all PSF cables (including zero duration outages) in the cable failure data is 8.7 days,[217] which indicates that: (i) there are many more M2 events than M3 and M5, as expected from Ausgrid's definitions; and (ii) the average MTTR for M2 mode types of 7.4 days (1.06 weeks) appears to be reasonable.

463. In conclusion, we consider that the corrective (M2), breakdown (M3) and 3rd Party (M5) MTTRs assumed by Ausgrid are likely to be reasonable in the context of determining cable unavailability using the process described above. As a final check of reasonableness, we considered the model outputs, as discussed below.

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[211] Cable Risk Model REV2_TRANSGRID v1_3 - FINAL (6yr Failure Data)

[212] *TransGrid-IR030-Ausgrid-Q34 Ausgrid Oil Cable_Failure Tree_MTTR May 2017-20170526-CONFIDENTIAL*

[213] *Ibid*

[214] There is likely to be significant time required for preparation works relating to investigation, identification, permits and approvals etc. There may also be access limitations in some locations, extending the duration of the repair. Preparation work would normally be done before excavation, repair, and re-energisation occurs

[215] Ausgrid response – *op. cit.,* pages 11-12

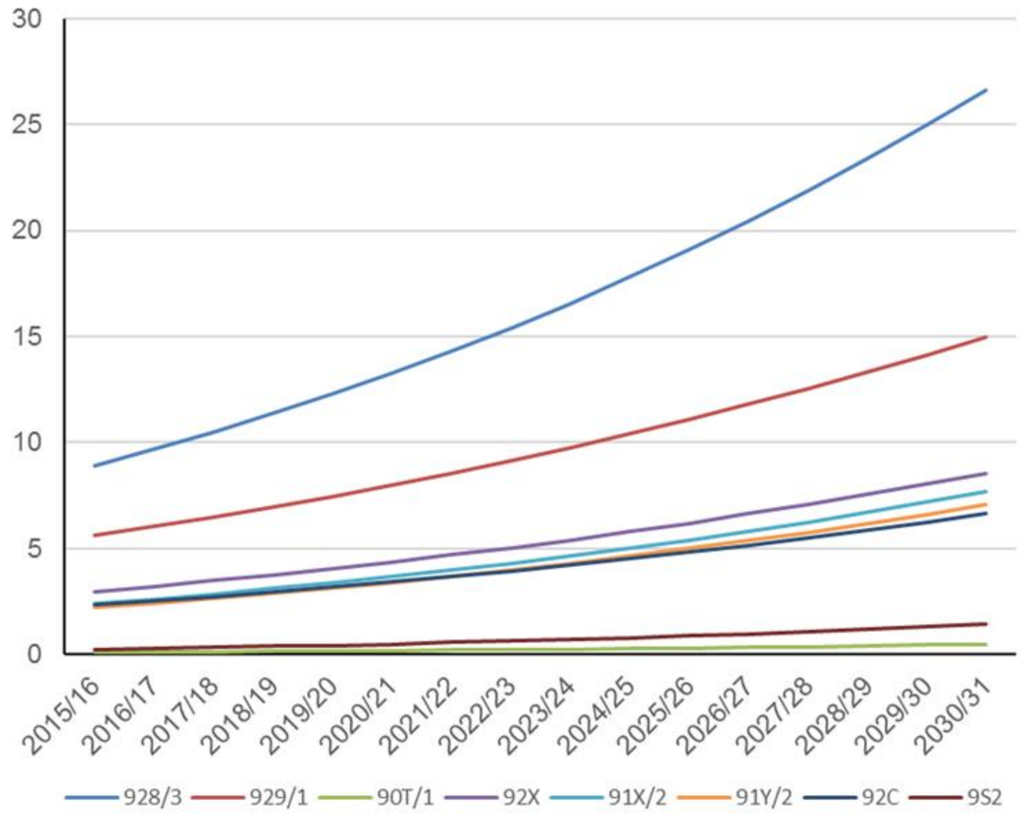
[216] *Ausgrid, 20170512 - Outage data for PSF cables v1.0.xls*

[217] Removing the three highest repair times of 174.3, 153.7 and 138.3 days reduces the MTTR to 7.6 days, which is still a reasonable correlation with the 'expert-derived' M2 MTTR

8.3.4 Modelling results

464. We have considered the output of Ausgrid's model as it relates to the eight 132kV cables that we understand to be the focus of the PSF project. The failure curves for these cables show the sort of relationship we would expect given: (i) the age profile of the cables, (ii) the relatively good fit of the data to the regression line (per the cumulative age-failure plot), and (iii) the adjustments for individual cables Ausgrid included in its methodology. For example, Figure 31 shows the forecast M2 failure rate for the eight 132kV oil-filled Ausgrid cables.

Figure 31: Ausgrid M2 (corrective) failure rate for eight Ausgrid 132kV cables (Number of corrective failures per year)



Source: Ausgrid D17 234506 Ausgrid-PSF 132kV oil-filled cable avoidable repair costs and monetised environmental risk-20170308

465. From Figure 31, cable 90T1 (35 years) and 9S2 (28 years) are the youngest cables with the lowest projected failure rates, and cable 928/3 is the equal oldest cable at 50 years old with the highest projected failure rate, which intuitively makes sense.

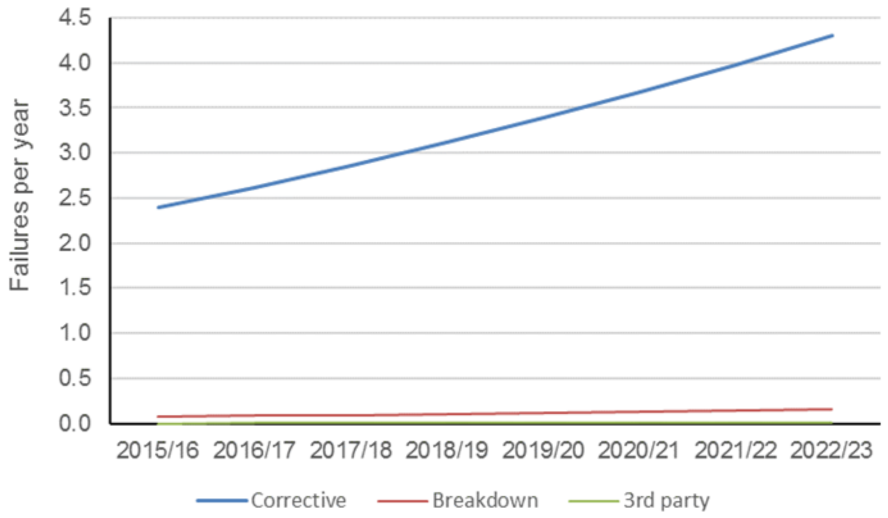
466. Figure 32 shows the results of Ausgrid's modelling for cable 91X/2. The relatively high forecast failure rates for corrective defects compared to breakdown and 3rd party modes are as we would expect based on the high volume of M2 defects included in the modelling. Similarly, the dominant contribution of the corrective defects to the total cable unavailability shown in Figure 33, is to be expected given the high failure rate and the 1.06 week MTTR.

467. This analysis illustrates that the unavailability results are most sensitive to the assumed corrective MTTR designated as M2 (i.e. rather than the breakdown and 3rd Party MTTRs). Noting the concerns with the source data described earlier, additional means to confirm the appropriateness of the data and model would be for Ausgrid to:

- Confirm that its classification of M2 failures in its source data is correct (i.e. confirm that they are not M1 events);
- Plot the actual failure rates for the eight cables, including 2015/16 and 2016/17 data against these curves;
- Derive the M2 MTTR from the last 3-5 years of actual data, which should not suffer from the same data quality issues evident in earlier years and is more reflective of current cable performance; and
- Derive the M2 failure rates including only events that led to cable unavailability. This would require the MTTR to be adjusted to exclude zero times to repair.

468. CutlerMerz identified five potential means of improving/refining Ausgrid's cable failure model. Ausgrid has provided satisfactory responses to each of these improvement opportunities. Despite these improvement opportunities, CutlerMerz considered Ausgrid's approach and technique to be credible for forecasting failures and prioritising feeders based on historic cable failures and condition.[218]

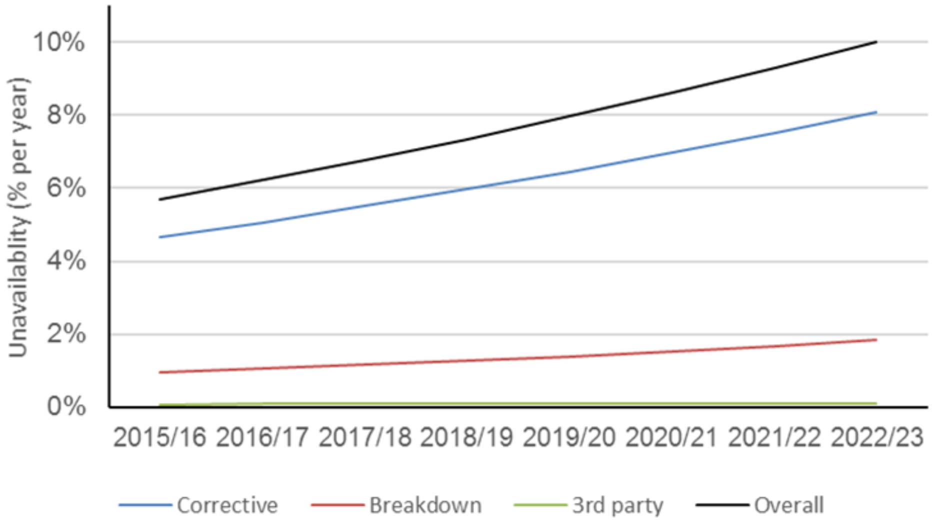
Figure 32: Ausgrid's failure rate prediction for cable 91X2



Source: EMCa analysis of Ausgrid Subtransmission Feeder Unavailability Analysis 20170309.xls

[218] *Ausgrid response - AER Information request 25 - Supply to inner Sydney and CBD v1.1,* pages 14, 17-18

Figure 33: Unavailability prediction for cable 91X/2



Source: EMCa analysis of Ausgrid Subtransmission Feeder Unavailability Analysis 20170309.xls

8.4 Summary

469. We have assessed the methodology and the input parameters used by Ausgrid to determine cable un-availability for the Ausgrid cables that supply inner Sydney and the CBD. We have not considered how TransGrid has applied the cable unavailability in its own analysis, nor have we reviewed any information pertaining to TransGrid's analysis or modelling.

470. We find that:

- Ausgrid's methodology for predicting the failure rate of the oil-filled cable population and the individual oil-filled cables we reviewed is reasonable;
- The methodology for predicting the unavailability of the individual oil-filled cables is reasonable; and
- The key parameters and assumptions underpinning the calculations of the failure rate and unavailability are likely to be reasonable, noting that we were unable to examine the models in which Ausgrid derived the Crow-AMSAA plots, nor how it adjusted the oil-filled cable population β and λ parameters with the individual cable Z-factors.