Nuttall Consulting

Regulation and business strategy

AER repex modelling

Assessing Endeavour Energy's replacement forecast

A report to Endeavour Energy

Confidential final

7 February 2018

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Executive Summary

Introduction

Nuttall consulting has been engaged by Endeavour Energy (Endeavour) to undertake an assessment of its replacement expenditure (repex) forecast. This assessment must use the predictive model that the Australian Energy Regulator (AER) has indicated it will use as part of its assessment process. This model is called the AER repex model. The assessment must also follow the method the AER has used to assess repex forecasts using this model in its recent round of decisions.

In accordance with this method, we have used data reported in various Endeavour Regulatory Information Notices (RIN) to prepare this model. This preparation has been supported by other data provided by Endeavour and other comments and advice provided during the course of a number of meetings with relevant Endeavour personnel. This has resulted in some minor adjustments to reported RIN data, where we considered this should improve the modelling.

We have used various AER documents to guide our assessment approach, including its expenditure assessment guideline, its repex model manual, and most importantly, its recent decisions.

In accordance with the AER's assessment approach, we have assessed Endeavour's forecast over the five-year period commencing at the start of Endeavour's next regulatory period (2019/20 to 2023/24) using model parameters calibrated to the last five years of Endeavour's reported data (2012/13 to 2016/17).

The AER only applies its approach to a subset of the repex forecast. Endeavour has requested that we apply the AER's assessment approach to the following:

- the portion of Endeavour's repex forecast that is usually assessed by the AER, which covers $632 million[1] (73%) of Endeavour's repex forecast (2019/20 to 2023/24).
- all of Endeavour's repex forecast, which covers $865 million (2019/20 to 2023/24)[2].

Assessment findings

Our assessment using the AER's repex model supports Endeavour's repex forecast.

The assessment supports Endeavour's forecast when all of Endeavour's repex is covered by the assessment. In this scenario, the *alternative estimate* produced by the model is $1,337 million or 155% of Endeavour's repex forecast of $865 million.

The assessment also supports Endeavour's forecast when only the portion of repex normally assessed by the AER using its repex model is covered. In this scenario, the *alternative estimate* produced by the model is $789 million or 125% of Endeavour's comparable repex forecast of $632 million.

[1] All expenditure quoted in this report is in Real June 2019 dollars, unless stated otherwise.
[2] This includes $15 million allocated by Endeavour to the Public Lighting asset group in the RIN table 2.2.1.

These results are shown in Figure E1 below, which indicates these two components of Endeavour's repex, and the two *alternative estimates* produced by the repex model.

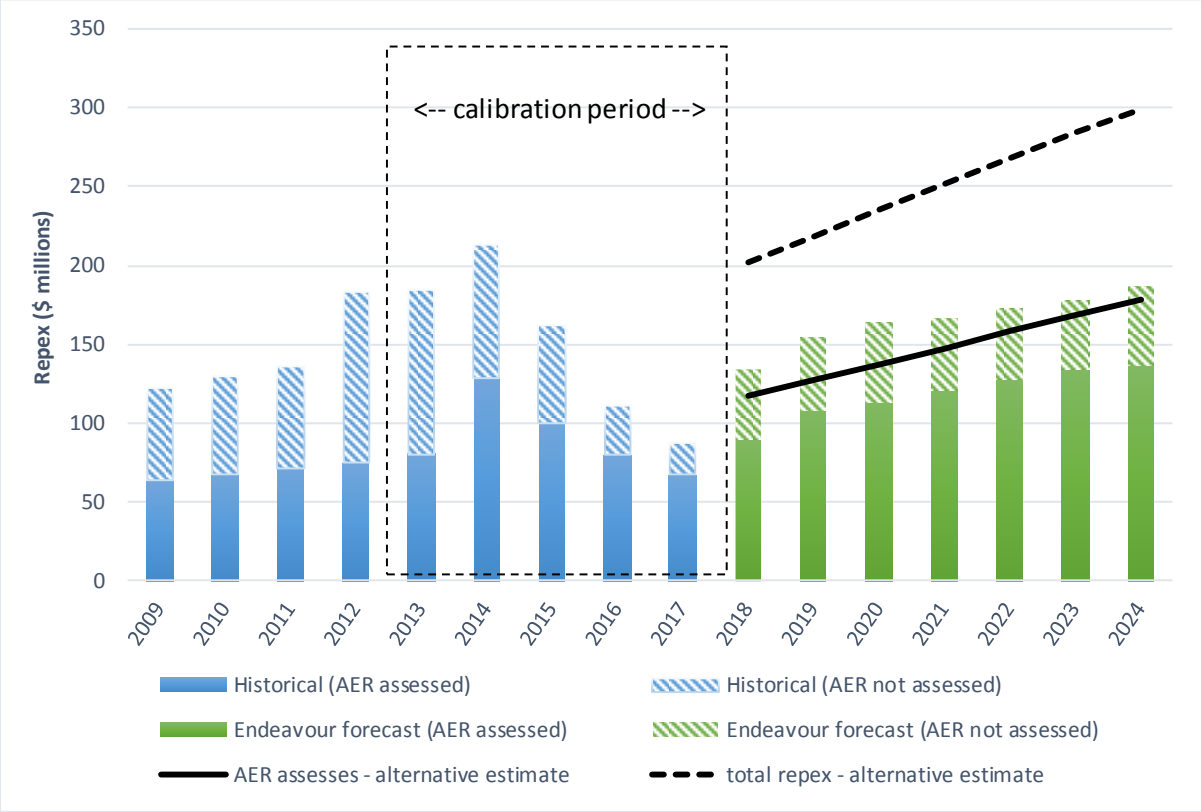

Figure E1 – Assessment results summary

Our studies suggest that, in aggregate, Endeavour's forecast unit costs are higher than its historical unit costs, but its forecast unit costs are broadly in accordance with AER benchmark unit costs. There is a large discrepancy with the LV cable unit costs, which is driving the majority of the increase in unit costs. Based on advice from Endeavour, we understand that this is due to Endeavour overestimating the historical volume of replacements in this asset category reported in its RINs because of the high level of "gifted" assets associated with this category. This would cause the apparent historical unit cost used in our analysis to be much lower than the true cable replacement unit cost. Without this discrepancy, we consider that Endeavour's historical and forecast unit costs would be more comparable, and below the AER's benchmarks.

Our studies suggest that, in aggregate, the asset lives that underpin Endeavour's forecast are longer than its historical lives. However, this favourable finding is also affected by the cable discrepancy noted above. Without this discrepancy, we consider that Endeavour's forecast lives, in aggregate, are shorter than its historical lives. These lives also appear to be shorter than AER benchmark lives; although, it is important to note that at this point the AER has not used these benchmark lives as primary parameters in its assessment method.

1 Introduction

1.1 Background and scope

Endeavour Energy (Endeavour) has engaged us, Nuttall Consulting, to assist in its preparations for its next regulatory determination by the Australian Energy Regulator (AER). This determination will cover the five-year period from 1 July 2019 to 30 June 2024.

As part of this engagement, Endeavour has requested that we:

- develop a model of Endeavour's replacement capex (repex) using the AER's repex model
- use the model to assess Endeavour's repex forecast, using an approach based on that used by the AER in its recent determinations
- reconcile the model forecast with Endeavour's own replacement forecast to identify the parameters within the model driving the differences
- prepare an independent report, which can be used as a supporting document to Endeavour's building block proposal to the AER, that sets out the forecast and explains how we developed the model and forecast.

This document serves as the report indicated above.

The following definitions are used in this report:

- **Replacement capex** (or **repex**) has the meaning given to it by the AER in its recent advice on how it will conduct expenditure forecast assessments, which broadly covers the non-demand-driven replacement of assets with their modern equivalent asset.
- We use the term **AER repex model** to mean the generic excel workbook that the AER has advised it will use as an assessment technique in its determinations – and the AER calls the repex model.
- We use the term **Endeavour repex model** to mean the model we have prepared of Endeavour's network using the AER repex model. The Endeavour repex model is used here to produce repex forecasts of the Endeavour network.
- When discussing the model and providing results, we will use the year representation 200*x*, to represent the regulatory year 200*x*-1/200*x*.

In addition, all expenditure and costs shown in this report represent **direct real June 2019 dollars**.

1.2 Nuttall Consulting experience in this task

Nuttall Consulting, using Dr Brian Nuttall (the author of this report), developed the excel workbook that serves as the basis of the AER's repex model and advised the AER on the model's possible roles and application in regulatory determinations.

Moreover, we were engaged by the AER to provide advice that informed the AER's past determinations of the Victorian and Tasmanian Distribution Network Service Providers (DNSPs). As part of these engagements, Dr Nuttall developed repex models and forecasts, using an approach very similar to that described in the AER's repex model documentation (and used here).

1.3 Key information sources

We have used the following information to develop the Endeavour repex model:

- the AER repex model and AER repex model handbook, published on the AER website
- the AER's most recent decisions where it has used its repex model to assess DNSP's repex forecasts
- Endeavour's Category Analysis Regulatory Information Notices (category analysis RIN), which were submitted to the AER for the years, 2008 to 2013, 2013/14, 2014/15, 2015/16, 2016/17.
- Endeavour's 2016/17 age profile, which is in the format of table 5.2.1 of the category analysis RIN
- Endeavour's replacement capex forecast, covering the period from 2017/18 to 2023/24, which is in the format of table 2.2.1 of the AER's Reset RIN, plus various working files
- AER benchmark asset unit costs and lives, as the AER applied in various recent decisions.

We have also held a number of workshops with relevant Endeavour personnel to clarify data requirements. Where there are limitations with the available data, we have made a number of assumptions to prepare the models. The critical assumptions and their basis are discussed in this report.

1.4 Structure

This report is structured as follows:

- In section 2 we review the AER's approach to using its repex model in recent decisions; in particular, how it has used it to determine an "alternative estimate" for the repex forecast of each DNSP. We then explain how we have applied this in our assessment approach.
- In section 3 we summarise and discuss the results of our assessment approach.

- In Appendix A we provide an overview of the AER repex model, summarising how it develops a forecast, its inputs and outputs, and how model parameters can be calibrated to an outcome. We then discuss the methodology we have used to develop the Endeavour repex model, including the Endeavour data we have used.
- Finally, in Appendix B we discuss differences at the asset category level between the repex model forecast and Endeavour's forecast. Here, we also explore the model parameters (i.e. asset lives and unit costs) that are causing these differences.

2 Assessment approach

Our assessment approach is based upon the approach used by the AER in recent decisions.

In this section, we first provide a summary of the AER's approach. We then explain how this has been used for our assessment.

2.1 AER assessment approach

It is important to note that the following represents our understanding of the approach the AER applied, which we have determined from explanations provided in recent AER decisions. We have not confirmed with the AER that this understanding is strictly correct. Furthermore, the AER decisions are unclear on the specific circumstances that the AER may depart from this approach when deciding whether it will accept a DNSP's repex forecast.

In recent decisions, the AER has used its repex model to define an *alternative estimate* for a large component of each DNSP's repex forecast. This component of the DNSP's repex was accepted if it was less than this estimate.

Importantly, the estimate represented the **aggregate** repex over the regulatory period being assessed i.e. it was not a year-by-year figure or a figure developed for each asset group or category.

2.1.1 The repex component assessed through the model

The component of the DNSP's repex forecast assessed by the AER using the repex model covered the following asset groups (as defined in RIN Tables 2.2.1 and 5.2.1):

- poles
- overhead conductors
- underground cables
- services
- transformers
- switchgear.

The AER excluded the following from its modelling and assessment:

- all replacement associated with the pole top structure, public lighting and SCADA, protection and control asset groups and the "other" asset group
- other programs within the DNSP's forecast that were defined by the DNSP as not suitable for repex modelling.

2.1.2 Defining the alternative estimate

The alternative estimate is determined from a set of model studies. Each study reflects a forecast prepared by the model, using a different set of the model's planning parameters (i.e. asset lives and unit costs).

The AER has considered a large number of studies when assessing each DNSP. However, it has evaluated each study (for each DNSP) in order to accept or reject it as an appropriate basis for defining its alternative estimate. In this way, it has only used three studies to define the estimate for any DNSP, and these three studies have been common across the DNSPs.

All three of these studies use asset lives that are *calibrated* to reflect the last five years of the DNSP's reported replacement volumes (as reported in its RINs). As such, the studies are uniquely defined by variations in the unit cost parameter set used for each study, as follows:

- **Study 1** - historical unit costs – This study uses a set of unit costs that are calibrated to reflect the last five years of the DNSP's replacement expenditure and replacement volumes as reported in its RIN
- **Study 2** - forecast unit costs - This study uses a set of unit costs that are calibrated to reflect the DNSP's replacement expenditure and replacement volume forecasts over its next regulatory period, as reported in its RIN
- **Study 3** - AER's benchmark unit cost – This study uses a set of unit costs that the AER has calculated as the average historical unit costs (as calculated above) across all the NEM DNSPs[3].

Typically, the lowest repex forecast from the studies using the DNSP's historical and forecast unit costs (Study 1 and Study 2) is used to define the alternative estimate for each DNSP.

The AER has applied a more relaxed role for its benchmark unit cost study (Study 3), using this to gauge whether the DNSP's unit costs are reasonably representative of efficient costs. As such, it has typically not used this to define its alternative estimate in circumstances where this study is the lowest, but not by a significant margin. However, as far as we are aware, it has not explicitly defined what such a margin would be, and therefore, we still consider that this is an important study for defining the alternative estimate.

2.2 Our assessment approach

2.2.1 Assessment and calibration period

In accordance with the AER's approach, we have used a five-year assessment period to apply the model. This means that when we were calibrating the model's planning parameters (i.e. asset lives and unit costs):

- historical calibrations used data for the years 2012/13 to 2016/17

[3] See the AER's determinations on its website for more information on the methodology the AER applied to derived these benchmarks.

- forecast calibrations used data for the years 2019/20 to 2023/24.

2.2.2 Repex component modelled

Endeavour has requested that we assess its total repex forecast using the AER's repex model. Therefore, to allow comparisons to the AER's usual approach, we have considered two components of Endeavour's repex for our assessment:

- **AER assessed repex** - which covers repex reported to the six asset groups normally assessed by the AER using the model. This component covers $632 million (73%) of Endeavour's repex forecast (2019/20 to 2023/24).
- **Total repex** - which covers all the asset groups defined in the Repex RIN tables, including the above six groups plus the pole top structure, public lighting, SCADA, protection and control and "other" asset groups. This covers $865 million of Endeavour's repex forecast (2019/20 to 2023/24)[4].

It is worth noting that there is still a small element of repex within these components that cannot be directly modelled. This relates to asset categories where the available data (i.e. the data reported in the RIN) does not allow the necessary relationships to be set up in the model. This occurs in circumstances where the asset may have an age profile (Table 5.2.1), but there is no replacement data (i.e. in Table 2.2.1) necessary to calibrate the parameters or vice versa.

This has only occurred in limited circumstances and is not material on the aggregate findings. Nonetheless, to ensure full consistency with Endeavour's forecast, where a portion of repex has not been able to be modelled, we have used the model forecast for the associated asset group to estimate the forecast for that portion and added this to the model results.

Finally, it is also important to note that the AER only produces benchmark parameters for the asset categories within the six asset groups it normally covers in its assessment. Therefore, we have not been able to apply this study to these asset groups.

[4] This includes $15 million allocated by Endeavour to the Public Lighting asset group in the RIN table 2.2.1.

3 Repex forecast assessment

In this section we discuss our assessment of Endeavour's forecast, using studies defined in the previous section. In keeping with the AER's recent approach, this assessment is focused on the aggregate repex forecast.

3.1 Repex model results

Table 1 summarises the repex model forecasts for the three studies defined in Section 2.1. The table shows the repex model results in comparison to Endeavour's forecast repex and its historical repex over the 5-year calibration period. The results are provided as a total repex over the periods indicated. The table also shows the breakdown of repex into the various RIN asset groups, indicating the portion normally covered by the AER's assessment and the portion that is not normally covered.

Table 1 Assessment study results summary

	Asset group	*actual repex (2012/13-2016/17)*	Forecast repex (2019/20 to 2023/24) - $ millions			
			Endeavour repex forecast	repex model (S1 - HUC)	repex model (S2 - FUC)	repex model (S3 - BMUC)
AER assessed	Poles	*79*	*159*	156	118	120
	OH conductors	*127*	*103*	271	127	148
	UG cables	*44*	*85*	77	868	581
	Services	*60*	*64*	63	46	93
	Transformers	*64*	*107*	132	65	120
	Switchgear	*82*	*114*	90	92	104
	Total AER assessed	***456***	***632***	**789**	**1315**	**1166**
AER not assessed	Pole top structures	*0*	*0*	0	0	-
	Public lighting	*30*	*15*	83	33	not modelled
	SCADA & protection	*70*	*48*	122	15	not modelled
	Other	*202*	*171*	343	489	not modelled
	Total AER not assessed	***301***	***234***	**548**	**537**	-
Total		***757***	***865***	**1337**	**1852**	**1166**

The profile of Endeavour's repex compared to the model's forecasts is shown further in Figure 1 (the portion of Endeavour's repex normally assessed by the AER) and Figure 2 (Endeavour's total repex)[5]. These figures show the various repex model studies, with the limiting study that would define the alternative estimate as the solid black line.

[5] Note, the y-axis years in both figures represent financial years e.g. 2009 represents 2008/09.

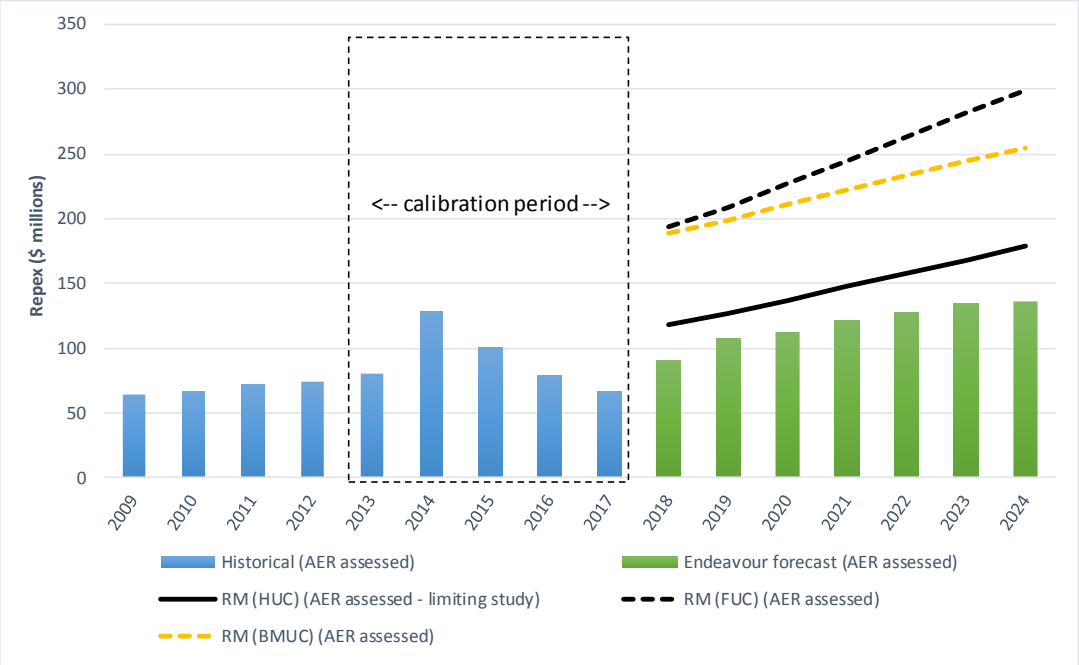

Figure 1 Repex model results – AER studies

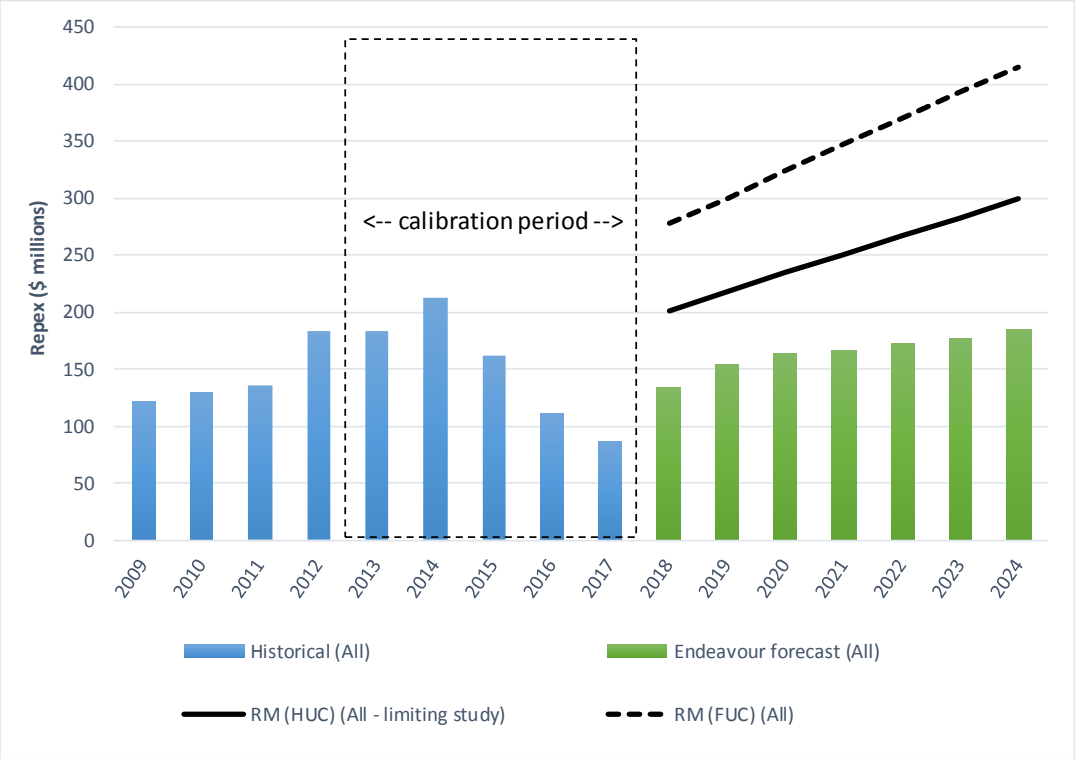

Figure 2 Repex model results – additional studies

3.2 Discussion – AER assessment

The results of this repex model assessment support Endeavour's forecast.

The assessment supports Endeavour's forecast when all of Endeavour's repex is covered by the assessment. For this scenario, Endeavour's repex forecast of $865 million (2019/20 to 2023/24) is below the bound set by the model's alternative estimate of $1,337 million. That is, Endeavour's forecast is 65% of the model's alternative estimate.

The assessment also supports Endeavour's forecast when the assessment only allows for the component of repex that is normally assessed by the AER using the repex model. For this component, Endeavour's forecast of $632 million (2019/20 to 2023/24) is below the bound set by the model's alternative estimate of $789 million. That is, Endeavour's forecast is 80% of the model's alternative estimate.

For both components of repex assessed, the study using Endeavour's historical lives and unit costs produces the lowest forecast and so defines the AER's alternative estimate. It is also important to note that the model is predicting the need for an ongoing increase in replacement volumes, at least over the medium term (i.e. the next 10 to 15 years). This result is driven by the relative age of the network compared to the asset lives, whereby the model considers that the majority of the network has not reached the peak of its replacement cycle, and this is not predicted to occur at least over the next few regulatory periods.

3.3 Discussion – model parameters

In the recent round of DNSP decisions, the AER has mainly applied its assessment using the repex model at the aggregate level as discussed in the section above. However, the model studies and underlying calibrated parameters can also be used to guide where the AER could have concerns with a forecast, and so for example could investigate these matters via a detailed review.

Therefore, we note some of these key matters here, as they may provide some guidance to Endeavour on where key risks in its repex forecast could lie, and so, where it may need to ensure its documents provide adequate support.

In Appendix B , we discuss in more detail the variations in unit costs and lives within asset groups.

Note – this discussion only provides a guide to the significant matters as seen through this repex modelling exercise. Therefore, this should not be taken as an exhaustive list of all matters that must be addressed through Endeavour's repex forecast supporting documents.

Unit costs

The model results provide some support to Endeavour's unit costs.

At first sight, the large increase in the total forecast repex produced by the model study using Endeavour's forecast unit costs (Study 2) compared to the study using its historical unit costs (Study 1) suggests that Endeavour's forecast unit costs are significantly higher, on average, than its historical unit costs. However, this unfavourable result is very much driven by the increase due to the underground cable asset group.

Without this increase due to the underground cable asset group, the study result using forecast unit costs is below the historical unit cost study result. Furthermore, this study result would be below the study using the AER's benchmark unit costs (Study 3), if the underground cable asset group is excluded. This would suggest that Endeavour's forecast unit costs, on average, are broadly in line with its historical unit costs and the AER's benchmarks, if the cable group is excluded.

Our investigations of the underground cable categories suggest the historical unit cost for LV cable replacements, deduced through the model calibration process, is very low ($71,000 per km). This would appear to be anomalously low for a true replacement cost. From our discussions with Endeavour, we understand that this apparent very low historical unit cost is because of the overestimation by Endeavour of historical replacement volumes. As we understand matters, Endeavour estimated historical replacement volumes as a percentage of the volume of historically installed assets. However, this method did not adequately allow for the effects of "gifted" assets, which has been particularly high in the LV cable category.

As such, this discrepancy appears to be largely driven by a problem with the historical reported data and not the forecast data. Allowing for this inconsistency, we consider that the study results provide some support to Endeavour's unit costs, at the aggregate level.

There are other significant differences at the asset group level, but the increases in forecast unit costs in one asset group tend to be offset by lower unit costs in another. As such, this could be partly reflective of allocation issues. Of most note:

- Setting aside the discrepancy noted above, the cable asset group has the most significant increase of the groups usually assessed by the AER compared to the AER benchmark unit costs, particularly in the LV cable category. It is difficult to know what could be driving this difference, as it is not clear from the available information published by the AER what the benchmark unit cost represents. Endeavour had advised that its unit costs include all other works that would be performed during replacement of the cable and other capitalised works associated with its underground network. It could be that these works are allocated to the underground cable "other" asset category by other DNSPs, and therefore, not allowed for in the benchmark. If this is the case then this could be the reason for the apparent significant difference.
- The "other" asset group has the most significant increase of the groups not usually assessed by the AER, where the forecast unit costs are noticeably higher than Endeavour's historical unit costs.

The differences in unit costs will be discussed in more detail in Appendix B.

Asset lives

The model results provide limited support to Endeavour's lives.

The significantly higher model study result, using Endeavour's forecast unit costs (Study 2) compared to Endeavour's forecast repex suggest that, in aggregate, the asset lives that

underpin Endeavour's forecast are longer than its historical lives[6]. However, this favourable finding is also affected by the cable discrepancy noted above. Without this discrepancy, we consider that Endeavour's forecast lives are shorter than its historical lives in aggregate across the asset groups usually assessed by the AER. These lives also appear to be shorter than AER benchmarks lives (although, it is important to note that at this point the AER has not used these benchmark lives as primary parameters in its assessment method).

There are other significant differences at the asset group level, with unfavourable results in most asset groups being offset by the very favourable results in the "Other" asset group. However, in general, the pattern suggests that the lives underpinning Endeavour's forecast are shorter than its recent historical lives, particularly in the asset groups assessed by the AER. Of most note:

- The poles, services, transformers, switchgear and SCADA/protection asset groups have shorter forecast lives compared to their historical lives, causing significant differences between the model and Endeavour's forecast volumes.
- The poles, conductors, cable, services and switchgear asset groups also have shorter forecast lives compared to the AER's benchmark lives, which would cause a significant difference between the model and Endeavour's forecast volume should the AER use these parameters in its assessment (noting, it has not up to this point).
- The SCADA and protection asset group is the most significant of the groups not usually assessed by the AER, whereby the forecast lives are significantly shorter than Endeavour's historical lives.

The differences in asset lives will be discussed in more detail in Appendix B.

3.4 Summary and conclusions

Our application of the AER's assessment method supports Endeavour's forecast. Endeavour's repex forecast is well below the alternative estimate produced by the repex model, ranging between 65% and 80% of the model's alternative estimate depending on the portion of repex covered by the assessment.

Allowing for likely inconsistencies in reported RIN data, the modelling suggests that unit costs in Endeavour's repex forecast, on average, are below its historical unit costs and the AER benchmark unit costs. However, the asset lives that are implied by its forecast, on average, are shorter than the lives implied by its historical replacement levels and AER benchmark lives. This result suggests that the replacement volume forecast implicit in the alternative estimate is below Endeavour's forecast, in aggregate.

[6] That is, given the underlying unit costs assumptions should be the same, any difference in the repex forecast must be due to asset volume differences, and hence difference between historical and forecast asset lives – at the aggregate level.

A Endeavour repex model development

A.1. The AER's repex model

A.1.1. Overview of repex model

The AER repex model is an excel workbook, with a structure, formulas and VBA functions and macros pre-defined in order that it can be used by the AER to develop a network model of a DNSP and use this to prepare repex forecasts. The model is very similar in principle to a model used by the UK energy regulator, Ofgem.

The DNSP's network is constructed within the AER repex model as a series of asset populations. The model uses a probabilistic replacement algorithm to make predictions of replacement needs for this population. The probabilistic replacement algorithm assumes the economic life is normally distributed for any asset population represented within the model. From this, the model predicts future replacement volumes based upon a current age profile for the asset population. This approach is similar to survivor-type models, which are used in various disciplines to model mortality, replacement and reliability.

From an engineering point of view, it is worth noting that although the model relies upon the ages of assets and uses age-based lives, there is no inherent assumption within the model (or its use) that purely age-based replacement strategies are used by the DNSP. The asset life simply reflects the distribution in the life of a population of assets[7] - irrespective of the factors that define the life.

The AER has indicated that it will use this model to make top-down assessments of a DNSP's repex forecast, covering both intra-company and inter-company benchmark forecasts.

A.1.2. AER repex model form, inputs and output

Network specification inputs – asset categories, groups and age profiles

As indicated above, a DNSP's network is defined as a series of distinct asset categories within the repex model. To facilitate analysis and reporting, each asset category is assigned to a smaller set of asset groups. In this regard, a model may use 100 asset categories or more, to improve the accuracy of the analysis, but may use 10 asset groups to provide aggregate forecast for reporting (and benchmarking) purposes.

An age profile must be provided for each asset category used in the model. This age profile represents a snap shot of the ages of the population of assets in that category for the initial

[7] For example, for many assets, the distribution in the life could result from detailed condition and risk analysis to determine the optimal time to proactively replace each asset. For others, it could be simply the age when each asset fails.

year of the model. That is, the age profile is essentially a vector that holds the volume of assets at one-year increments of age.

The AER has predefined the asset categories and asset groups that the DNSP should use as the basis of their models. This will be discussed further in A.2.1.

Planning parameters inputs

The model uses three planning parameters to define the approach it uses to predict future replacement needs:

- The replacement life, which is represented as a normal probability distribution is defined by two parameters: its mean life and the standard deviation of the life.

  It is worth noting that the replacement life actually represents the life that an asset is replaced or the life when a life extension may be used, if this is a feasible option. These parameters, via the asset age profile, allow the model to predict the future volume of assets that will need to be replaced (or have their life extended).

- The third parameter reflects the average replacement unit cost.

  That is, the volume forecast multiplied by the replacement unit cost produces the expenditure forecast.

  Importantly, depending on the asset, the replacement cost parameter may represent an actual replacement cost, or a life extension cost, or in some cases a blended cost that represents both.

Model outputs

The model produces various outputs. These outputs provide various measures of the input age profiles, such as average age, average life, total quantity, and total replacement cost (i.e. quantity x replacement unit cost).

The model also produces forecasts (by year over a 20-year period), including replacement volumes, replacement expenditure, average age, and average remaining life.

These various outputs are provided at the asset category, asset group and total network level. When averages are calculated at the asset group or network level, the model uses a weighted average using the replacement cost of each asset category as the weighting.

A.1.3. Model planning parameter calibration

The calibration of a DNSP's model is the critical process that is applied to produce the intra-company benchmark model.

The calibration process concerns deriving the set of planning parameters that reflects historical replacement outcomes (volumes and expenditure) over the calibration period (e.g. the last 5 years)[8].

[8] It worth noting that a similar process could be applied to calibrate the model to other outcomes, for example the forecast replacement volumes and expenditure.

Assuming the actual volumes and expenditure data is available for each asset category in the model (or a reasonable estimate) then the following process can be used (this process should be in line with the explanation provided in the AER repex model handbook).

Replacement unit cost

The replacement unit cost parameter for each asset category is simply the actual expenditure over the calibration period divided by the actual replacement volume over that period.

Life planning parameters

The two life parameters for each asset category need to be set to ensure the model reflects the volume replaced over the calibration period.

However, the calculation of the two life planning parameters is more complicated because:

- we have two parameters to determine and typically only one variable (the total volume replaced)
- the replacement volume calculated by the model is dependent on the probabilistic replacement algorithm, and therefore, we need to perform a simulation through the model
- the available age profile represents the end point of the calibration period – not the start or mid-point.

Therefore, the calibration of the life parameters is slightly more involved and involves the following two assumptions.

- First, in the absence of better information, the need to determine the standard deviation is removed by making it dependent on the mean. The AER has advised that it will assume that the standard deviation is taken to be the square root of the mean. We have used this assumption here.
- Second, the mean life is set to ensure that the first year of the forecast produced by the model equals an *adjusted* average annual replacement volume during the calibration period. The adjustment is set to reflect the initial growth rate in replacement volume that is forecast by the model. This adjustment is necessary to approximate the change due to using the end-point age profile, rather than the profile that reflects the mid-point of the calibration period[9].

  Given the above, and allowing for the 5-year calibration period, the *adjusted* average annual replacement volume is calculated as:

  (1 + x%)^3.(total volume replaced of asset replaced over calibration period) / 5

  where *x*% is the initial forecast growth rate calculated through the model, and the power of 3 is necessary to advance the growth over 3 years i.e. from the mid-point in the calibration period to the first year of the forecast.

[9] It is worth noting that the actual trend in the historical replacement volumes is typically not used as this may be influenced by incentives associated with the regulatory regime.

A.2. Endeavour repex model

A.2.1. Endeavour repex model structure set up

Setting up the model structure concerns defining the asset categories and asset groups, and populating the Endeavour model with the relevant age profiles.

Repex model asset categories and age profiles

The Endeavour network is constructed within the repex model using the asset classifications and Endeavour's asset age profiles defined in table 5.2.1 of the category analysis RIN. That is, each asset category in the Endeavour repex model corresponds to a line item in table 5.2.1 (i.e. the individual asset categories defined by the AER).

For models used here, Endeavour has provided a set of age profiles in this format that represent its network in 2016/17.

Repex model asset groups

The asset groups in the model have been defined using the asset groups specified by the AER in table 5.2.1 of the category analysis RIN.

A.2.2. Model calibration set up

The calibration of model lives and unit costs is an important element of this modelling exercise. Therefore, for transparency, we explain our method to do this here.

The model calibration set up involves developing the historical data necessary to perform the calibration process (discussed in Section A.1.3). This involves calculating for each asset category in the model (i.e. in table 5.2.1), for the calibration periods (2012/13 to 2016/17):

- historical repex
- historical replacement volumes.

The basis of this data is the historical replacement volumes and expenditure that Endeavour has reported in table 2.2.1 of the category analysis RIN. This data covers the period from 2008/09 to 2016/17 and across categories that are largely equivalent to table 5.2.1.

This data set has been prepared by mapping and consolidating the asset categories and data reported in the various category analysis RIN templates up to 2016/17.

The key steps in preparing the table 2.2.1 data set for the calibration process are as follows:

1 **Escalation** - the table 2.2.1 expenditure has been escalated using CPI data (provided by Endeavour) to place all expenditure on a real June 2019 basis.

2 **2.2.1 to 5.2.1 mapping** - rules have been developed that map the 2.2.1 asset categories (i.e. the asset that was installed) to the 5.2.1 asset categories (i.e. the asset that was retired). In most cases this was considered to be a direct one-to-one mapping using the equivalent asset categories in 2.2.1 and 5.2.1. However, in some circumstances, categories do not map directly or map to multiple categories. In these case, Endeavour advised the mapping rules through discussions.

Of most note here is wood poles, where mapping is required to allocate the staking of poles to correct "unstaked" wood pole categories, and the portion of the replaced wood poles to the correct "staked" and "unstaked" wood pole categories. Endeavour has provided historical information for these purposes. The calculations for this can be seen in the model working files.

A.2.3. Adjustments to data and calibration

Based upon discussions with Endeavour, we have applied a small number of adjustments to the Endeavour RIN data to apply the model and perform the calibration. These adjustments have been applied to improve the modelling accuracy.

The main adjustments are as follows:

- **Towers** - Endeavour has added a "towers" category to the poles asset group. For modelling purposes, similar to wood poles, the volume forecast has been set to reflect the forecast volume of end-of-life replacements and life-extension refurbishments. As such, the unit costs and lives reflect "blended" parameters covering these two activities. It is worth noting that the historical data does not show any repex or volumes for towers, and as such, this adjustments has not affected the historical data.
- **LV cables** - Endeavour has provided data indicating the split between cable length replacements and other replacement activities in its forecast repex and replacement volumes associated with its LV underground network. It has also indicated the split in repex we can use for its historical data.

  Based on this data, we have adjusted the model input data, to use only the cable length volumes for calibrating the asset lives and unit costs. As such, volumes forecast by the model should equate to only the length of replaced cable. However, the unit cost is effectively a "blended" unit cost, that covers both the replaced length of cable and the other activities. A such, the forecast changes in these other activities should change in proportion to forecast length changes.
- **Substation establishments** – In Endeavour's historical and forecast RIN data it had added a number of asset categories in the "other" asset group associated with substation establishments. We understand that these reflect major substation refurbishment/replacements, involving significant replacement of switchgear, transformers, and civil works. The volume counts associates with these categories represent substation volumes.

  To ensure there is no double-counting between repex forecast in these categories and the switchgear and transformer categories, for its forecast, Endeavour has extracted the portion of repex associated with these asset type and re-allocated this to the switchgear and transformer categories. The switchgear and transformer replacement volumes associated with these establishments have also been added to the switchgear and transformer categories.

For historical data, Endeavour has estimate the portion of repex associated with these asset types. We have used these splits to re-allocate historical repex from the establishment categories to the relevant switchgear and transformer categories. We have also used these proportions and forecast data to estimate the volumes of switchgear and transformer replacements that are likely to have occurred via the historical establishments and added these to the historical reported RIN volumes.

- **Distribution substation** - In Endeavour's historical and forecast RIN data it had added a number of asset categories in the "other" asset group associated with distribution substation replacements. Endeavour has advised that these categories will capture repex associated with transformers and switchgear associated with the distribution substations. To more closely align the modelling and assessment of Endeavour's repex with the AER approach, we have assigned these categories to the switchgear transformer asset groups. The unit costs associated with these substations are similar to those associated with related transformer categories in the AER benchmarks. Therefore, we consider that this is a reasonable adjustment, and should not materially affect the assessment.

A.2.4. Model calibration process

For each asset category in the Endeavour model, the calibration process has involved the following steps:

1 Calculate the replacement unit cost as the total historical escalated repex divided by the total historical replacement volumes (using the mapping described above).

2 Determine the mean life that sets the 1st year of the forecast equal to the (unadjusted) average annual historical volume. Excel's goal seek function is used for this purpose.

3 Determine the initial growth rate in the volumes predicted by the model i.e. the growth from the first to the second year of the forecast.

4 Calculate the adjusted average annual historical volume using this growth rate and the formula above.

5 Determine the mean life parameter that sets the 1st year of the forecast equal to the adjusted average annual historical volume. Excel's goal seek function is used for this purpose.

Note on transformers calibration

Endeavour has small populations of transformers in the various transformer asset categories that the AER has defined to capture different transformer types with a rating greater than 15 MVA. There was concern that this could affect the calibration of individual asset lives for each of these asset categories. Therefore, we have grouped these asset categories together to calibrate a single asset life to apply across these asset categories.

B Assessing forecast differences

In Section 3, we used the Endeavour repex model to provide an alternative estimate for Endeavour's repex forecast, using an approach the AER has applied recently.

In this appendix, we use the Endeavour repex model to identify the asset groups that vary the most between the model and Endeavour's forecast, and in turn, to determine how the model's lives and unit costs contribute to this variance.

These findings indicate the asset matters that the AER may have the most concern with should it use the repex model for these purposes.

In this appendix, we also provide some commentary on the possible reasons for some of the most significant differences, based on discussions with Endeavour during our various meetings. This commentary is provided to aid in highlighting matters that could be relevant to the engineering review that the AER could conduct and its relevance to the repex model results. It important to stress however that we have not conducted a detailed review of these matters, and therefore, the commentary provided here should not be taken as an endorsement or otherwise of the accuracy, prudency or efficiency of the matters raised by Endeavour.

Note on terminology in discussion below

When discussing differences in asset group lives and unit costs, the asset group life or unit cost implied by the discussion is a weighted average across the relevant asset categories calculated through the model. The weightings applied to unit costs are the forecast volumes and the weightings applied to volumes are the forecast unit costs.

We have used a materiality bound of $10 million to identify the asset categories that we consider differences in unit costs or lives are significant enough to highlight below.

It is important to note that the lives we discuss in this section are those associated with producing forecasts using the repex model (i.e. the mean population life, which forms an input parameters of the model). These lives could be different to the lives used by Endeavour to produce its forecast or for other internal purposes, which should be dependent on the underlying forecasting methodology or purpose. Importantly, the lives discussed here are very unlikely to represent the average age of the assets at the time of their replacement for the assets that either have been replaced over the calibration period or are forecast to be replaced over the next regulatory period. Therefore, Endeavour, the AER or the AER's advisors should take care when making inferences between these two parameters.

Finally, we have developed the benchmark unit costs and lives we discuss below from AER repex model files that the AER has published with recent decisions. These may not represent its latest benchmarks or those it could subsequently develop to use to assess the NSW DNSPs.

B.1. Asset groups normally assessed by the AER

B.1.1. Poles

Endeavour's repex forecast for the poles asset group is the most significant of the asset groups normally assessed by the AER, accounting for $159 million (18%) of Endeavour's repex forecast and 25% of the repex in the asset groups normally assessed by the AER.

Endeavour's repex forecast for the poles asset group is $3 million higher than the forecast predicted by the repex model's alternative estimate. This marginal increase is driven by shorter forecast lives compared to Endeavour's historical lives.

In aggregate, Endeavour's forecast unit costs are lower than its historical unit costs. These forecast unit costs are higher than the AER benchmarks used in our studies. However, some caution should be applied to this finding on the AER's benchmarks. We do not have an AER benchmark for towers, and therefore, we have used the 132 kV steel pole benchmark for this study. This unit cost is likely to be significantly lower than the tower unit cost. If the tower category is removed from this study then the Endeavour poles unit costs are more in line with the AER benchmarks.

In aggregate, Endeavour's forecast lives are shorter than its historical lives and the AER benchmarks.

B.1.2. Switchgear

Endeavour's repex forecast for the switchgear asset group is the second most significant of the asset groups normally assessed by the AER, accounting for $114 million (13%) of Endeavour's repex forecast and 18% of the repex in the asset groups normally assessed by the AER.

Endeavour's repex forecast for the switchgear asset group is $23 million higher than the forecast predicted by the repex model's alternative estimate. This increase is primarily driven by unfavourable lives.

In aggregate, Endeavour's forecast unit costs are in line with its historical unit costs and less than the AER benchmarks. The are no asset categories with materially unfavourable unit costs.

In aggregate, Endeavour's forecast lives are shorter than its historical lives and the AER benchmarks.

B.1.3. Transformers

Endeavour's repex forecast for the transformers asset group accounts for $107 million (12%) of Endeavour's repex forecast and 17% of the repex in the asset groups normally assessed by the AER.

Endeavour's repex forecast for the transformer asset group is $25 million less than the forecast predicted by the repex model's alternative estimate. This reduction is driven by favourable forecast unit costs, which offset the effects of unfavourable asset lives.

In aggregate, Endeavour's forecast unit costs are lower than its historical unit costs and the AER benchmarks. However, Endeavour's forecast lives are shorter than its historical lives and the AER benchmarks.

With regard to the larger power transformers, the model lives of these asset categories can be more sensitive to the volume of replacements over the short term because of the smaller population size. It is also important to stress that the lives quoted above are population lives, calibrated to achieve the forecast outcome. They are unlikely to represent the lives of the actual assets that will be replaced, which could be much older.

We note that Endeavour advised during our meetings that these replacements have been determined from extensive condition information associated with these transformers. We have not reviewed this data, but would expect that this information would need to be assessed through the AER's engineering review to support the appropriateness of the lives of the assets forecast to be replaced.

B.1.1. Overhead conductors

Endeavour's repex forecast for the overhead conductor asset group accounts for $103 million (12%) of Endeavour's repex forecast and 16% of the repex in the asset groups normally assessed by the AER.

Endeavour's repex forecast for the overhead conductor asset group is $168 million lower than the forecast predicted by the repex model's alternative estimate. It is noted that this very favourable result is the primary reason for the scale of the overall favourable result for the asset groups normally assessed by the AER.

This large reduction is driven by favourable unit costs. In aggregate, Endeavour's forecast unit costs are lower than its historical unit costs and the AER benchmarks.

In aggregate, Endeavour's forecast lives are similar to its historical lives, but they are shorter than the AER benchmarks.

B.1.1. Underground cables

Endeavour's repex forecast for the underground cable asset group accounts for $85 million (10%) of Endeavour's repex forecast and 13% of the repex in the asset groups normally assessed by the AER.

Endeavour's repex forecast for the underground cable asset group is $8 million higher than the forecast predicted by the repex model's alternative estimate. This increase is driven by forecast unit costs, which are significantly higher than historical unit costs.

In aggregate, Endeavour's forecast unit costs are significantly higher than its historical unit costs and higher than the AER benchmarks.

In aggregate, Endeavour's forecast lives are longer than its historical lives, but shorter than the AER benchmarks.

The most significant asset category is the <=1 kV cable (LV cable), which has a forecast unit cost that represents an approximate 12-fold increase over its historical cost. Notably, the

forecast unit cost is higher than the AER benchmark cost, but the historical unit cost is much lower than the AER benchmark.

However, the LV cable replacements unit cost is very low ($71,000 per km). This would appear to be anomalously low for a true per unit length replacement cost for LV underground cable in urban areas.

From our discussions with Endeavour, we understand that historical reporting of replacement volumes in this category would have significantly overstated the volume of replaced LV cable due to the effect of "gifted" asset on the methodology Endeavour used to estimate the replacement volumes. Endeavour advised that historical volumes were estimated by assuming a fixed percentage of the total installed volume in a historical year was due to replacement. However, particularly for LV cables, a large amount of the installed volume were "gifted" assets, and as such, this assumed percentage is likely to have significantly overstated the true replacement volume in this asset category.

Therefore, this discrepancy appears to be largely driven by a problem with the historical reported data and not the forecast data. Allowing for this inconsistency, we consider that the historical unit costs, on a true per km basis, are likely to much closer to the forecast unit costs.

Setting aside the discrepancy note above, the forecast unit cost for the LV cable replacement is still significantly higher than the AER benchmark. It is difficult to know what could be driving this difference, as it is not clear from available information what the benchmark unit cost represents. Endeavour had advised that its unit costs includes all other works that would be performed during replacement of the cable and other capitalised works associated with its LV underground network. Data provided by Endeavour suggests that this could account for approximately 50% of the unit cost. It could be that these works are allocated to the underground cable "other" asset category by other DNSPs, and therefore, not allowed for in the AER benchmark. If this is the case then this could be the reason for the apparent significant difference.

B.1.2. Services

Endeavour's repex forecast for the services asset group is the least significant of the asset groups normally assessed by the AER, accounting for $64 million (7%) of Endeavour's repex forecast and 10% of the repex in the asset groups normally assessed by the AER.

Endeavour's repex forecast for the services asset group is $1 million higher than the forecast predicted by the repex model's alternative estimate. This marginal increase is driven by Endeavour's forecast lives being shorter than its historical lives.

There is only one asset category being modelled in the services asset category, covering LV residential service connections of a simple type. Endeavour's forecast unit cost is lower than its historical unit cost and the AER benchmark.

However, Endeavour's forecast life for this asset category is shorter than its historical life and significantly shorter than the AER benchmark.

Endeavour has advised through our meetings that its volume forecast for this asset category has been prepared from recent service condition and failure data and is in accordance with safety obligations defined by the NSW Department of Energy with regard to the management of overhead services.

B.2. Asset groups not normally assessed by the AER

B.2.1. Other

Endeavour's repex forecast for the "other" asset group is the largest of the asset groups not normally assessed by the AER, accounting for $171 million (20%) of Endeavour's repex forecast and 73% of the repex in the asset groups not normally assessed by the AER. In the repex model, this asset group largely covers substation establishment projects.

Endeavour's repex forecast for the "other" asset group is $172 million lower than the forecast predicted by the repex model's alternative estimate. This reduction is driven by the effect of very favourable lives, which offset the effect of unfavourable unit costs.

In aggregate, Endeavour's forecast unit costs are higher than its historical unit costs.

In aggregate, Endeavour's forecast lives are significantly longer than its historical lives (62 years, on average, compared to 54 years, on average).

B.2.2. SCADA, protection and control

Endeavour's repex forecast for the SCADA, protection and control asset group accounts for $48 million (6%) of Endeavour's repex forecast and 21% of the repex in the asset groups not normally assessed by the AER.

Endeavour's repex forecast for the SCADA, protection and control asset group is $75 million lower than the forecast predicted by the repex model's alternative estimate. This reduction is driven by very favourable unit costs, which offset the effects of unfavourable lives.

In aggregate, Endeavour's forecast unit costs are much lower than its historical unit costs.

In aggregate, Endeavour's forecast lives are much shorter than its historical lives – although, the effects of these unfavourable results are not sufficient to offset the more favourable effects of the forecast unit costs.

B.2.1. Public lighting

Endeavour's repex forecast for the public lighting asset group only accounts for $15 million or 2% of Endeavour's repex forecast, which is only 6% of the repex in the asset groups not normally assessed by the AER.

Endeavour's repex forecast for the public lighting asset group is $68 million lower than the forecast predicted by the repex model's alternative estimate. This reduction is driven by both favourable unit costs and lives.

B.3. Material parameters differences

The two tables below summarise the asset categories where differences in unit costs and lives are most materially on the favourable and unfavourable differences in the repex forecasts discussed above.

		unit cost ($'000)		
group	asset category	forecast	historical	AER benchmark
Poles	> 1 kV & < = 11 kV; Wood	6.9	8.5	4.5
Poles	Other - Towers	211.7	211.7	18.9
OH conductors	> 1 kV & < = 11 kV	75.0	147.2	79.1
OH conductors	> 22 kV & < = 66 kV	250.0	641.5	220.1
OH conductors	> 66 kV & < = 132 kV	250.0	1267.5	322.7
UG cables	< = 1 kV	862.8	70.9	243.8
Services	< = 11 kV ; Residential ; Simple Type	0.7	1.0	1.4
Transformers	Pole Mounted ; < = 22kV ; > 60 kVA and < = 600 kVA ; Multiple Phase	11.7	20.4	27.2
Transformers	Kiosk Mounted ; < = 22kV ; > 60 kVA and < = 600 kVA ; Multiple Phase	11.7	62.6	39.4
Transformers	Kiosk Mounted ; < = 22kV ; > 600 kVA ; Multiple Phase	11.6	95.4	76.9
Transformers	Ground Outdoor / Indoor Chamber Mounted; > = 22 kV & < = 33 kV ; < = 15 MVA	1702.8	4007.0	411.7
Transformers	Ground Outdoor / Indoor Chamber Mounted; > = 22 kV & < = 33 kV ; > 15 MVA and < = 40 MVA	1685.2	2647.5	2035.4
Transformers	Ground Outdoor / Indoor Chamber Mounted; > 66 kV & < = 132 kV ; > 100 MVA	1930.7	1930.7	4710.2
Public lighting	Other - Streetlights	3.5	8.7	na
SCADA & protection	Field Devices	5.0	58.5	na
SCADA & protection	Communications Network Assets	31.9	993.4	na
SCADA & protection	Communications Linear Assets	55.0	248.2	na
Other	Substation Establishment: Major Indoor	23500.0	14685.9	na
Other	Substation Establishment: Medium Indoor	19500.0	7468.6	na
Other	Substation Establishment: Type B	40500.0	12526.2	na
Switchgear	11/22 - kiosk and pad mount <=500kVA Substn	25.9	20.8	39.4
Switchgear	11/22 - kiosk and pad mount >500kVA Substn	33.6	26.9	76.9

group	asset category	Life (years) forecast	historical	AER benchmark
Poles	Staking of a wooden pole	25.8	21.0	21.7
Poles	> 1 kV & < = 11 kV; Wood	48.8	57.2	69.8
Poles	> 1 kV & < = 11 kV; Concrete	26.2	19.6	47.7
Poles	Other - Towers	71.0	94.2	58.0
OH conductors	< = 1 kV	72.5	67.9	75.3
OH conductors	> 1 kV & < = 11 kV	65.8	62.6	75.9
OH conductors	> 22 kV & < = 66 kV	58.2	60.4	86.2
UG cables	< = 1 kV	62.2	50.5	67.5
UG cables	> 1 kV & < = 11 kV	69.3	42.8	68.0
UG cables	> 11 kV & < = 22 kV	40.6	20.7	61.5
UG cables	> 22 kV & < = 33 kV	73.4	44.1	67.9
UG cables	> 66 kV & < = 132 kV	81.4	49.1	46.3
Services	< = 11 kV ; Residential ; Simple Type	35.8	40.2	58.0
Transformers	Pole Mounted ; < = 22kV ; > 60 kVA and < = 600 kVA ; Multiple Phase	44.3	56.2	53.1
Transformers	Ground Outdoor / Indoor Chamber Mounted; > = 22 kV & < = 33 kV ; > 15 MVA and < = 40 MVA	51.9	55.3	48.2
Transformers	Ground Outdoor / Indoor Chamber Mounted; > 66 kV & < = 132 kV ; < = 100 MVA	51.9	55.3	55.3
Switchgear	< = 11 kV ; Switch	51.1	46.9	64.3
Switchgear	< = 11 kV ; Circuit Breaker	41.2	52.4	54.6
Public lighting	Other - Streetlights	56.9	51.5	na
SCADA & protection	Communications Site Infrastructure	4.7	30.6	na
SCADA & protection	Communications Linear Assets	10.2	55.6	na
Other	Substation Establishment: Major Indoor	53.8	46.3	na
Other	Substation Establishment: Major Outdoor	66.1	57.4	na
Other	Substation Establishment: Medium Indoor	49.8	39.6	na
Other	Substation Establishment: Medium Outdoor	64.9	57.2	na
Other	Substation Establishment: Small Indoor	27.6	14.8	na
Other	Substation Establishment: Type A	55.6	45.0	na
Other	Substation Establishment: Type B	71.0	61.6	na
Switchgear	11/22 - kiosk and pad mount <=500kVA Substn	41.6	46.3	50.5