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Report

Assessment of Ageing Coal-Fired Generation Reliability

Australian Energy Market Operator Limited, for publication

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1 Introduction

AEP Elical has been appointed by AEMO to provide support through the development of a '**Projection of Thermal Generation Reliability and Forced Outage Rates (FOR)**' report, that may be published on the AEMO website and may be used as an input by AEMO's Forecasting and Operations teams.

Thermal generation stations play a key role in providing a secure supply of electricity to the National Electricity Market (NEM). As these stations draw towards their closure dates, it is important to form an educated view on their future performance and ability to continue to provide a secure supply.

Traditionally for base load power plant, AEMO has forecast future performance based on historical performance. It acknowledges that this is not always the case and that owners of the plants will strive to maintain a level of reliability and availability of plant consistent with their business' economic models, with the market providing appropriate opportunity for compensation.

Changing market conditions will encourage some plants to move away from the traditional base load operation to load cycling. Such changes to the operating regime will result in a revision to maintenance planning. Planned outages may become more frequent; metal fatigue and creep on high pressure and temperature components will be accelerated; and asset management plans may be required to reflect the need for greater levels of capital and operational expenditure. Depending on the financial returns to the owners, decisions in this regard may have a noticeable impact on a plant's outage rates and reliability.

There is a need, therefore, for AEMO to consider each of the sixteen coal power stations in the NEM on their individual merits, where they sit in the network with the growth of renewable energy projects in the energy system as well as on a technology – black coal and brown coal – state and fleet basis as well as the historical performance and trends.

To assist AEMO in this consideration, AEP Elical has been commissioned to provide forward-looking projections for:

- Planned outage (maintenance) rates and either of the following:
    - Full forced outage rates (**FOR**), partial forced outage rates (EPOH) and average partial derating;
    - Full forced outage rates and partial forced outage rates assuming the average partial derating will not change; and
    - Effective forced outage rates (**EFOR**) comprising the sum of **FOR** and **EPOR** (which is the product of EPOH and average partial derating).

AEP Elical has elected to provide forward looking projections for **FOR**, **EPOR** and **EFOR**.

2 Methodology Overview

The approach adopted by AEP Elical, for predicting Forced Outage Rates (**FOR**) and Effective Forced Outage Rates (**EFOR**) for the coal fired power plant in the NEM, has been through a model that bases future performance on historical data modified by station specific and generic changes '**growth factors'** [1]. This analysis considers the mode of operation and maintenance of the aging assets, particularly whether specific maintenance actions or capital investments could influence the starting point for future projections. The analysis considers two scenarios that comprise business as usual and a lower level of coal fired plant generation caused by an increase in variable renewable generation.

The coal fired stations in the NEM are tabulated below.

TABLE 2-1: COAL FIRED GENERATOR IN THE NEM

Black Coal Fired Power Plant	State	Age (Years)
Bayswater	NSW	36
Eraring A	NSW	36
Liddell	NSW	47
Mt Piper	NSW	26
Vales Point B	NSW	41
Callide B	QLD	30
Callide C	QLD	18
Gladstone	QLD	43
Kogan Creek	QLD	12
Millmerran	QLD	17
Stanwell	QLD	24
Tarong	QLD	34
Tarong North	QLD	16
Brown Coal Fired Power Plant	**State**	**Age (Years)**
Loy Yang A	VIC	33
Loy Yang B	VIC	24
Yallourn W	VIC	39

[1] The phrase 'growth factors' is used for brevity: growth factors can include shrinkage as well as growth

The forecasts developed are based on AEP Elical's knowledge of the operation of some of these assets and assets of a similar nature, as well as through discussions with representatives from most of the stations.

The analysis assumes that the plants are being operated on the fuel for which they were originally designed. For fuel availability, economic or environmental reasons, an owner may attempt to operate on an alternative fuel with a different operating range. Such an action can cause changes to a forecast model, however, there was no evidence to show that this was a material concern for any of the assets considered in this study.

The performance of plants will depend on the owners' investment in refurbishment, strategic spares and planned maintenance. This will also be influenced by expectations of market revenue. While with enough incentive, almost any reasonable level of reliability is achievable this was not considered explicitly.

Projections for **FOR** were predicated on the historical data supplied by AEMO but modified by excluding, at a station level, a number of high impact low probability (**HILP**) events. The impact of these events was incorporated at a state or fleet level.

The planned closure date of each station was considered. For plants approaching their end of life, planned maintenance outages generally continue as normal until the last 4 or so years of operation after which AEP Elical expects maintenance expenditure will be reduced to meet statutory obligations only. This is expected to result in increases in **FOR** and **EPOR** values in the final years of operation.

3 Review of Outage Data

A review of documents provided by AEMO was undertaken. The primary documents comprised:

- Guidebook for Forced Outage Data Recording
- Coal Outage Events with Reasons (Excel), FY2016 to end March 2020, updated to include partial outage data derating values, **'Outage Events'**.
- Outage Data for Coal Units (Excel), FY2011to end March 2020, with weighted values for full outage rates (**FOR**), partial outage hours (POH), and partial outage deratings, '**Outage Data'**.

AEP Elical used the **Outage Data** file to derive effective partial outage rates (**EPOR**) and effective forced outage rates (**EFOR**) which are the sum of the **FOR** and **EPOR**.

While the data in the **Outage Events** file correlated fairly well with the summary data in the **Outage Data** file, this events data was used to identify causes of outages, not to quantify the overall outage rates as these were taken to be the values in the **Outage Data** file. The identification of causes was constrained as the causes for outages have only been provided as free format text box descriptions, but AEP Elical used its experience and judgement as appropriate to interpret the phrases in the text boxes.

3.1 Outage Categories

Details of forced and partial outages as supplied to AEMO from the stations from FY2016 to March 2020 were studied and analysed in order to understand and quantify the causes.

The outage data provided by AEMO included the number of hours units at each station suffered full outages (i.e. a unit was offline) and partial outages (i.e. the number of hours a unit was operating at an unplanned reduced load). The outage causes were reviewed by the AEP Elical team and categorised as follows:

TABLE 3-1: OUTAGE CATEGORY BREAKDOWN

Category Number	Description	Explanation
1	Fuel supply	In particular issues of coal quality and supply plus transfer to bunkers
2	Fuel system	Includes plant and equipment for processing and transferring coal from bunkers to the furnace
3	Boiler	Including furnace, water walls, superheaters, reheaters, economisers and all headers and pressure parts plus main steam lines

Category Number	Description	Explanation
4	Flue gas and ash systems	Includes FD and ID fans, air heaters, bag filters, precipitators, fly ash and bottom ash handling plant, stack (but not emissions constraints)
5	Steam turbine	HP/IP/LP turbine plant plus auxiliaries
6	Condenser and feed heating system	Condensers, HP/IP/LP heaters, deaerators, boiler feed pumps, plus main cooling water system and water treatment plant
7	Generator	Generator plant including excitation and generator auxiliaries
8	Transformers	Generator and unit transformers
9	C&I systems	Distributed control systems, plant controls and instrumentation, data processing, logic controllers
10	Auxiliary mechanical plant	Other mechanical plant not covered elsewhere including compressed air, auxiliary cooling water plant and fire protection systems
11	Auxiliary electrical plant	Other electrical plant not covered elsewhere including batteries, switchgear, secure and emergency supply systems, diesel generator plant
12	Human factors	Human error
13	Other / unspecified	A bucket category for outages that could not be categorised elsewhere
14	Environmental emissions	Aqueous and gaseous excursions to environmental limits

There were approximately 480 forced outage entries and 7630 partial outage / derating entries. While some entries were straightforward to categorise, there were many that required a judgement regarding the primary cause of the outage / derating and some stations used a 'Null' descriptor. The Nulls were initially categorised as 'Other / unspecified' but in some instances for forced outages, station representatives provided more data that allowed better classification.

The causes of forced outages and of partial outages / deratings are very different as shown in **Figure 3-1** and **Figure 3-2** below.

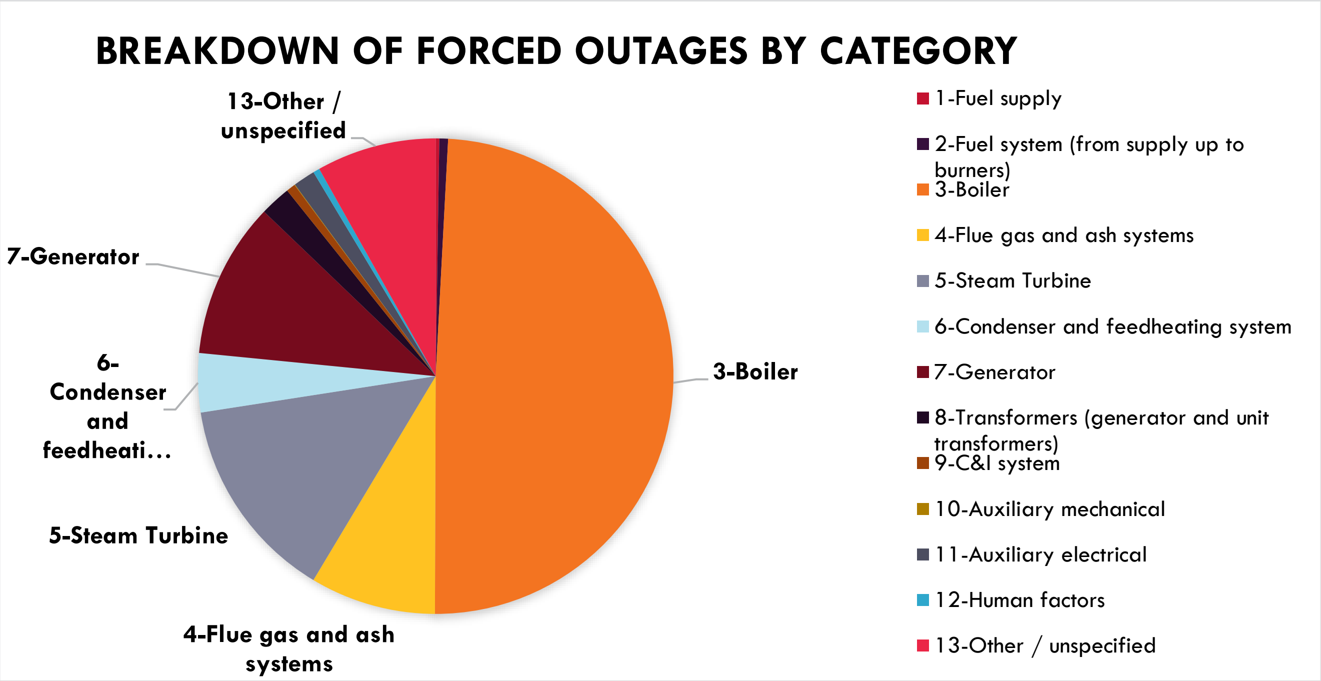


FIGURE 3-1: BREAKDOWN OF FORCED OUTAGE RATE BY CATEGORY

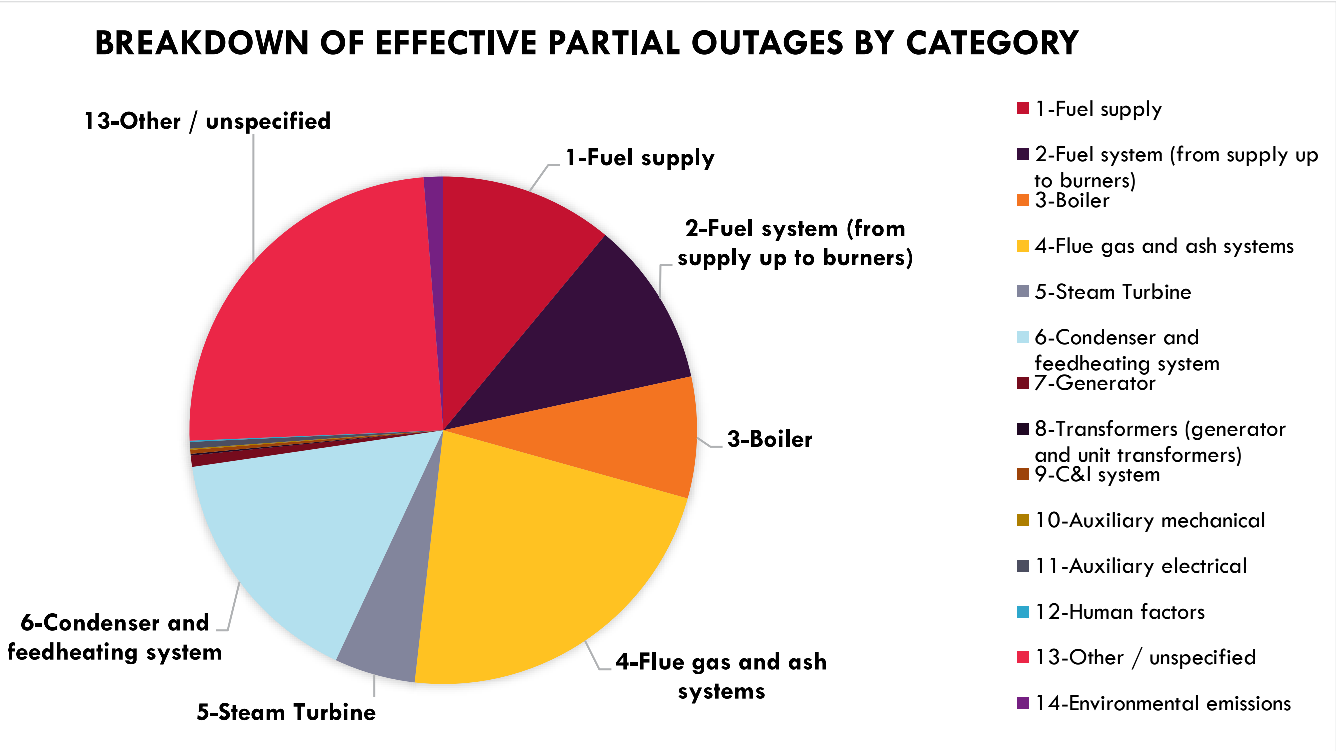


FIGURE 3-2: BREAKDOWN OF PARTIAL OUTAGES BY CATEGORY

Figure 3-1 and **Figure 3-2** above show that the primary causes for forced outages are quite different from the causes for partial outages / deratings. The most significant cause of forced outages is boiler problems, in particular steam leaks from failed tubing, with significant contributions from steam turbine and generator issues. However, a major part of the forced outage losses from turbine and generator outages are caused by a small number of high impact low probability (**HILP**) events as discussed in the next section. Excluding these the condensate and feedheating and flue gas and ash categories become more significant. For partial outages / deratings boiler issues are a secondary category with the major causes being the condensate and feedheating and flue gas and ash categories plus fuel supply and fuel system losses which cause a negligible proportion of the forced outages.

3.2 Major (**HILP**) Events

The **Outage Events** file included a number of high impact low probability (**HILP**) events that have a large impact on the **FOR** of the stations in the years that they occur. Therefore, AEP Elical has identified and quantified these **HILP** events as a separate category.

For the period from FY2016 onwards the following events have been categorised as **HILP** events

TABLE 3-2: LIST OF **HILP** EVENTS

Event	Financial Year of Event	Forced Outage Hours	FOR Impact in Year
Steam turbine failure	FY2017	1007	2.76%
Steam turbine failure	FY2017	631	2.28%
Steam turbine failure	FY2018	4227	13.57%
Generator failure	FY2018	583	1.85%
Generator transformer failure	FY2018	387	2.44%
Steam turbine failure	FY2019	1865	7.73%
Arc flash incident causing fatality	FY2019	1613	6.51%
Generator failure	FY2020	4236	10.93%
Generator transformer failure	FY2020	1153	13.93%

3.3 Allocation of Major Events

As shown in Table 3-2, **HILP** events are associated with the turbines, generators, and major transformers plus electrical switchgear. These types of event can occur in any station, regardless of the fuel type and the frequency of events by year is also variable. Given this uncertainty, AEP Elical considers it reasonable to:

- Average the impact of **HILP** events across the years for which there is data
- Average the impact of **HILP** events across stations

The following table shows the impact of **HILP** events when averaged by state and across the fleet of coal-fired stations.

TABLE 3-3: IMPACT OF **HILP** EVENTS ON **FOR**, FY2016 TO MARCH 2020

Grouping	Impact on FOR
Fleet	1.16%
NSW	1.18%
QLD	0.35%
VIC	2.46%

3.4 Derivation of Start Point for Forward Predictions

In order to produce a start point for its forward projections, AEP Elical has isolated the **HILP** events from the individual financial year summaries of **FOR**. It has then determined a four- year [2]rolling average of **FOR** by state and fleet.

It then adjusted the 4-year **FOR** average by the statewide aggregated average of the impact of **HILP** events over the past (approximately) five years. This removes the year on year variability caused by these low probability events. This results in the adjusted **FOR** as shown in **Table 3-4** below

TABLE 3-4: FOR STARTING POINTS FOR FORWARD PROJECTIONS

Station / State	4-year rolling average **FOR** all data, for 2020	4-year rolling average **FOR** excluding **HILP** events, for 2020	**HILP** event factor	Adjusted 4-year rolling average **FOR**, for 2020
Fleet	5.77%	4.70%	1.16%	5.86%
VIC	7.74%	5.58%	2.46%	8.04%
NSW	6.92%	5.76%	1.18%	6.95%
QLD	3.15%	2.83%	0.35%	3.18%

The historical **FOR** for the fleet and states are shown in the figures below.

[2] A four year rolling average was selected as this aligns with the four yearly maintenance cycle that is typical for much of the fleet.

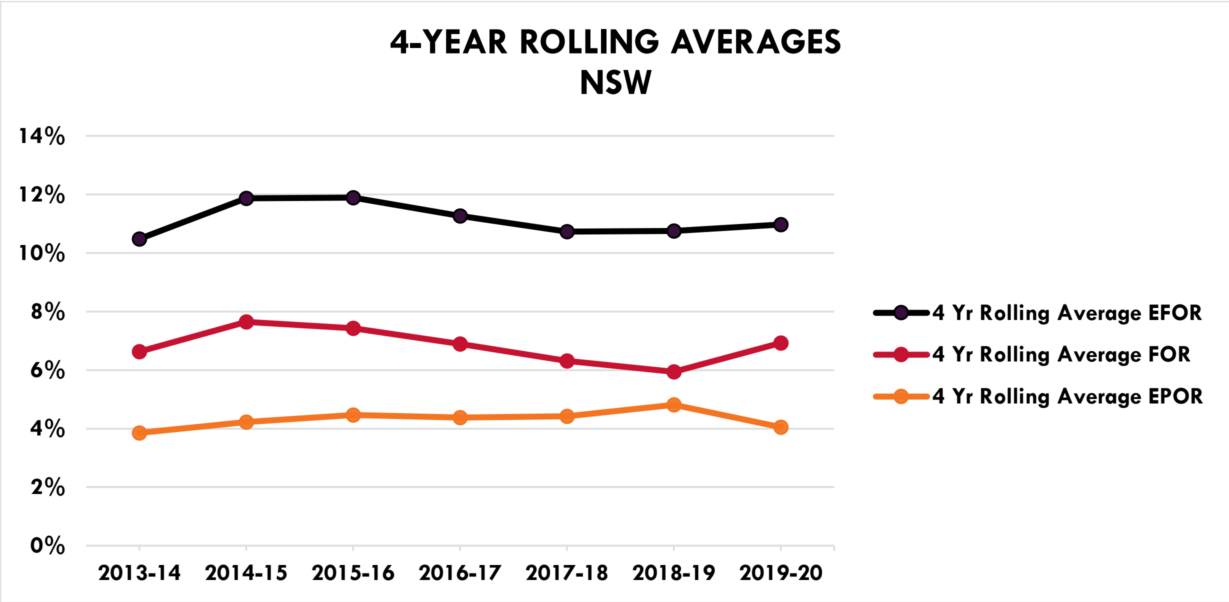


FIGURE 3-3: NSW 4-YEAR ROLLING AVERAGES

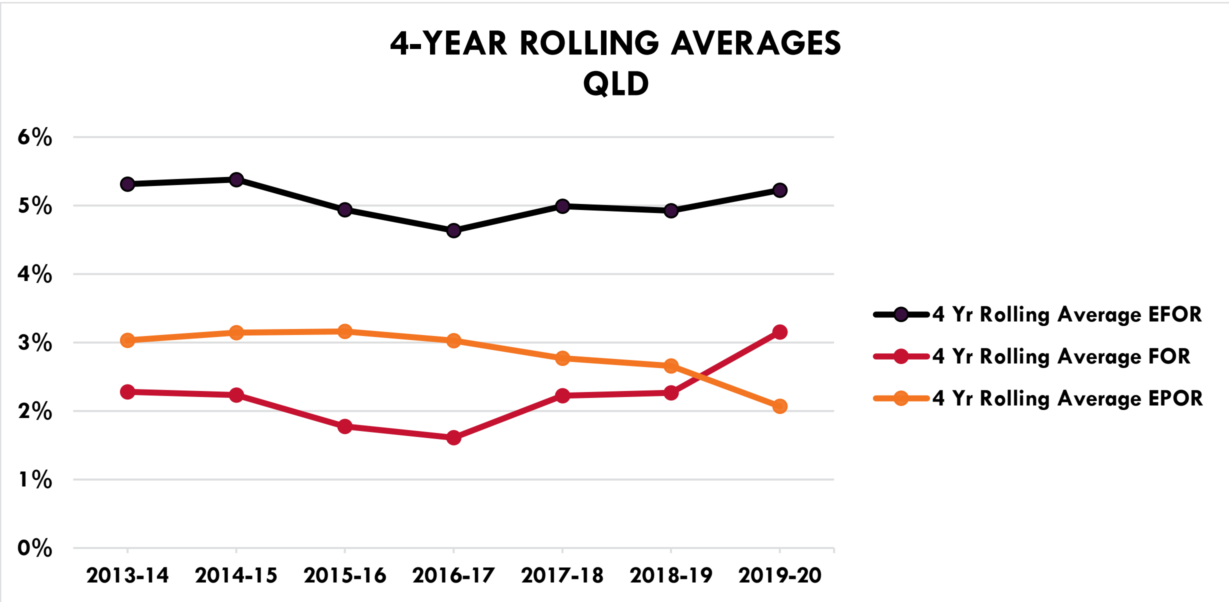


FIGURE 3-4: QLD 4-YEAR ROLLING AVERAGES

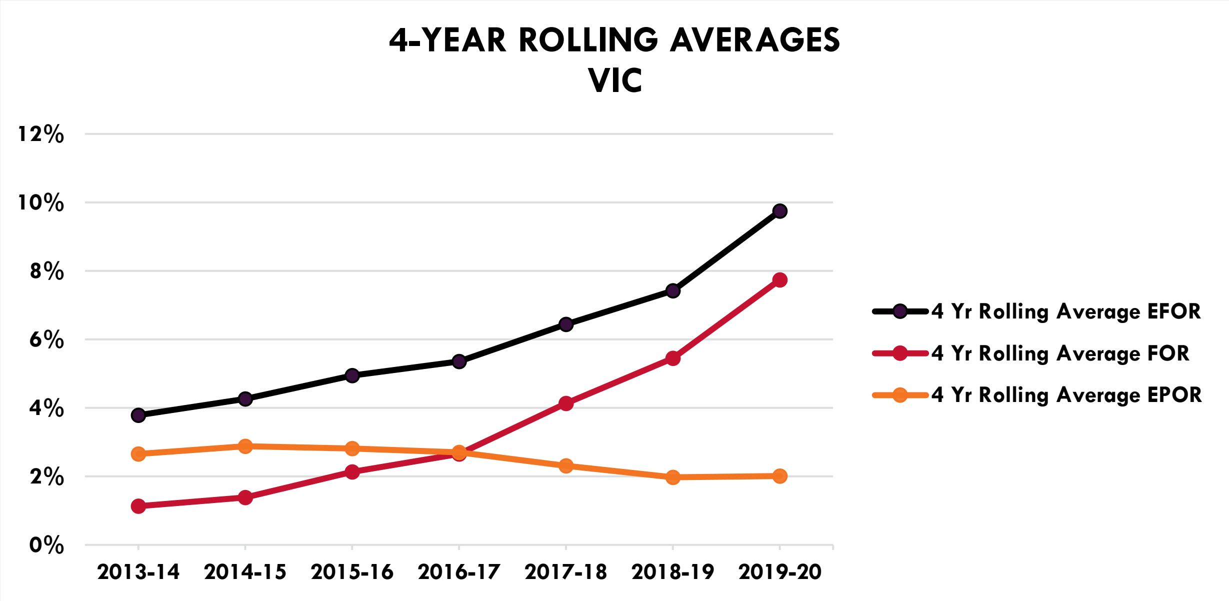


FIGURE 3-5: VIC 4-YEAR ROLLING AVERAGES

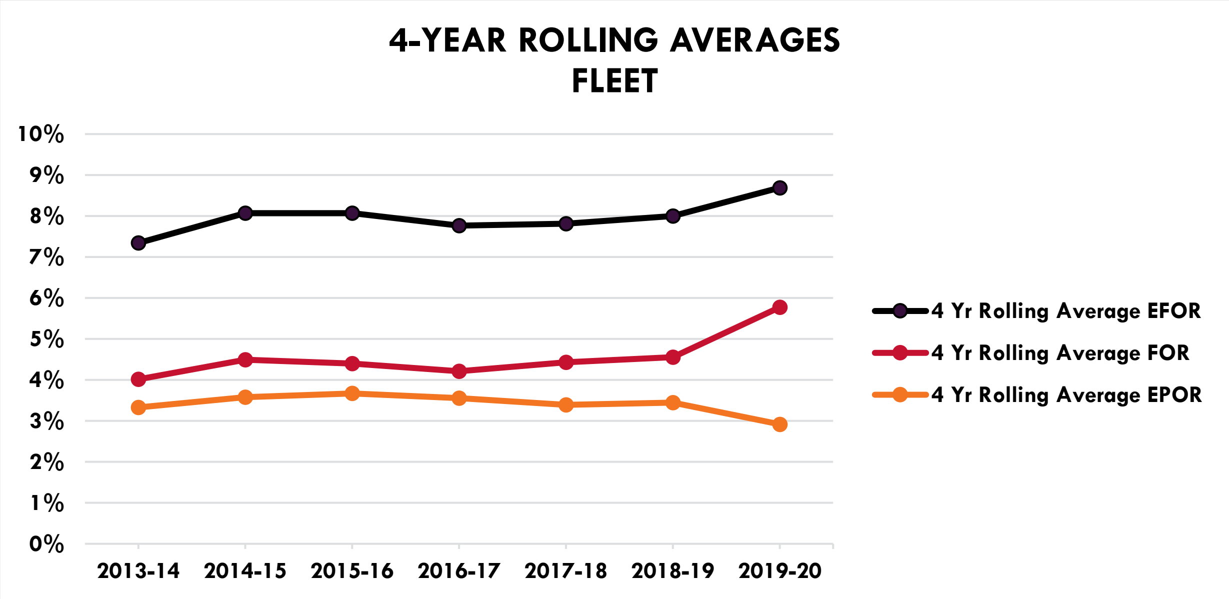


FIGURE 3-6: FLEET 4-YEAR ROLLING AVERAGES

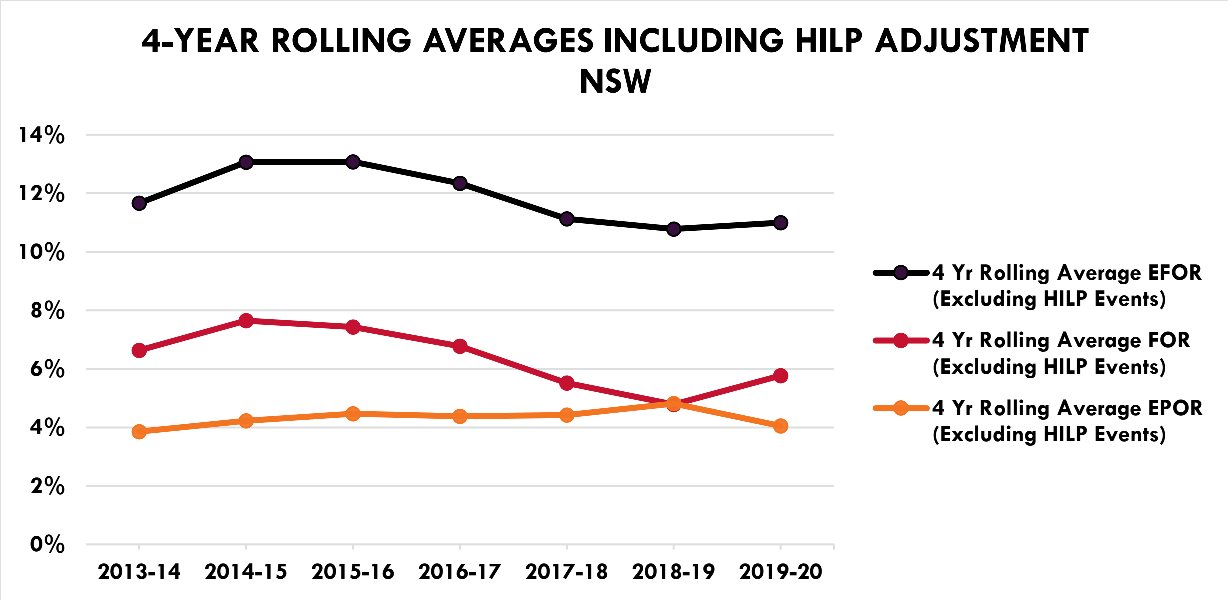


FIGURE 3-7: NSW 4-YEAR ROLLING AVERAGES INCLUDING HILP ADJUSTMENT

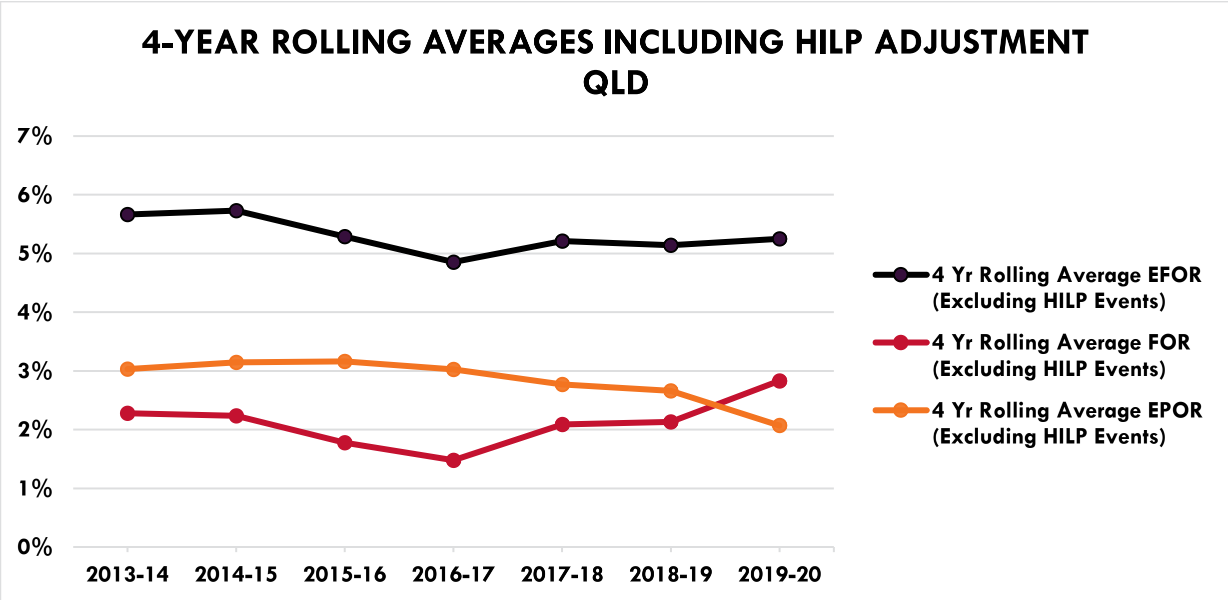


FIGURE 3-8: QLD 4-YEAR ROLLING AVERAGES INCLUDING HILP ADJUSTMENT

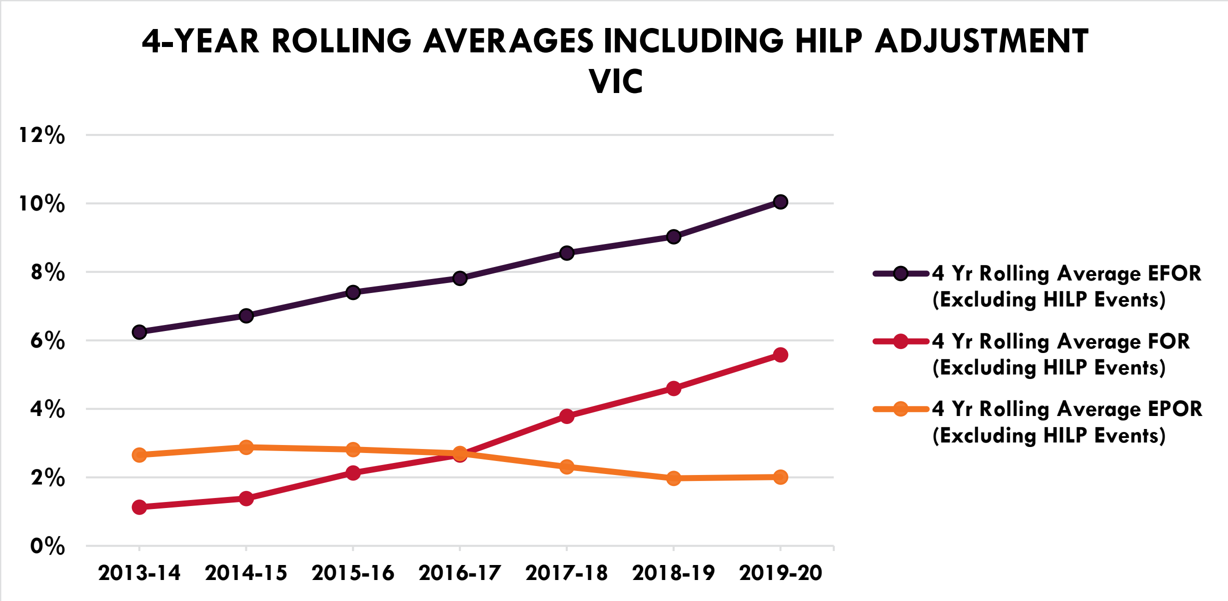


FIGURE 3-9: VIC 4-YEAR ROLLING AVERAGES INCLUDING HILP ADJUSTMENT

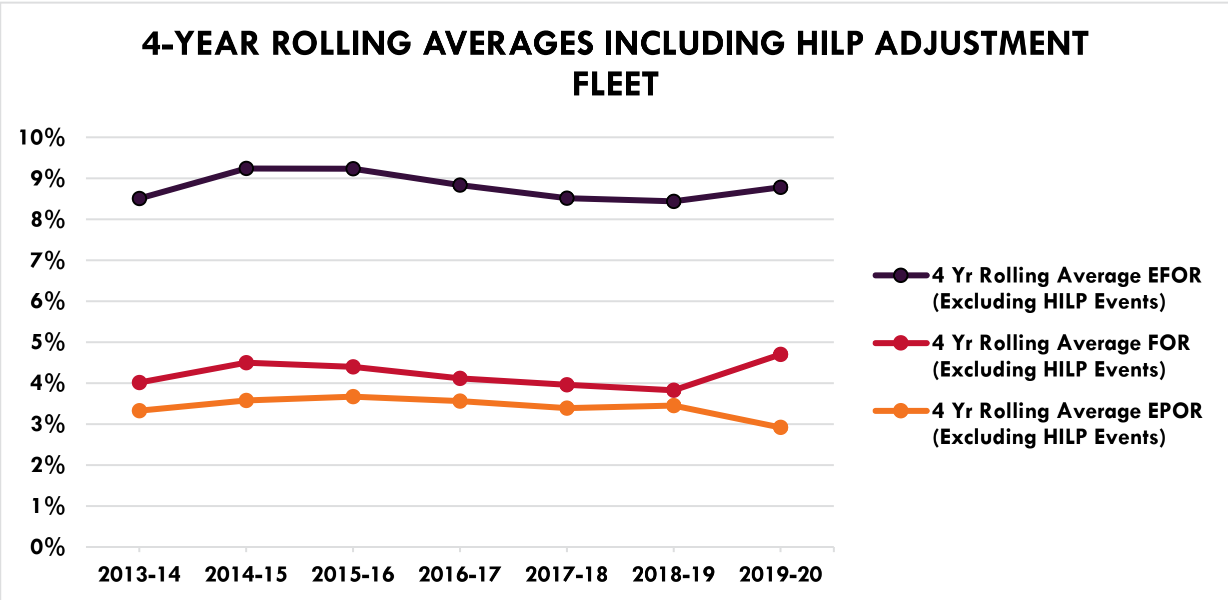


FIGURE 3-10: FLEET 4-YEAR ROLLING AVERAGES INCLUDING HILP ADJUSTMENT

Note that the figures include the rolling averages for **EPOR** and **EFOR** as well as for **FOR**. There is no impact of **HILP** events on the **EPOR**.

4 Feedback from Station Representatives

Discussions were held with representatives of most of the coal fired power stations to ascertain:

- History of major events that impact station **FOR**
- Planned maintenance and capital investments that might impact future **FOR** and **EPOR**
- Expected planned maintenance regime
- Engineering provisions to allow more flexible operation

The Station personnel were asked a series of questions that also provided AEP Elical with details of the maintenance programmes for each unit and the long term planned operating and maintenance regimes.

AEP Elical has reviewed the discussions with station representatives to identify any specific instances where redesign or significant refurbishment is occurring that should reduce the incidence of outages from particular categories of cause. This is considered to occur at approximately half of the stations. The categories where changes have been made are summarised below at state and fleet level, weighted by station capacity as shown in the table below. Note that the weighting change is applied to the historical weighting. While most of the changes are small this is due to the collation at state or fleet level: individual stations may have zero or larger changes.

TABLE 4-1: WEIGHTING CHANGES FROM 4-YEAR ROLLING AVERAGE

Site	Initial Weighting Changes From 4-Year Rolling Average Categories					
	1	3	4	5	7	9
	Fuel supply	Boiler	Flue gas and ash systems	Steam turbine	Generator	C&I system
NSW	-6%	-15%	0%	-6%	0%	-6%
QLD	0%	-5%	-4%	-1%	0%	0%
VIC	0%	-5%	-3%	0%	-38%	0%
FLEET	-3%	-10%	-2%	-3%	-7%	-3%

4.1 International data comparison

The most comprehensive data for **FOR** of coal-fired (and other) generating plant is for North American stations as reported in the North American Electric Reliability Corporation (NERC) 2019 State of Reliability document[3]. This notes that the 2018 weighted equivalent generation forced

[3] www.nerc.com

outage rate is above the five-year average for the second year in a row and has also increased since 2016. It also reports that coal-fired plant shows a slight increasing trend.

While there is no mention of station capacity factors, AEP Elical notes that it is common knowledge that coal fired generation has decreased in North America in recent years due to the growth of generation from, in particular, unconventional gas.

NERC also reports data in its 'Generating Data Statistical Brochure' collected as part of the Generating Availability Data System (GADS). The 2014-20218 statistical data report dated 30 July 2019 gives **FOR** and **EFOR** values for coal-fired plant for different ranges of capacity. The overall FOR and EFOR plus weighted averages for plants between 300 to 800MW are shown in **Table 4-2.**

TABLE 4-2 COMPARISON OF NERC AND NEM OUTAGE RATES

	FOR	EFOR
All NERC coal-fired plants	7.22%	9.63%
NERC coal-fired plants between 300 and 800 MW	6.80%	9.15%
All NERC brown coal (lignite) plants	4.55%	8.5%
All NEM coal-fired plants	5.86%	8.78%
NSW stations	6.95%	11.00%
QLD stations	3.18%	5.25%
VIC brown coal stations	8.04%	10.04%

The above table indicates that the stations in the NEM are performing to a standard consistent with the stations reported in the NERC document, albeit better in general for **FOR** across the fleet. The brown coal stations in Victoria have a higher **FOR** than the NERC average, while the Queensland coal-fired plants have a lower **FOR** than the overall and 300MW to 800MW capacity NERC units.

5 Approach to Forecasting FORs and EPORs to End of Life

The approach taken by AEP Elical is to take the start point for each station and state derived in **Section 3.4** and to adjust this, as appropriate by the maintenance / capex weighting factors derived through reviews of the stations. This gives an adjusted starting point for FY2020.

In this section we will describe how we:

- Derive generic growth factors for each of the categories of causes of forced and partial outages and for the likelihood of major events,
- Determine likely increases in **FOR** and **EPOR** in the years leading to station closure, and
- Combine these growth and end of factors with the weighted categories of causes of forced and partial outages.to produce station and state-wide forecasts.

5.1 Generic Growth Factors

Generic growth factors have been produced for two scenarios as specified by AEMO:

- Business as usual with most operation at high load but reductions to minimum load at periods of low prices, 'business as usual' scenario; and
- A combination of high load operation with significant operation at minimum load and 30 to 40 weekend (or longer) outages each year, the 'weekend outage' scenario

Factors have been derived for each of the fourteen categories as described below.

5.1.1 Fuel supply system

The historical data shows very low full outage losses and significant partial losses due to fuel supply issues. In coming years, several plants will be obtaining coal from alternative sources or from mines that are moving into more difficult conditions and potentially experiencing more interruptions or poorer quality. The resulting losses are not likely to be significantly different for the business as usual and weekend shutdown scenarios. Accordingly, a generic growth factor of 1% has been assumed for both scenarios.

5.1.2 Fuel system from feeders through to burners

The historical data shows very low full outage losses but significant partial losses due to fuel system issues. With aging plant, it can be assumed that there will be some increase in losses due to materials handling system failures and deterioration of milling, pulverised fuel transport and burner components. The weekend shutdown scenario is likely to add to losses in this area due to more frequent start-up of milling and associated plant and of oil burners. For business as usual, a growth factor of 0.5% has been assumed, while for the weekend shutdown scenario a growth factor of 2% is considered more likely.

5.1.3 Boiler system including pressure parts and main steam system

Boiler system losses represent about half of all full outage losses and a significant proportion of partial losses. Boiler pressure parts and furnace components are particularly affected by temperature related life issues and erosion related failures. As plants age, it is reasonable to expect that these failures will increase. A growth factor of 2% has been assumed for the business as usual case. For the weekend shutdown scenario, the more frequent shutdown and restart cycles with associated temperature changes are likely to increase the frequency of tube leaks and, also, the more frequent cycling of dampers and valves will add to availability losses. A growth factor of 4% has been assumed for this scenario.

5.1.4 Flue gas and ash systems

Flue gas and ash systems make a small, but significant contribution to full forced outage losses and a substantial contribution to partial losses. As the plants age, these losses can be expected to show small increases, estimated at 0.5% for the business as usual case. For the weekend shutdown scenario, a growth factor of 2% has been assumed to account for increased activity of valves and dampers and temperature variations and effects of fuel oil contamination and below dewpoint operation during start-up.

5.1.5 Steam turbine

Steam turbine losses represent the second highest contribution to full outage losses and a smaller contribution to partial losses (but with a reduced impact once **HILP** events are considered). It is likely that aging of turbines and associated steam admission systems will show some increases in availability losses. A growth factor of 0.5% has been assumed for the business as usual scenario and a slightly higher value of 0.75% assumed for the weekend shutdown scenario due to some increased life consumption of high temperature components.

5.1.6 Condenser and feed heating systems

Condenser and feed heating systems represent a small proportion of full outage losses and a substantial proportion of partial losses. As the plants age these losses can be expected to show some increases due to condenser tube leaks, feed heater tube leaks and related failures of valves and pipework. For the business as usual scenario, a relative low growth factor of 0.5% has been assumed. For the weekend shutdown scenario, a higher growth factor of 1.5% has been assumed due to likely start-up and other issues with feedpumps.

5.1.7 Generator

The historical data shows a significant contribution to full outages due to generator issues and an insignificant contribution to partial losses. The full outages generally relate to unit trips due to automatic voltage regulator faults or generator protection faults, some of which result from generator internal defects. These losses are likely to continue at much the same rate and are not likely to be significantly impacted by the weekend shutdown scenario. Accordingly, the same growth factor of 0.2% has been assumed for both cases.

5.1.8 Transformers

Generator and unit transformers have contributed only low levels of both full and partial availability losses. There is no reason to suspect that this pattern is likely to change as plants age, given that generators have generally implemented sound systems of transformer maintenance and monitoring. A low growth factor of 0.1% has been assumed for both business as usual and weekend shutdown scenarios.

5.1.9 C&I systems

Control and instrumentation systems have made insignificant contributions to both full and partial losses and it is expected that there will be only a small growth in these losses in future years. A growth factor of 0.5% has been assumed for both business as usual and weekend shutdown scenarios.

5.1.10 Auxiliary mechanical systems

Auxiliary mechanical systems have made only small contributions to both full and partial losses and are not expected to show substantial increases as the plants age. A growth factor of 0.1% has been assumed for the business as usual scenario and a slightly higher value of 0.2% for the weekend shutdown scenario.

5.1.11 Auxiliary electrical systems

Auxiliary electrical systems have made only small contributions to both full and partial losses and are not expected to show substantial increases as the plants age. A growth factor of 0.1% has been assumed for the business as usual scenario and a slightly higher value of 0.2% for the weekend shutdown scenario.

5.1.12 Human factors

Reported availability losses due to human error have been quite low and are not expected to increase substantially. For the weekend shutdown scenario, some increase in human error losses can be assumed due to increased operational activities during shutdown and start-up cycles.

There is also likely to be increasing pressure on availability of experienced operating staff due to aging workforces. A growth factor of 0.1% has been assumed for the business as usual case and 0.5% for the weekend shutdown case.

5.1.13 Environmental emissions

Losses due to environmental emission issues have been quite low. However, it is likely that increasing environmental pressures are likely to cause some increasing losses in this area and the weekend shutdown scenario could further add to losses during start-up of emission control equipment. A growth factor of 1% has been assumed for the business as usual case and 2% for the weekend shutdown case.

5.1.14 Other / unspecified

The other/unspecified category represents a substantial proportion of both full and partial losses. While the lack of information makes a detailed analysis impossible, growth factors of 2% for the business as usual scenario and 3% for the weekend shutdown scenario are considered reasonable.

TABLE 5-1: GENERAL AGEING GROWTH PER ANNUM FOR EACH OUTAGE CAUSE

General Ageing Growth Per Annum for Each Outage Cause							
Categories							
	1	2	3	4	5	6	7
Scenario	Fuel supply	Fuel system (from supply up to burners)	Boiler	Flue gas and ash systems	Steam turbine	Condenser and feed-heating system	Generator
Business as usual	1.00%	0.50%	2.00%	0.50%	0.50%	0.50%	0.20%
Weekend shutdowns	1.00%	2.00%	4.00%	2.00%	0.75%	1.50%	0.20%

TABLE 5-2: GENERAL AGEING GROWTH PER ANNUM FOR EACH OUTAGE CAUSE (CONT.)

General Ageing Growth Per Annum for Each Outage Cause							
Categories							
	8	9	10	11	12	13	14
Scenario	Transformers (generator and unit transformers)	C&I system	Auxiliary mechanical	Auxiliary electrical	Human factors	Other / unspecified	Environmental emissions
Business as usual	0.10%	0.50%	0.10%	0.10%	0.10%	2.00%	1.00%
Weekend shutdowns	0.10%	0.50%	0.20%	0.20%	0.50%	3.00%	2.00%

5.2 HILP Events

HILP events are expected to continue to occur occasionally though the causes and locations cannot be predicted, except in general terms. For all the stations in the fleet a small growth rate of 0.5% has been assumed for business as usual with a slightly higher growth rate of 1% for the weekend shutdown scenario due to the increased cycling of the plants.

5.3 End of Life Factors

As stations draw towards their end of life, i.e. 6 to 7 years prior to scheduled closure, the asset management plans generally consider reduced investment in plant maintenance. Station owners will provide sufficient investment in order to meet plant certification requirements and to meet any performance obligations under Power Purchase Agreements or other contractual arrangements. Investment in capital plant and equipment is unlikely and focus is on extending the life of critical items, rather than replacement. This inevitably results in a managed reduction to overall plant availability, with increases to both forced and partial outages.

Table 5-3 below shows AEP Elical's opinion on the impact that aging plant and equipment, coupled with the aforementioned reduction in CAPEX and OPEX has on **FOR**s in the final years of Station operation. The increases are cumulative and show an increasing rate of change as end of life is approached.

TABLE 5-3: END OF LIFE GROWTH PER ANNUM

End of Life Growth Per Annum				
Scenario	3 years in	2 years in	1 year in	EOL
Business as Usual	0.25%	0.30%	0.40%	0.50%
Weekend Shutdowns	0.25%	0.30%	0.40%	0.50%

5.4 Summary Growth Factors for States and Fleet

The table below shows summary start points and initial category and HILP growth factors for the states and the fleet noting that the consolidated category growth factors will change as plants retire from service. The category growth factors are determined using the generic values presented in **Section 5.1** multiplied by the fractional weightings for each category on a station by station basis as adjusted according to the factors in **Table 4-1** and renormalised (i.e. if a particular category weighting is changed all the categories are revised to maintain a total of 100%). The increase in **FOR** (and **EPOR**) is determined by applying the growth factor to the adjusted **FOR** (or **EPOR**) on an annual basis. Similarly the growth in **HILP** related **FOR** is determined by applying the **HILP** growth factor given in **Section 5.2** to the state (or fleet) **HILP FOR**. In addition, when determining the overall **FOR, EPOR** etc the end of life factors given in **Table 5-3** are applied to all stations.

TABLE 5-4: SUMMARY OF START POINTS AND GROWTH FACTORS

Site	FOR (FY20)	Adjusted FOR for FY21, prior to application of growth factors	Category Growth Factor Per Annum		State HILP FOR
			Business As Usual	Weekend Shutdowns	
Fleet	4.70%	4.37%	1.41%	2.88%	1.16%
VIC	5.58%	5.18%	1.47%	2.95%	2.46%
NSW	5.76%	5.23%	1.50%	3.05%	1.18%
QLD	2.83%	2.71%	1.25%	2.62%	0.35%

5.5 Predicted **FOR** by State and Fleet

The resulting **FOR**s etc for the states, the fleet and the individual stations are given in the following figures.

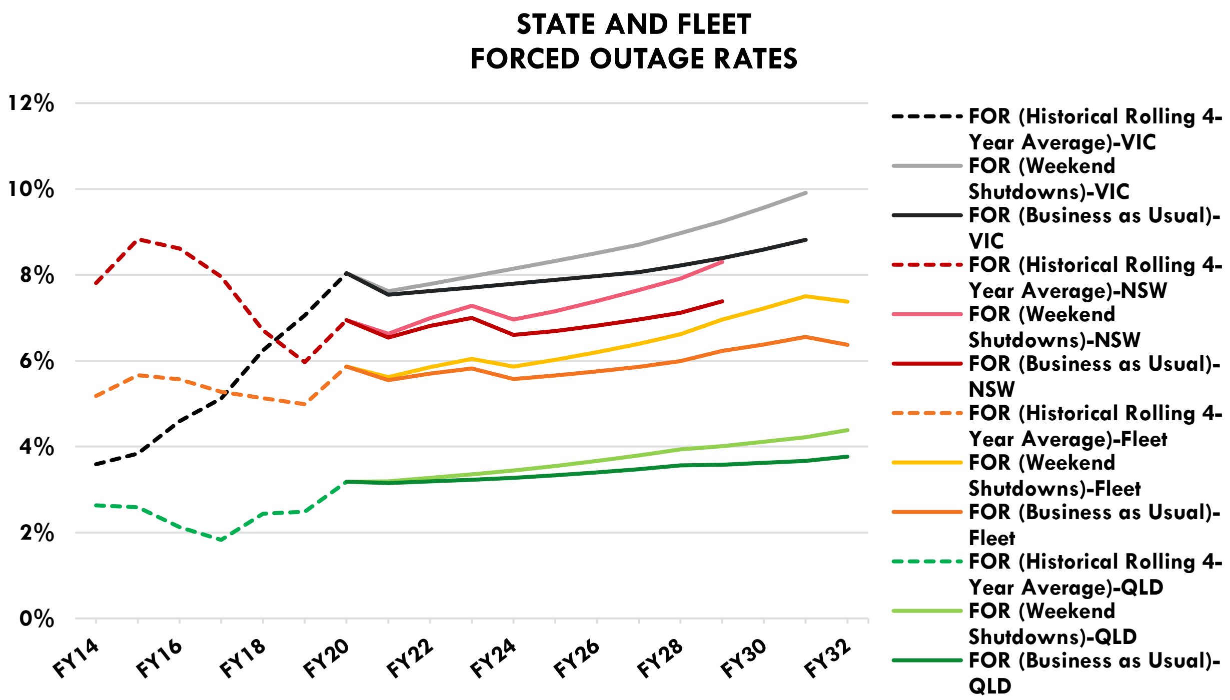


FIGURE 5-1: STATE AND FLEET FORCED OUTAGE RATES

5.6 Predicted **FOR**, **EPOR** and **EFOR** for States and Fleet

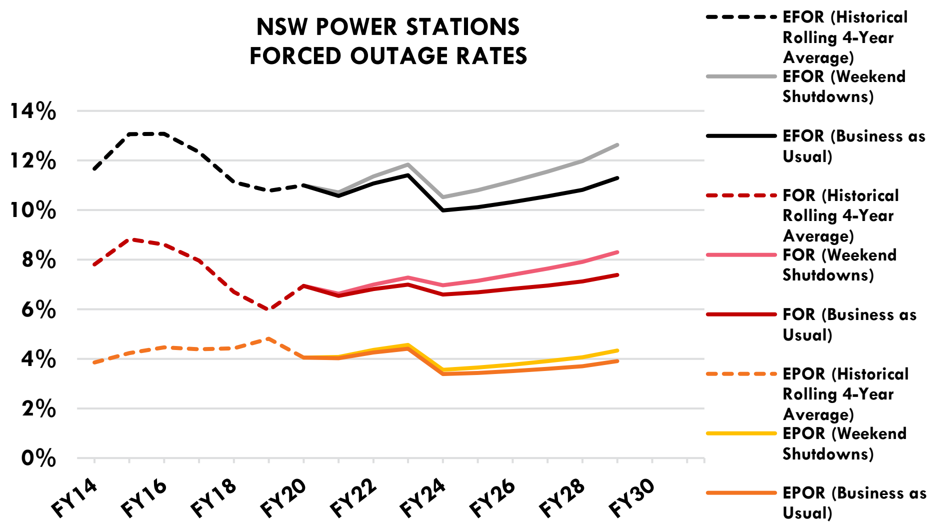


Figure 5-2: NSW forced outage rates

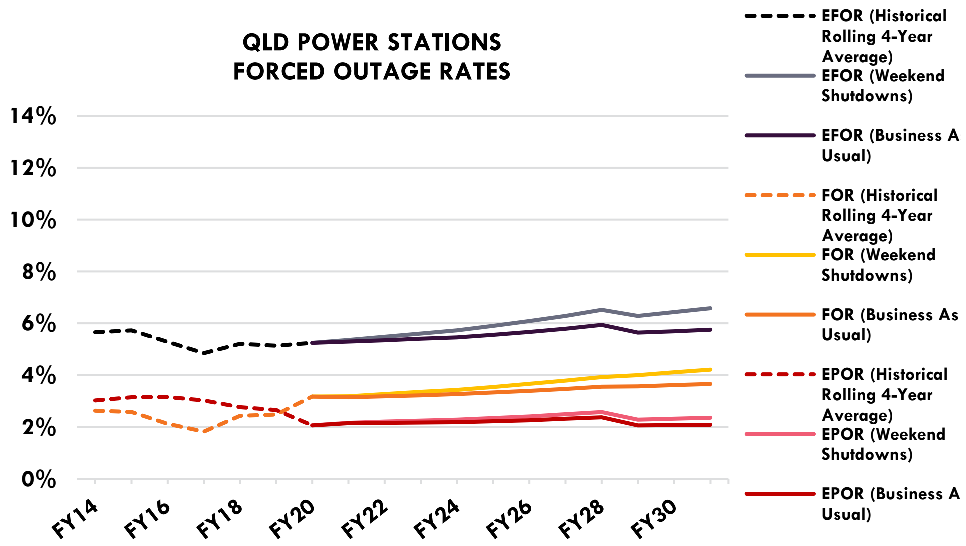


Figure 5-3: QLD forced outage rates

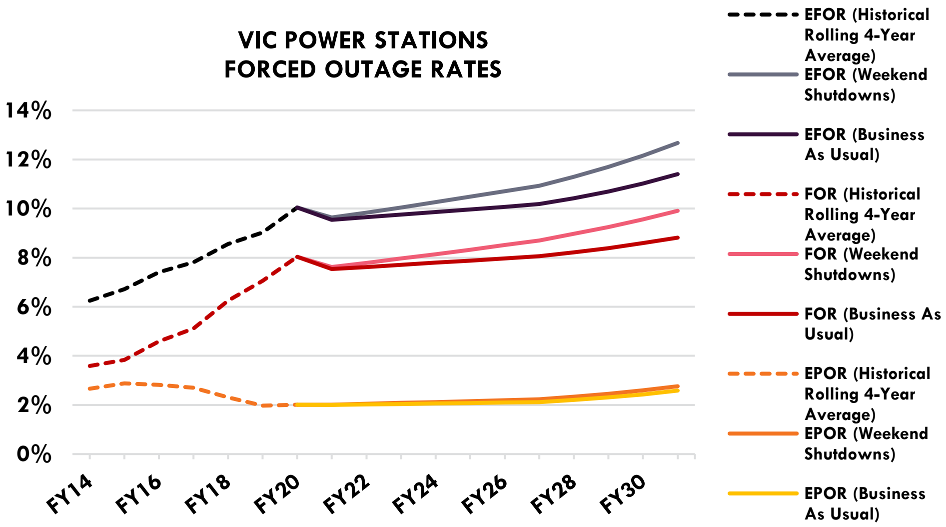


Figure 5-4: VIC forced outage rates

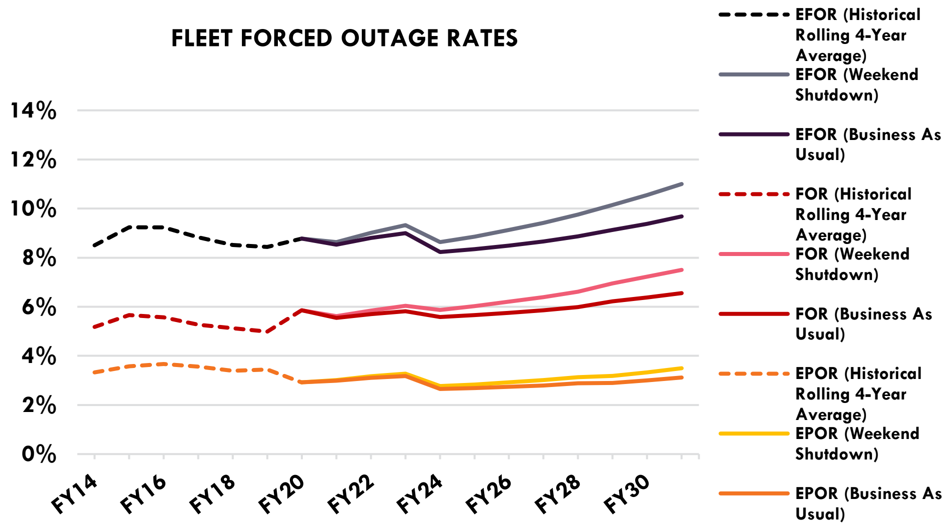


Figure 5-5: Fleet forced outage rates

6 Feedback from Forecasting Reference Group

The approach described above, and the preliminary results were presented to the AEMO Forecasting Reference Group on 10 June 2020. A copy of the AEP Elical presentation is shown Appendix A.[4]

Following the presentation there was a general discussion which is summarised in the minutes of the meeting. Key points raised included the observation that the higher **FOR** predicted in the weekend shutdown scenario might be mitigated by opportunistic maintenance during the shutdowns and that the more operation at lower loads might reduce the rate of damage to some pressure tubing thereby leading to less outages due to tube leaks. AEP Elical considers these valid observations but notes the lack of data to help quantify the factors.

[4] At the time of the presentation one HILP event was not identified. The presentation has been updated to include this. It does not impact the results to any significant extent.

7 Conclusions

AEP Elical has used data provided by AEMO and the information provided by representatives of most of the power stations to derive weightings for causes of full and partial outages / deratings. It has derived underlying rates by considering high impact low probability outages as a separate category and applied this HILP category on a state-wide or fleet basis to the 4-year rolling averages of the underlying rates.

For each category of cause a best estimate growth factor has been derived based on engineering knowledge of the cause and the plant. These category growth factors have been multiplied by the category fraction to get overall category growth factors for each station. The station outage rates are then consolidated into state and fleet values.

End of life factors have been derived based on the expectation of reduced expenditure on the stations in the last few years of operation. These are additional to the growth factors and cause an increase in outage rate growth in the last few years of each station's life.

The resulting predictions are considered a potential alternative approach to using historical data alone to predict future outage rates.

Appendix A: AEP Elical Presentation to the Forecasting Reference Group

Copy of presentation made to Forecasting Reference Group on 10 June 2020.

COAL FIRED GENERATION RELIABILITY AND FORCED OUTAGE RATES IN THE NEM

THE ASSIGNMENT

- **Provide forward looking reliability projections for the coal fired generators in the NEM:**
  - Planned outage (maintenance rates)
  - Full forced outage rates, plus partial forced outage rates (hours) and average partial derating or partial forced outage rates assuming derating does not change
  - Effective forced outage rates (sum of above)

- **Determine these on a station by station basis but summarise at a state and fleet level**

INPUTS

- **AEMO provided data:**
  - Forced and partial outage summaries by unit from FY2011onwards
  - Calculated station factors for FOR, EPOR etc
  - Lists of forced and partial outages with summary descriptions from FY2016 onwards

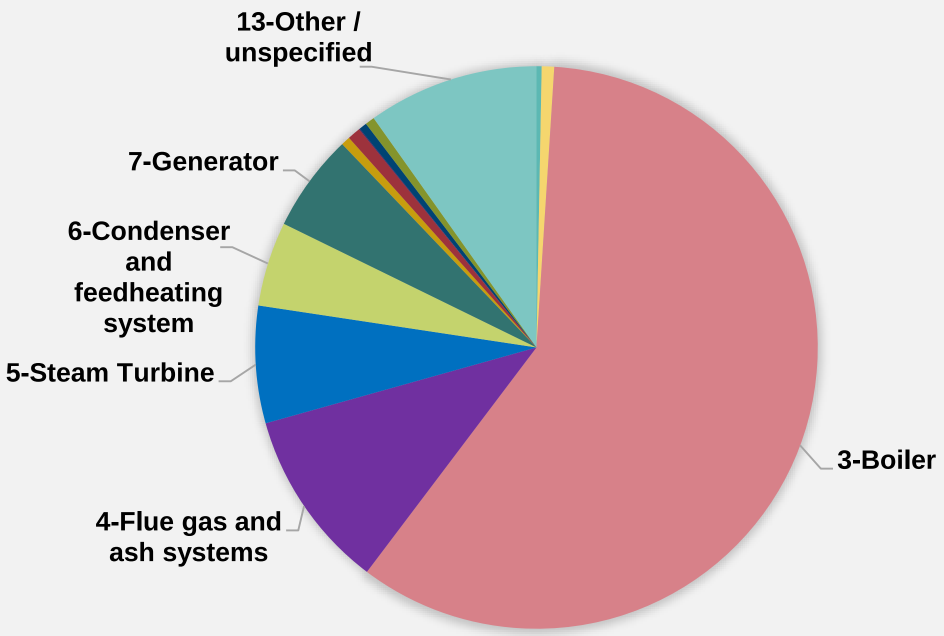
- **Generator provided data:**
  - Teleconferences with representatives of most stations to discuss history and plans etc.

APPROACH

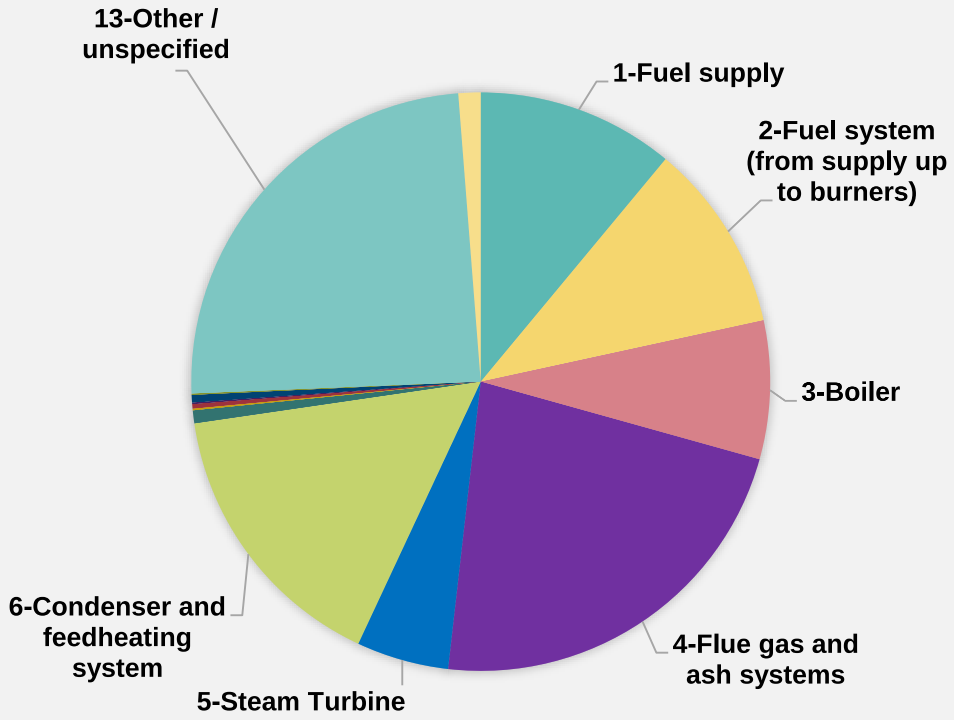
- Review reasons for outages and categorise these into 14 categories (examples of category splits are on next slide).
- Identify major events (low probability, high impact events) from FY2016 onwards and separate these from other outage events to get underlying rates.
- Reallocate the major events to stations on a flat, state-wide basis. The assumption being major events could occur at any station and that state-wide markets and capacities are key.
- Establish 4-year rolling average values for FOR and EPOR by station and state – the starting point for our projections. 4 years selected to reflect typical maintenance cycles.

CATEGORIES AND MAJOR EVENTS

BREAKDOWN OF FULL OUTAGES EXCLUDING MAJOR EVENTS



BREAKDOWN OF PARTIAL OUTAGES



IMPACT OF MAJOR EVENTS (2016 – 2020)

Region	FOR
Fleet	1.16%
NSW	1.18%
QLD	0.35%
VIC	2.46%

FORECASTING METHODOLOGY

- AEPE experience over many years and geographies employed to determine how different categories of causes (and the frequency of major events) may change over time assuming 'business as usual' and frequent low load operation with 30 to 40 weekend outages per year – the 'growth factors'

General ageing growth pa for each outage cause

	Categories						
	1	2	3	4	5	6	7
Scenario	Fuel supply	Fuel system (from supply up to burners)	Boiler	Flue gas and ash systems	Steam turbine	Condenser and feedheating system	Generator
Business as usual	1.00%	0.50%	2.00%	0.50%	0.50%	0.50%	0.20%
Weekend shutdowns	1.00%	2.00%	4.00%	2.00%	0.75%	1.50%	0.20%

General ageing growth pa for each outage cause

	Categories							
	8	9	10	11	12	13	14	
Scenario	Transformers (generator and unit transformers)	C&I system	Auxiliary mechanical	Auxiliary electrical	Human factors	Other / unspecified	Environmental emissions	Major events
Business as usual	0.10%	0.50%	0.10%	0.10%	0.10%	2.00%	1.00%	0.50%
Weekend shutdowns	0.10%	0.50%	0.20%	0.20%	0.50%	3.00%	2.00%	1.00%

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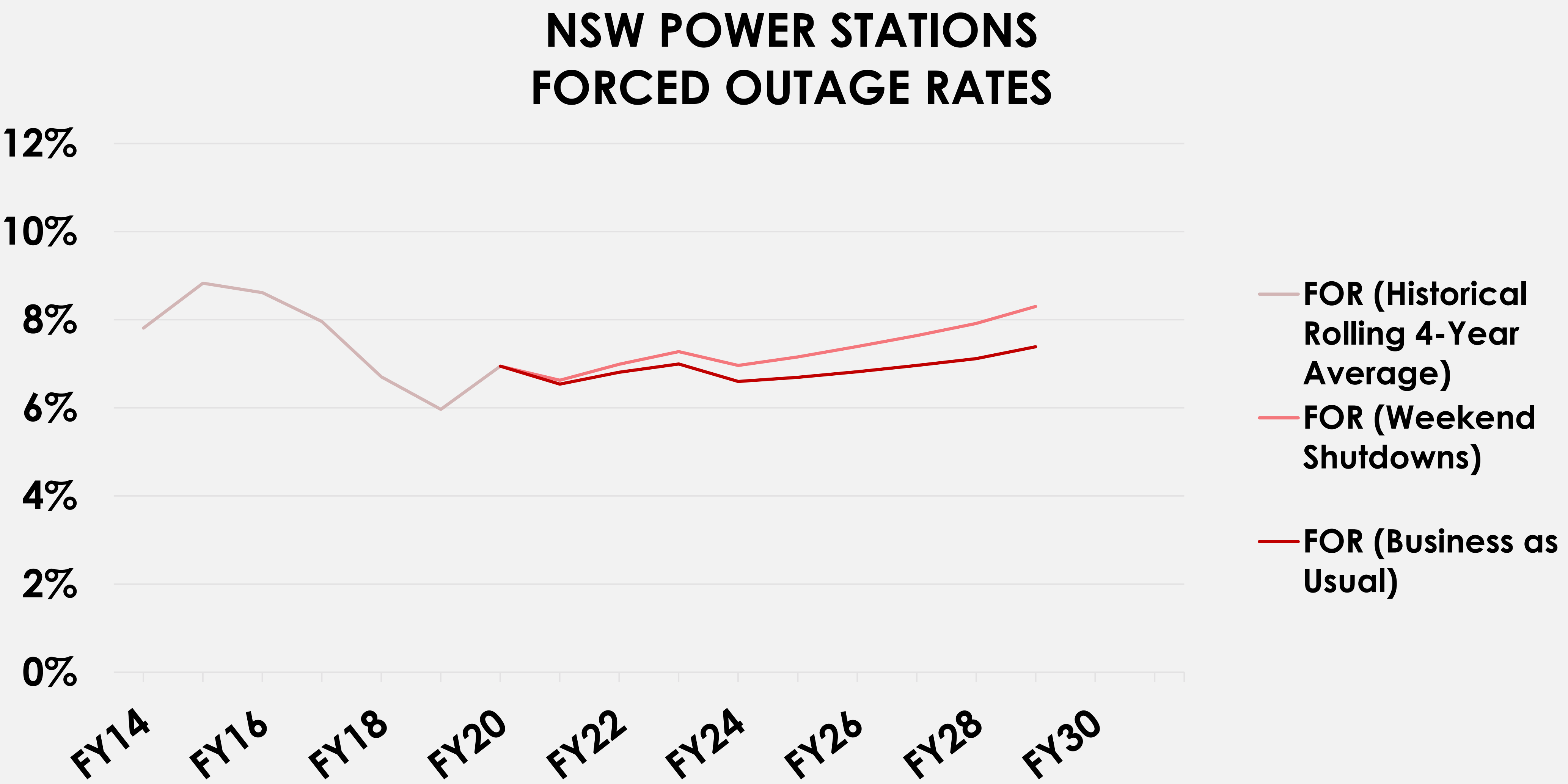
FORECASTING METHODOLOGY (cont'd)

- Outage rates expected to change in final few years of operation – noting market and other factors will be significant influencers

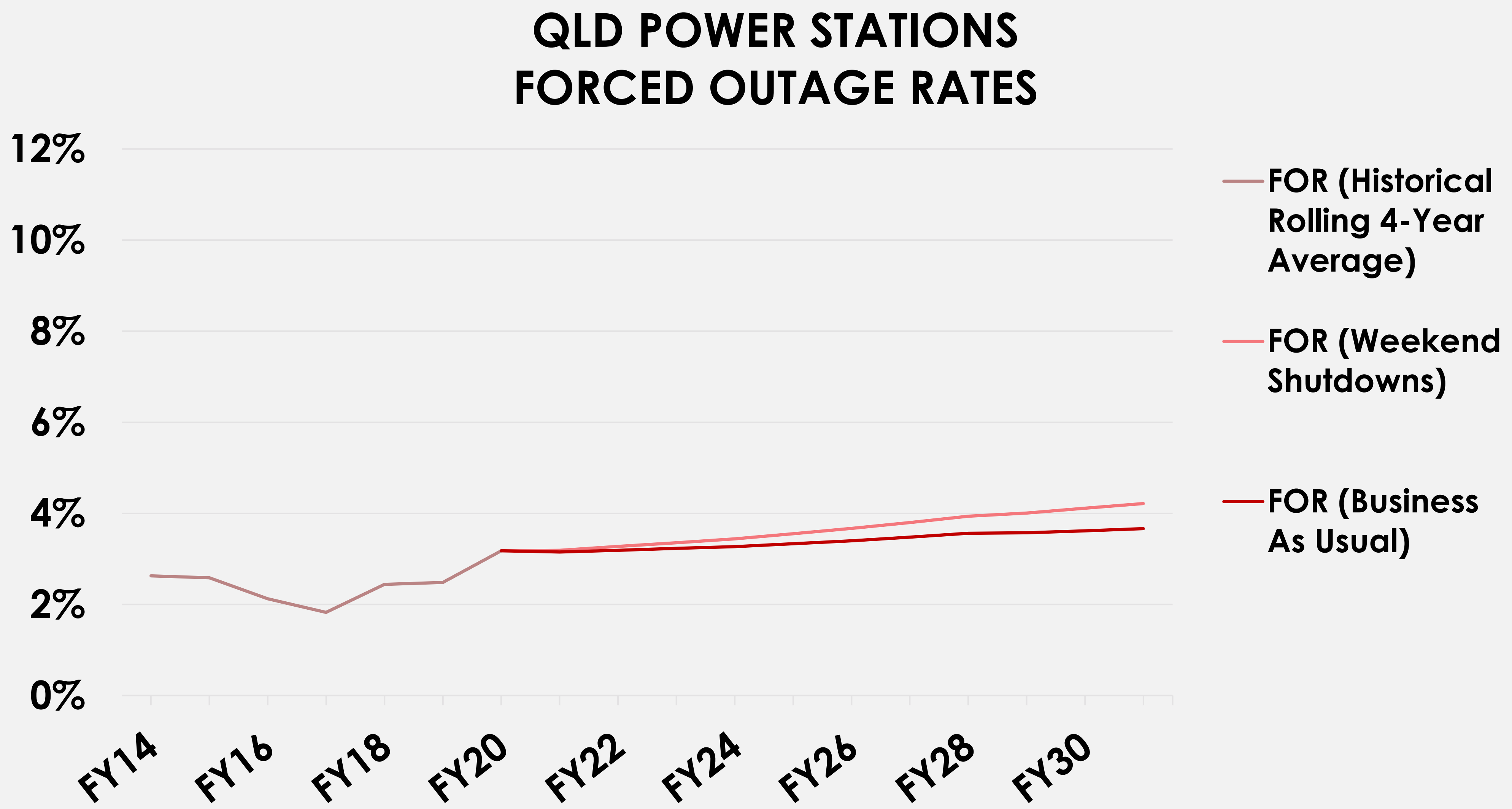
End of Life Growth Per Annum				
Scenario	**3 years in**	**2 years in**	**1 year in**	**EOL**
Business as usual	**0.25%**	**0.30%**	**0.40%**	**0.50%**
Weekend shutdowns	**0.25%**	**0.30%**	**0.40%**	**0.50%**

- AEPE reviewed information provided by Generators to determine if some categories of causes will change weighting in near future. It then modified start point for projections accordingly
  - Our analysis determined that there were few changes required
- AEPE used the category weighted growth factors on a station by station basis to determine FOR, EPOR and EFOR to end of planned station lives.
- Weighted statewide projections were derived from station data.

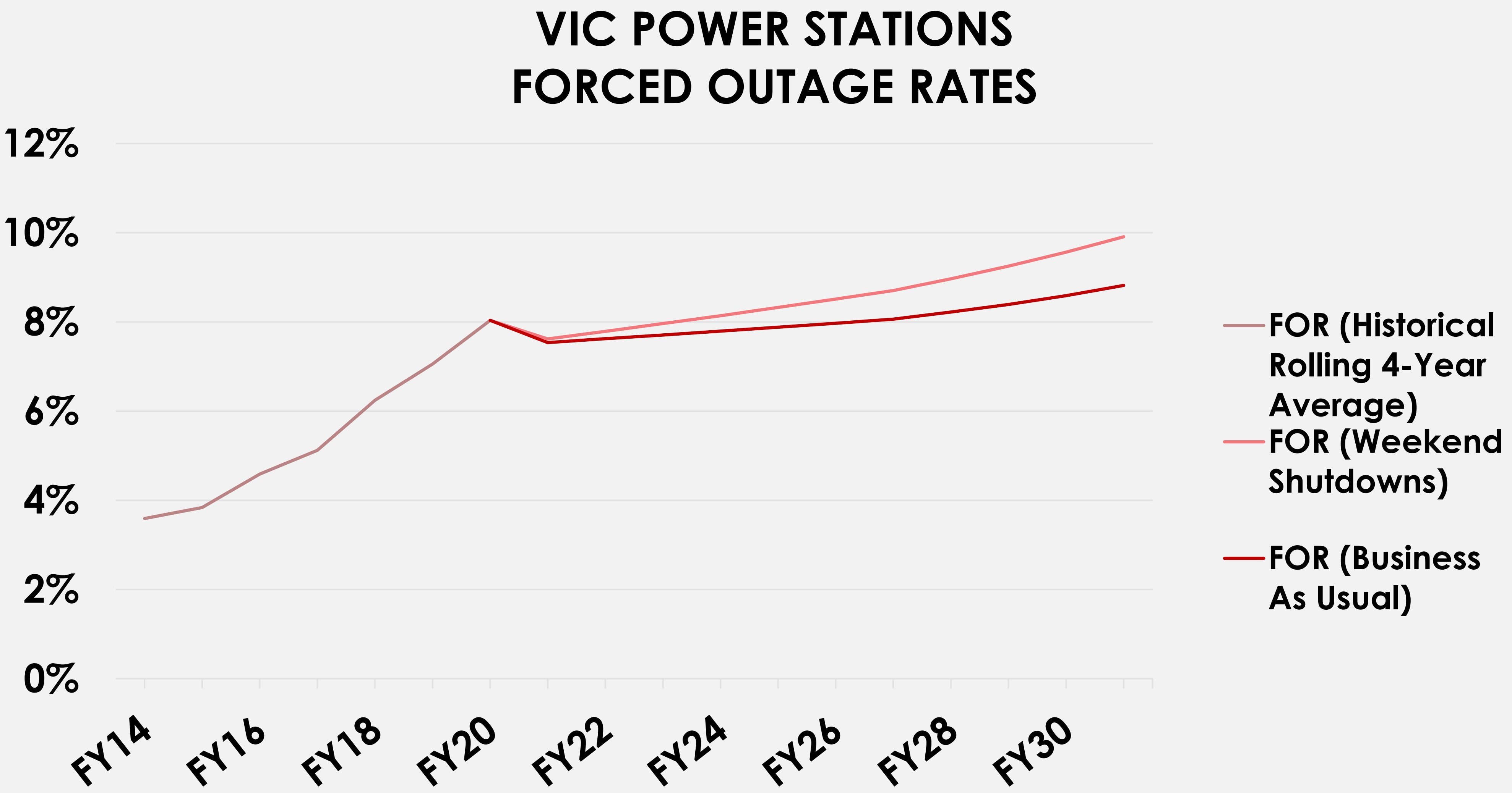
SUMMARY PROJECTIONS



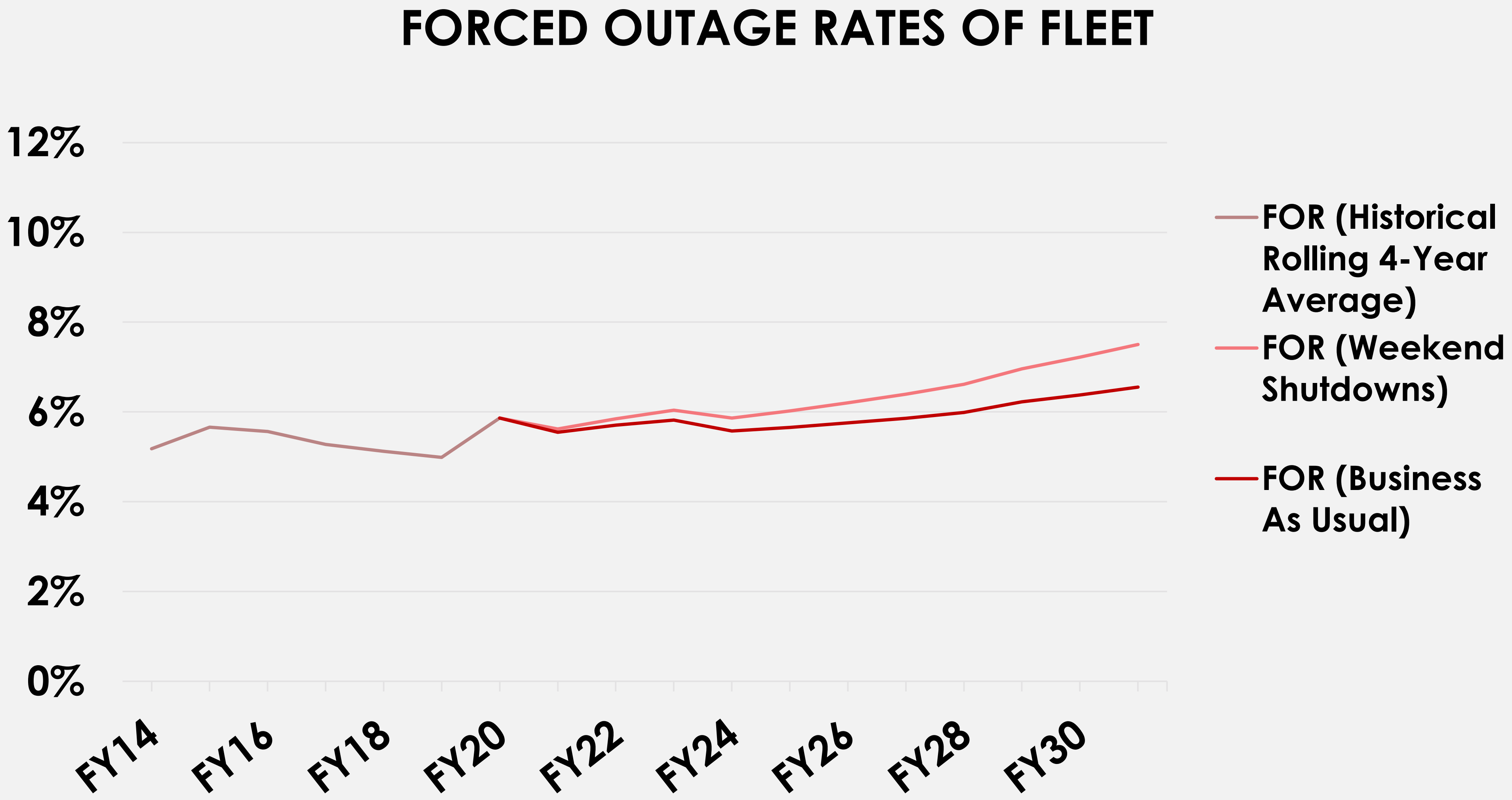
SUMMARY PROJECTIONS



SUMMARY PROJECTIONS



SUMMARY PROJECTIONS



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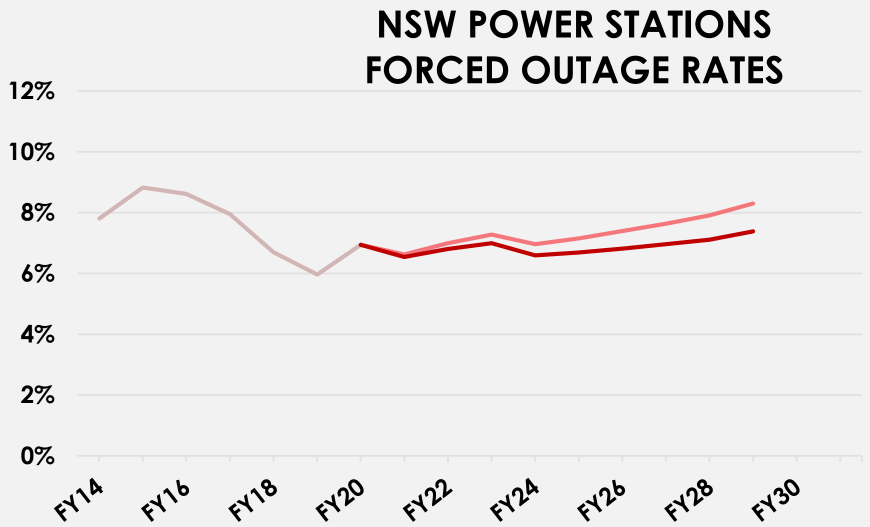
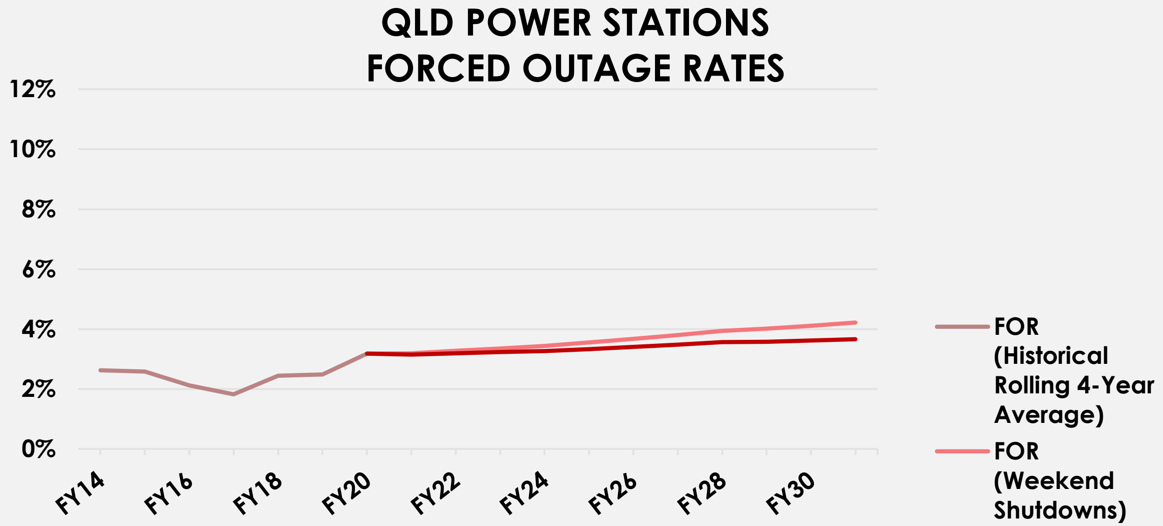
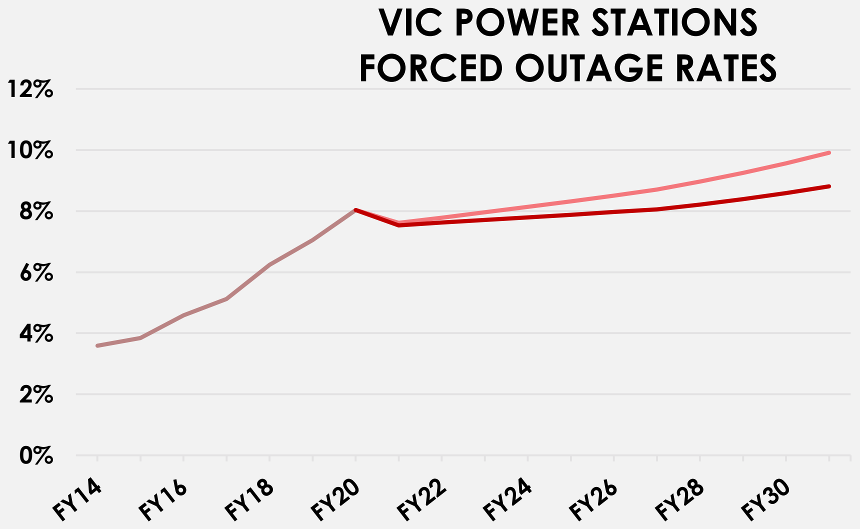
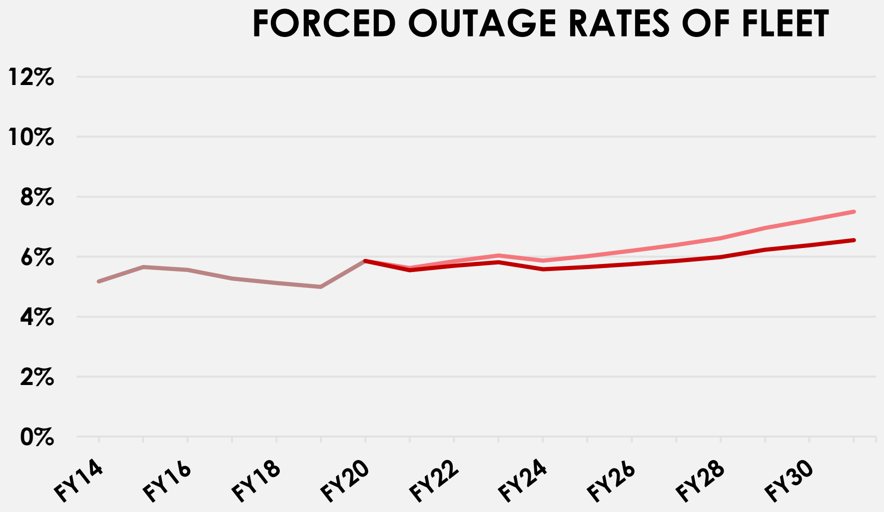
SUMMARY PROJECTIONS

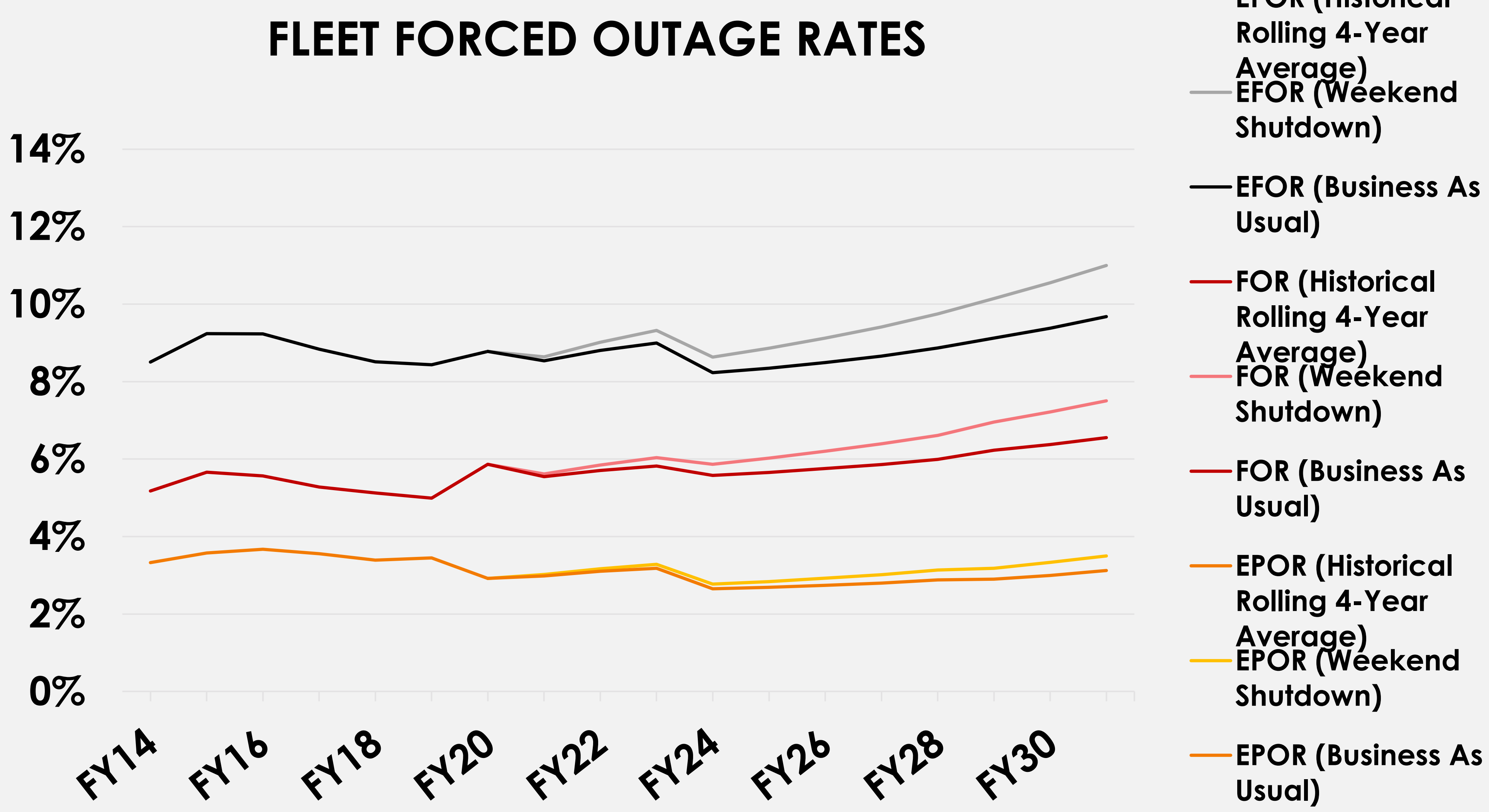








PROJECTIONS




THANK YOU
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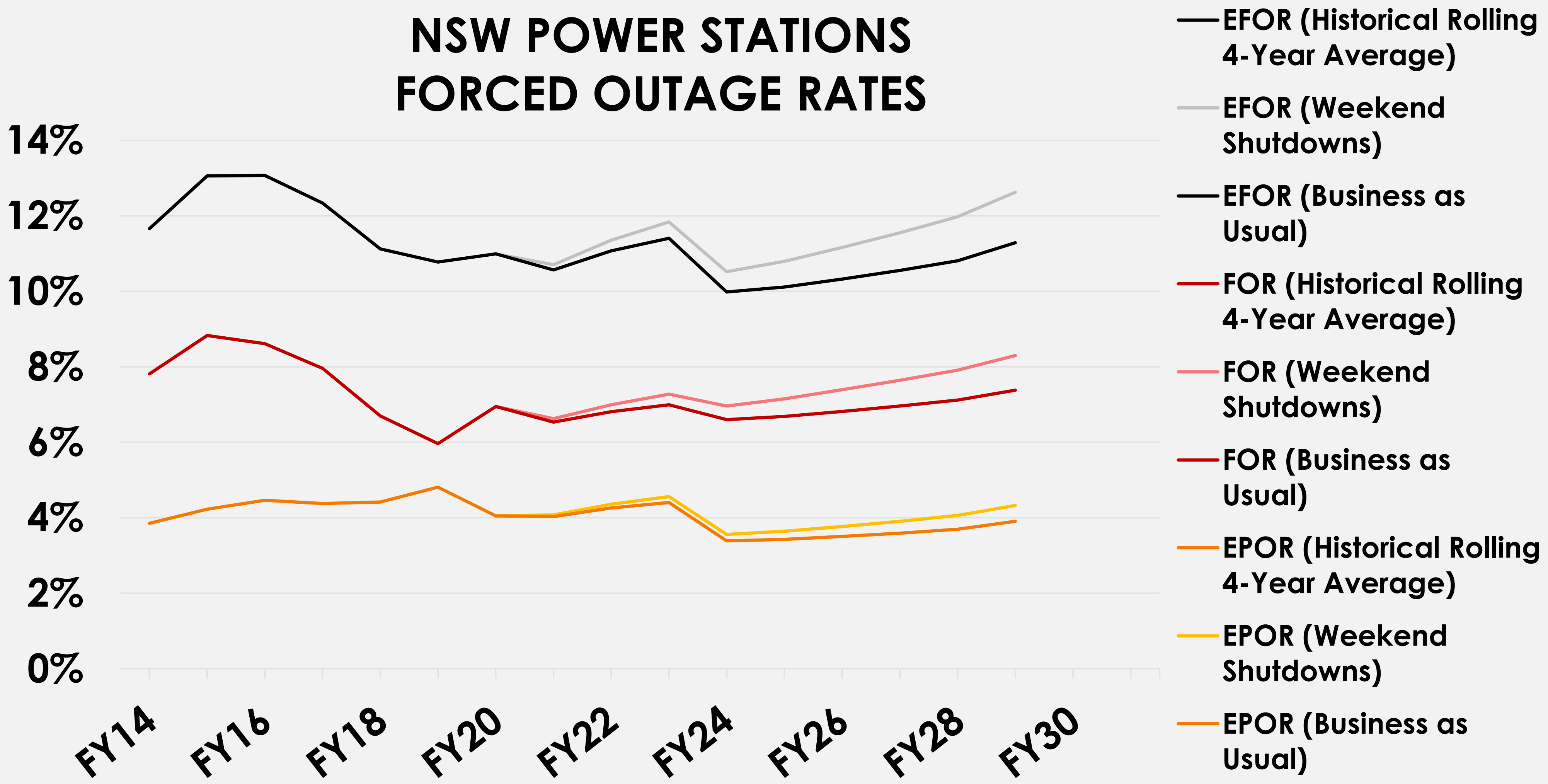
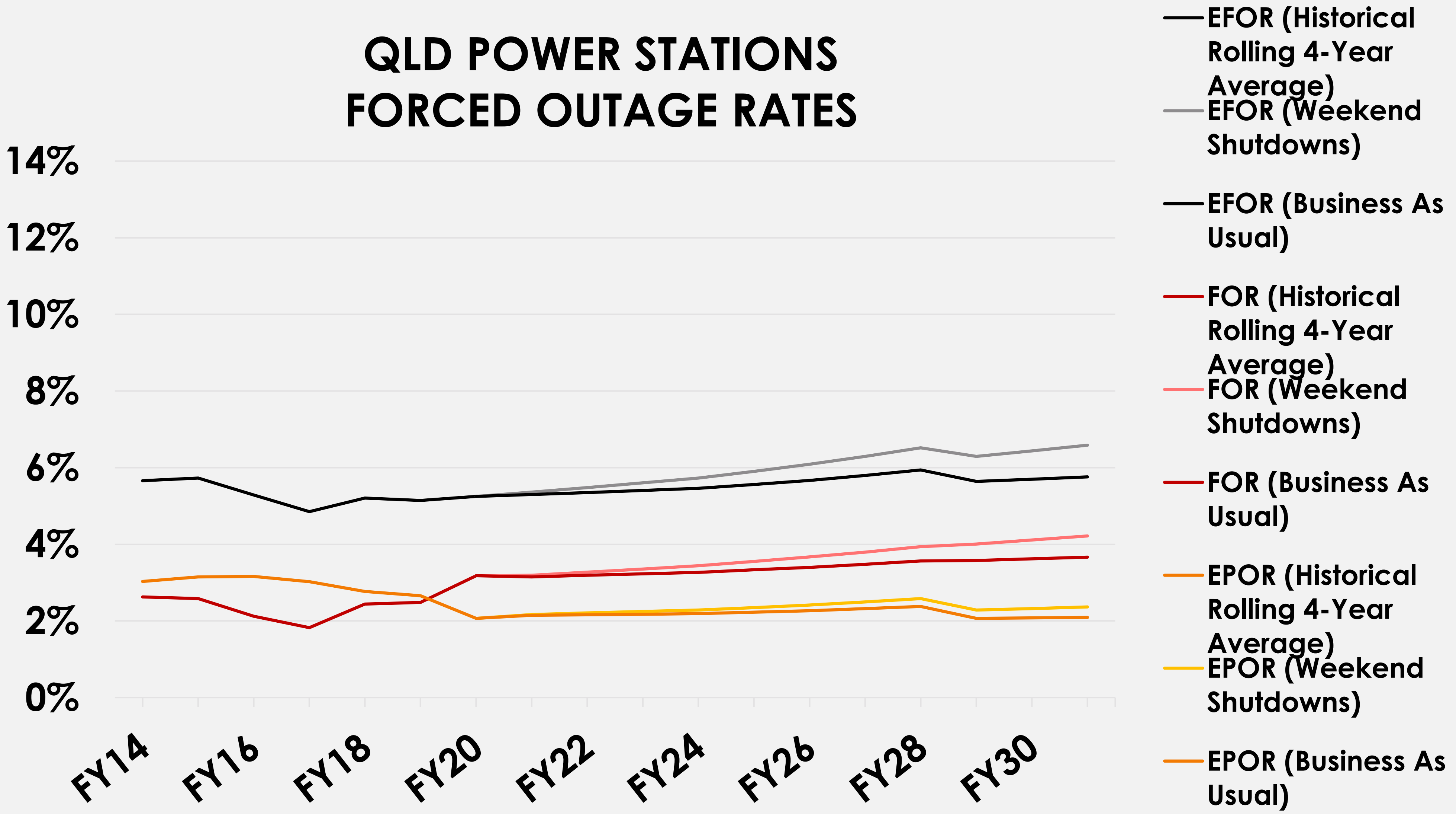
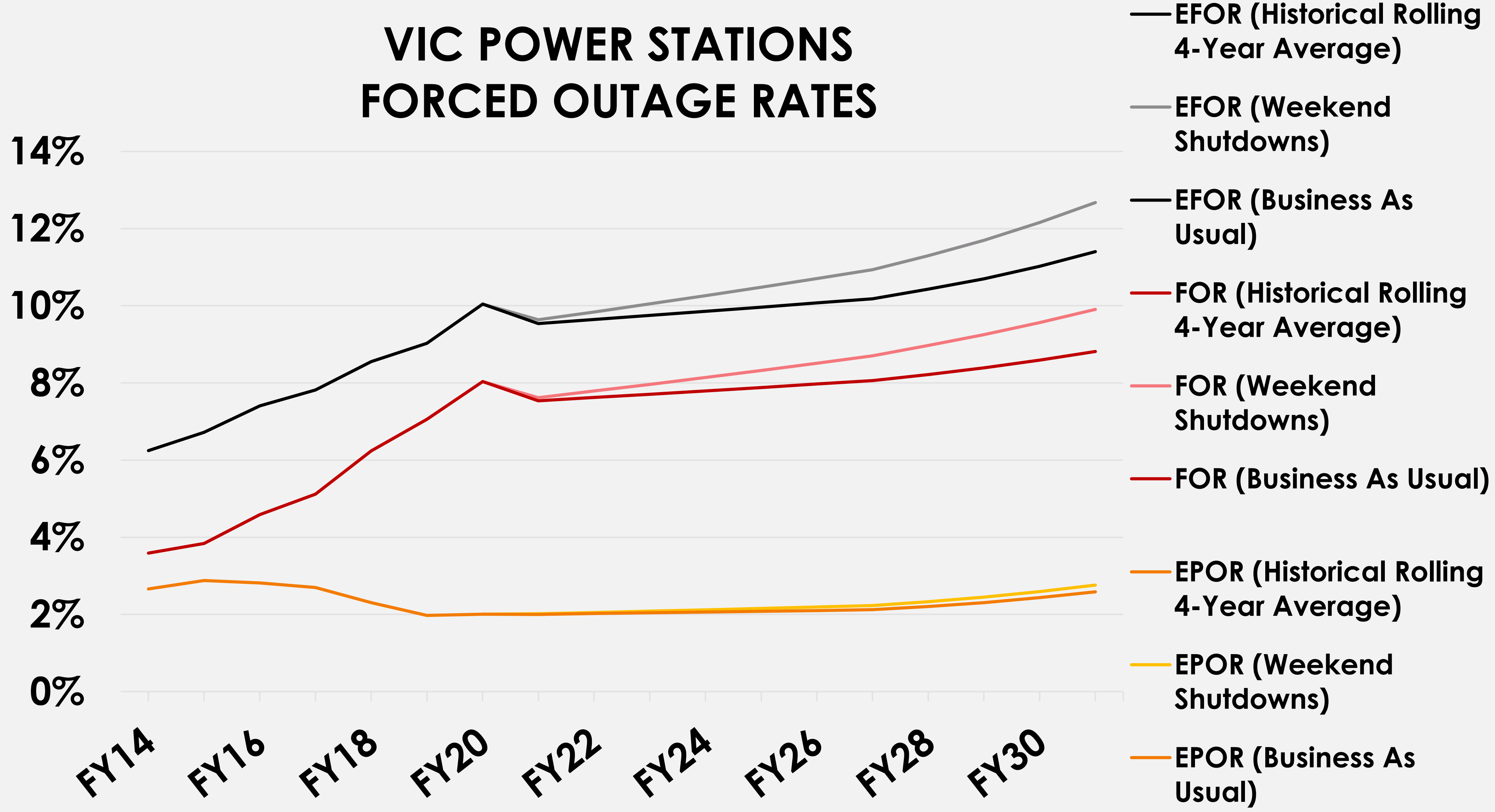
APPENDIX


NSW POWER STATIONS
FORCED OUTAGE RATES
14%
12%
10%
8%
6%
4%
2%
0%
FY14
FY16
FY18
FY20
FY22
FY24
FY26
FY28
FY30
EFOR (Historical Rolling 4-Year Average)
EFOR (Weekend Shutdowns)
EFOR (Business as Usual)
FOR (Historical Rolling 4-Year Average)
FOR (Weekend Shutdowns)
FOR (Business as Usual)
EPOR (Historical Rolling 4-Year Average)
EPOR (Weekend Shutdowns)
EPOR (Business as Usual)

APPENDIX


QLD POWER STATIONS
FORCED OUTAGE RATES
14%
12%
10%
8%
6%
4%
2%
0%
FY14
FY16
FY18
FY20
FY22
FY24
FY26
FY28
FY30
EFOR (Historical Rolling 4-Year Average)
EFOR (Weekend Shutdowns)
EFOR (Business As Usual)
FOR (Historical Rolling 4-Year Average)
FOR (Weekend Shutdowns)
FOR (Business As Usual)
EPOR (Historical Rolling 4-Year Average)
EPOR (Weekend Shutdowns)
EPOR (Business As Usual)

APPENDIX



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Document Control

Revision	Date Issued	Author	Approved by	Status	Comments
0	18 June 2020	BEE, TJ, MG, GH, SS	B Eagers	Issued to Client	
1	30 June 2020	BEE, TJ, MG, GH, SS	B Eagers	Issued to Client	

Reference Type:	Report
Author (Company):	AEP Elical
Title:	Ageing Coal-Fired Generation Reliability
Year:	2020
Date:	30/06/2020
Document No:	P1712-00-E-RP-0001
Client:	Australian Energy Market Operator Limited, for publication
Site Location:	Brisbane
Project No:	P1712
Filename:	P1712-00-E-RP-0001_0 Ageing Coal-Fired Generation Reliability (NEM) public draft.docx