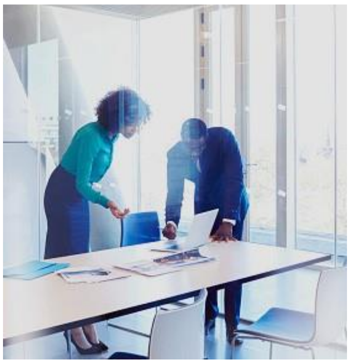
GHD Advisory



Generator Availability Analysis

Economic Regulation Authority

13 July 2020

Project Number: 12532719

Contents

Figures

Tables

Appendices

Executive summary

The Economic Regulation Authority (ERA) is conducting a one-off review in accordance with clause 4.11.1E of the Wholesale Electricity Market Rules (the Market Rules). In the review, the ERA is evaluating a mechanism that allows the Australian Energy Market Operator (AEMO) to reduce a Facility's Certified Reserve Capacity if their outage rate is above the thresholds stated in clause 4.11.1D of the Market Rules.

To assist the ERA with their assessment of clause 4.11.1(h) of the Market Rules, GHD has conducted research and provided information, in the form of this report and accompanying data sets (provided to the ERA), on:

i) The availability performance of the generation sector in the WEM for 10 years (1 October 2009 to 1 October 2019 – this aligns with Capacity Years under the Market Rules); and

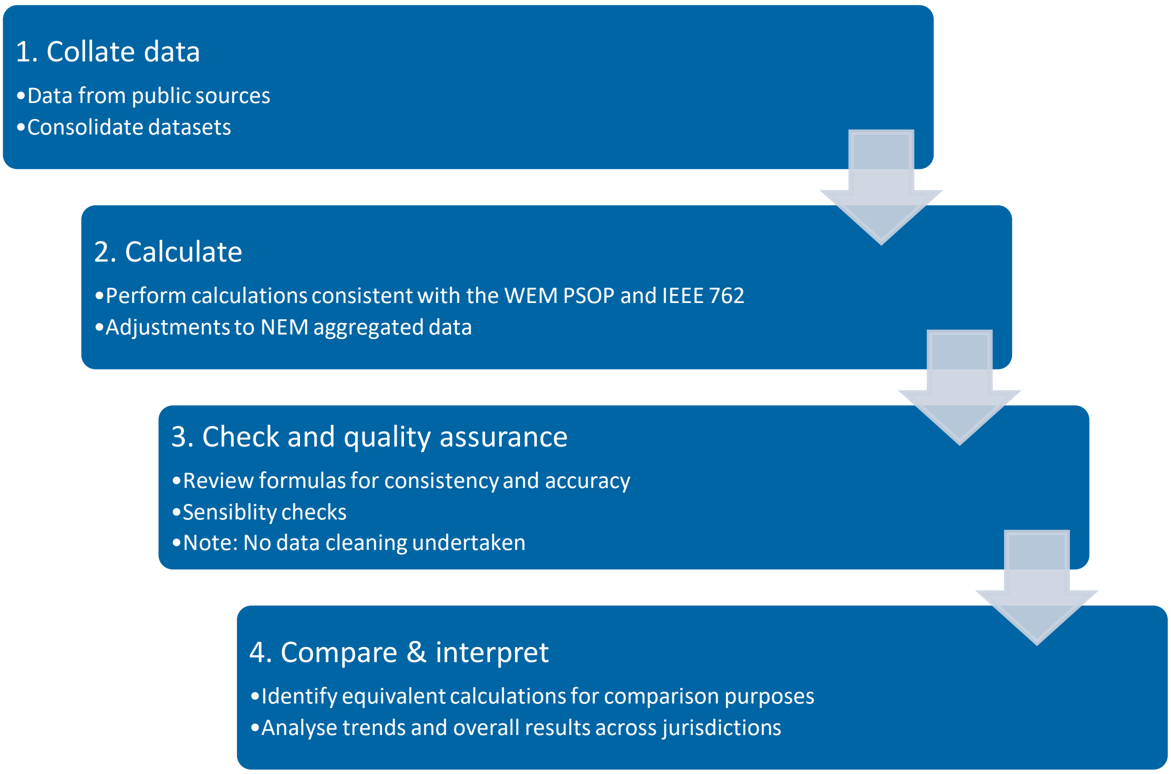
ii) A comparison with analogous generating plants in other markets.

This report provides analysis on the availability of scheduled generation in the Wholesale Electricity Market (WEM) with comparison to analogous fossil fuel generation plants in the NEM, the electricity wholesale market in the UK, and in North America. The North American data is collected by the North American Electric Reliability Corporation (NERC).

Method

GHD followed the four-step process outlined in Figure 1 (below) to collate and analyse scheduled generator availably data for the WEM and equivalent fossil fuel generation fleets in the UK, NEM, and North America.

Figure 1: GHD method

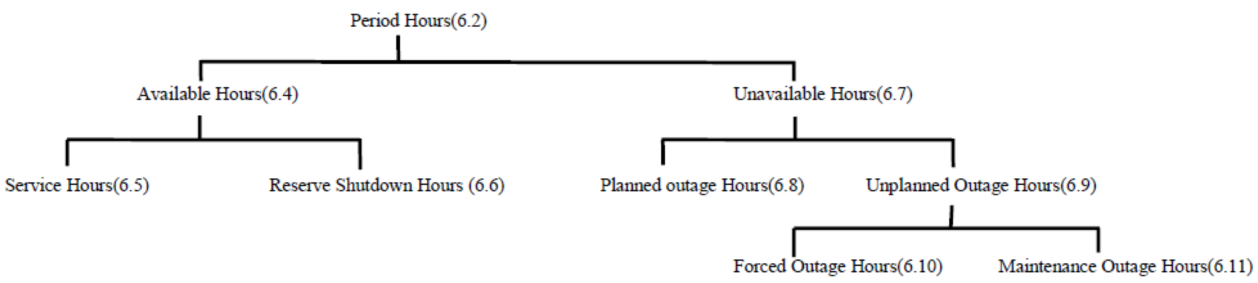


Calculations

To develop the final data tables and analysis, GHD undertook a series of calculations consistent with the AEMO's *WEM Rules Power System Operating Procedure: Facility Outages*[1] (the WEM PSOP) and the Institute of Electrical and Electronics Engineers Standard (IEEE) 762 – IEEE Standard Definitions for Use in Reporting Electric Generating Unit Reliability, Availability, and Productivity (IEEE 762).

The calculations each consider the amount of time units spend in various states outlined in Figure 2 (below) with the particular calculation considering a subset of the times. The categories in Figure 2 are designed to be mutually exclusive and to cover all hours, hence Period Hours is typically set equal to the number of hours in a year (8,760)[2] for annual calculations.

Figure 2: Time spent in various states



Source: IEEE 763, Figure 3, p. 16. Numbers in brackets refer to explanatory sections of IEEE 762.

The following table summarises the equations used by GHD. In each case, GHD used equivalent calculations that consider the role of partial outages. This compares to non-equivalent calculations where a partial outage, for example, is not treated as an outage.

Table 1: Calculations used for analysis

Calculation	Description	Comment
Equivalent outage rates	% of time that the generator is required to generate power but not able to do so due to a planned or unplanned failure	Aggregate fuel class outage rates are published by AEMO for the NEM.
Equivalent outage factor	% of time in which the generator is experiencing a full or partial outage	The same formula as the formula used for equivalent outage rates in the WEM PSOP.
Equivalent availability factor (EAF)	% of time that the generator is available to generate power	
Weighted equivalent availaby factor (WEAF)	Weighted average of the availability factors for the fleet or a particular class of generators (as specified)	Unit availability is weighted based on their proportion of capacity credits for the WEM and based on nameplate capacity for other markets.

[1] AEMO, *WEM Rules Power System Operation Procedure: Facility Outages*, version 7.0, 1 February 2020.

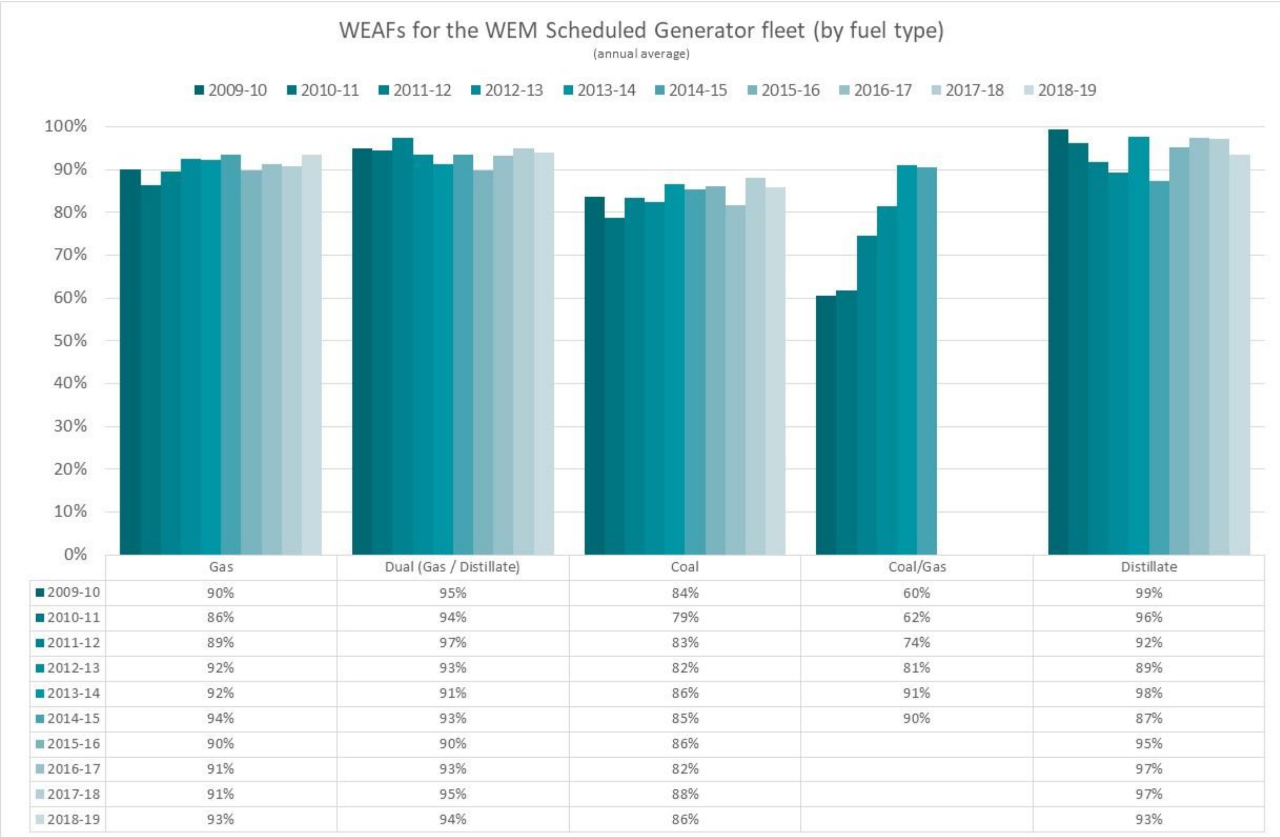
[2] Hours per year is 8,760 and 8,784 for leap years.

Results – WEM Scheduled Generators

The WEAF for all Scheduled Generators in the WEM has improved slightly over the 10-year analysis period, increasing from 86 and 83 per cent in 2009-10 and 2010-11 capacity years respectively to 91 per cent for the 2017-18 and 2018-19 capacity years respectively.

Figure 3 (below) shows the availability for most fuel classes has remained stable (dual (gas/distillate) and distillate) or increased slightly (gas, coal) over the analysis period. The exception is the coal/gas fleet, for which WEAF increased significantly from 60 per cent to 90 per cent in 2014-15 after which all the units were retired. The coal/gas units in the fleet are Kwinana G1, G3, G5 and G6.

Figure 3: Average annual WEAF for WEM Scheduled Generators (2009-10 to 2018-19) (by fuel type)



	Gas	Dual (Gas / Distillate)	Coal	Coal/Gas	Distillate
2009-10	90%	95%	84%	60%	99%
2010-11	86%	94%	79%	62%	96%
2011-12	89%	97%	83%	74%	92%
2012-13	92%	93%	82%	81%	89%
2013-14	92%	91%	86%	91%	98%
2014-15	94%	93%	85%	90%	87%
2015-16	90%	90%	86%		95%
2016-17	91%	93%	82%		97%
2017-18	91%	95%	88%		97%
2018-19	93%	94%	86%		93%

Source: GHD Advisory, 2020

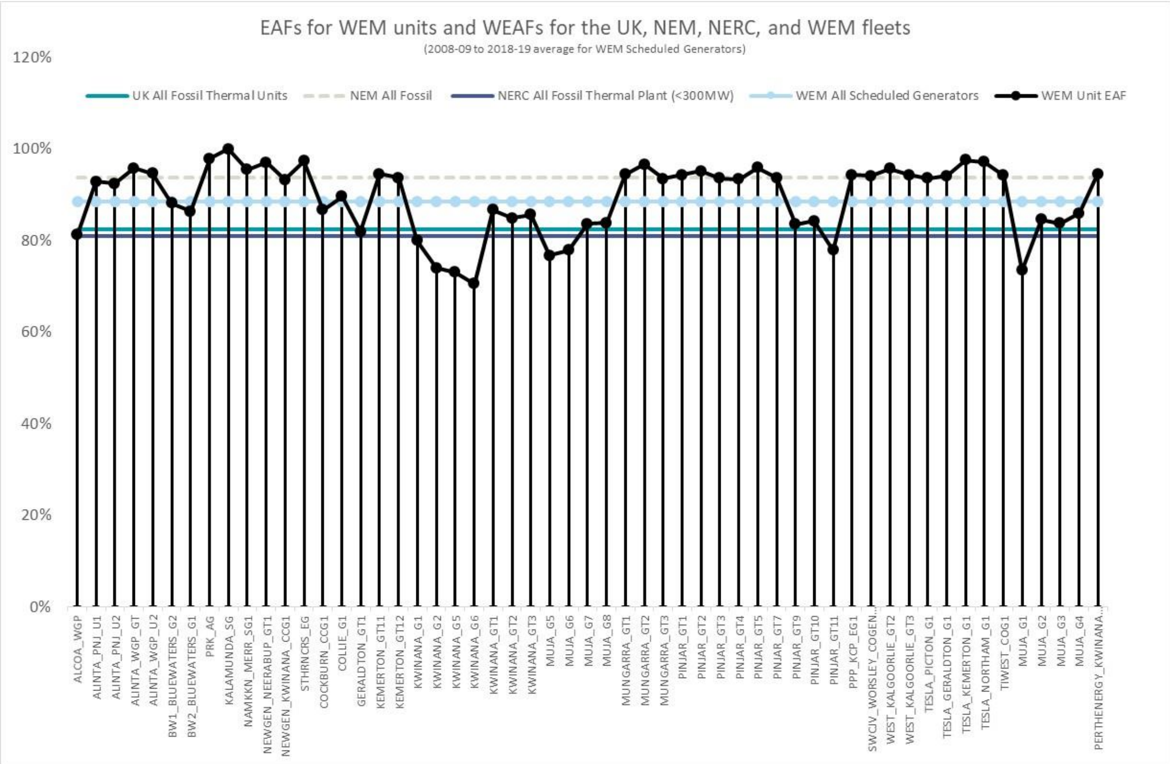
Results – International comparison

Figure 4 (below) provides a comparison of the 10-year average EAF for all Scheduled Generation units in the WEM, the WEAF for the WEM Scheduled Generator fleet and WEAFs for equivalent fossil fuel fleets in other jurisdictions.

The scheduled generation units in the WEM have an average WEAF of 89 per cent. Data indicates the units are, on average, more available than comparable fossil fuel fleets in the UK (83 per cent) and based on NERC data (80 per cent for units <300 MW), however they are less available than the equivalent fleet in the NEM (94 per cent).

Several of the generators with lower than average availability retired during the analysis period. Units that retired during the period are Geraldton GT1, Kwinana G1, G2, G5, G6 and GT1, Mungarra GT2, SWCJV Worsley Cogen COG1, and Muja G1, G2, G3, G4.

Figure 4: Comparison of WEM Scheduled Generators with equivalent fossil fuel fleets



Source: GHD Advisory, 2020

1. Introduction

The ERA is conducting a one-off review in accordance with clause 4.11.1E of the Wholesale Electricity Market Rules (the Market Rules). In the review, the ERA is evaluating a mechanism that allows AEMO to reduce a Facility's Certified Reserve Capacity if their outage rate is above the thresholds stated in clause 4.11.1D of the Market Rules.

This report provides analysis on the availability of scheduled generation in the Wholesale Electricity Market (WEM) with comparison to analogous fossil fuel generation plants in the National Electricity Market (NEM), the electricity wholesale market in the UK, and in North America. The North American data is collected by the North American Electric Reliability Corporation (NERC).

1.1 Background

The ERA's review under clause 4.11.1E of the Market Rules is to examine a mechanism in the Market Rules that potentially affects the availability of capacity of generators in the WEM that also participate in the Reserve Capacity Mechanism.

Clause 4.11.1(h) allows that AEMO may decide not to assign any Certified Reserve Capacity to a Facility, or to assign a lesser quantity of any Certified Reserve Capacity to a Facility than it would otherwise assign under clause 4.11.1, if:

i. the Facility has been in Commercial Operation for at least 36 months and has had a Forced Outage rate or a combined Planned Outage rate and Forced Outage rate greater than the applicable percentage specified in the table in clause 4.11.1D, over the preceding 36 months; or

ii. the Facility has been in Commercial Operation for less than 36 months, or is yet to commence Commercial Operation, and AEMO has cause to believe that over the first 36 months of Commercial Operation the Facility is likely to have a Forced Outage rate or a combined Planned Outage rate and Forced Outage rate greater than the applicable percentage specified in the table in clause 4.11.1D,

where the Planned Outage rate and the Forced Outage rate for a Facility for a period are calculated in accordance with the Power System Operation Procedure specified in clause 3.21.12.

Clause 4.11.1D sets out the relevant outage criteria to apply under clause 4.11.1(h) in specified Capacity Years. The thresholds under clause 4.11.1D of the Market Rules are replicated below in Figure 5.

Figure 5: Outage rate limit table in the Market Rules

For AEMO decisions related to the Capacity Cycle	Forced Outage rate greater than	Combined Planned Outage rate and Forced Outage rate greater than
Prior to 2015	15%	30%
2015	14%	28%
2016	13%	26%
2017	12%	24%
2018	11%	22%
2019 onwards	10%	20%

1.2 ERA consultation process

The ERA published an issues paper on 24 April 2020 and received submissions from three stakeholders[3].

In developing our recommendations, GHD has considered stakeholder feedback focussing on matters concerning the availability of generators and WEM data being used to inform analysis.

Table 2 (below) briefly summarises the feedback received in response to the issues paper relevant to our review.

Table 2: Submission to the ERA's consultation paper

Stakeholder	Relevance to technical standards
Alinta Energy	• The availability of a generation facility varies greatly depending on the type of fuel, the design of the facility, how the facility is operated/dispatched, and the stage of its lifecycle that the facility is at • While the IEEE Standard 762 is a standard measure in the northern hemisphere, the networks and systems there are very different from the SWIS in terms of scale, size, capacity and configuration and caution should be used when making comparisons
Synergy	• **Age of facility** – the performance and efficiency of facilities naturally deteriorate over the lifetime of the facility. As the facility ages, an increase in planned outage would be anticipated. • **Provision of ancillary services** – Facilities which are subject to high levels of cycling due to the provision of ancillary services will incur higher levels of wear and tear, expediting the rate of deterioration. • **Market trends** –The current generation mix in the SWIS is a significant departure from when the initial thresholds were set. Increased renewable penetration and the issue of the duck curve has led to heightened levels of cycling for generators which were originally designed to provide base-load generation. Further, thermal generation facilities are experiencing more breakdowns due to rapid load changes. Increased maintenance, and therefor increased planned outages, are now typical occurrences for affected facilities, suggesting that current outage thresholds are no longer appropriate.

[3] ERA Issues paper and submissions responding to the issues paper are available on the ERA website here: https://www.erawa.com.au/electricity/wholesale-electricity-market/methodology-reviews/2020-review-of-incentives-to-improve-availability-of-generators

Stakeholder	Relevance to technical standards
Perth Energy	• Under the IEEE Standard, a failure to start would be logged as a Forced Outage but as soon as the plant starts and synchronises it would be declared fully available…. Accurately applying the IEEE Standard gives a better indication of actual performance and is in line with international practice. • Over the coming years, with the retirement of Muja C and increased investment in intermittent generation, it is likely that gas-fired plant will take on a more important role in the WEM. It may be considered that fleet availability may increase because gas plant has, all things being equal, lower maintenance needs. However, the increase in intermittent generation will force gas plants more into a peaking and back-up role with increased stop-start and cycling operations, which in turn will increase the maintenance requirements of the gas fleet, especially as most of these generators [in the WEM] are heavy industrial-type machines.

1.3 Scope and areas of focus

To assist the ERA with their assessment of clause 4.11.1(h) of the Market Rules, GHD has conducted research and provided information, in the form of this report and accompanying data sets (presented as MS Excel spreadsheets), on:

i) The availability performance of the generation sector in the WEM for 10 years (1 October 2009 to 1 October 2019 – this aligns with Capacity Years under the Market Rules); and

ii) A comparison with analogous generating plants in other markets (the NEM).

GHD conducted the analysis based on 10 years of historical data for scheduled generators in the WEM and developed the following data sets for the ERA:

- Data sets for individual generators, including Availability Factor calculations; and
- Data sets that reflect Aggregated Scheduled Generator fleet Availability Factor calculations.

Analysis looked at five years of data of equivalent fleets in the UK and aggregated data for the NEM and North America.

This report refers to outage rates and outage factors. Descriptions of these terms and the relevant equations are outlined in Chapter 2.

1.3.1 Limitations and assumptions

We note the following limitations to our approach and the data sets that underpin our analysis:

- GHD did not undertake data cleaning activities that corrected or updated data that has, for example, been recorded incorrectly by generators or market operators. We have assumed that the data obtained, particularly for the WEM, was in a suitable format for the required analysis and was free from material errors or omissions.
- GHD did not undertake analysis on the whole of the market, and the total availability factors should not be interpreted in this way. The data considered included only scheduled generators in the WEM (i.e. wind and solar generator are excluded as they are non-scheduled) and equivalent generator fleet

information in comparator markets (i.e. coal, gas, and diesel fuel type generators only and excluded, for example, nuclear, biomass, wind, solar, and other forms of generation).

- GHD's analysis is based on historical data and intended to reflect actual historical experience only. We have not made, nor should any words be misconstrued to represent any estimates of the future availability for any plants, suites of plants or markets in this report.
- Where sufficient data was not made available to calculate a single equivalent availability factor figure (i.e. NEM ESOO data), GHD have calculated the maximum possible range of figures based on the published data. GHD have also provided a single figure for EAF within the range, based on reasonable assumptions for the number of full and partial outages occurring on average over the NEM fleet (details in section 2.2.6, differentiated by the published fuel types).

1.4 Disclaimer

This report has been prepared by GHD for Economic Regulation Authority and may only be used and relied on by Economic Regulation Authority for the purpose agreed between GHD and the Economic Regulation Authority as set out in section 1 of this report.

GHD otherwise disclaims responsibility to any person other than Economic Regulation Authority arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

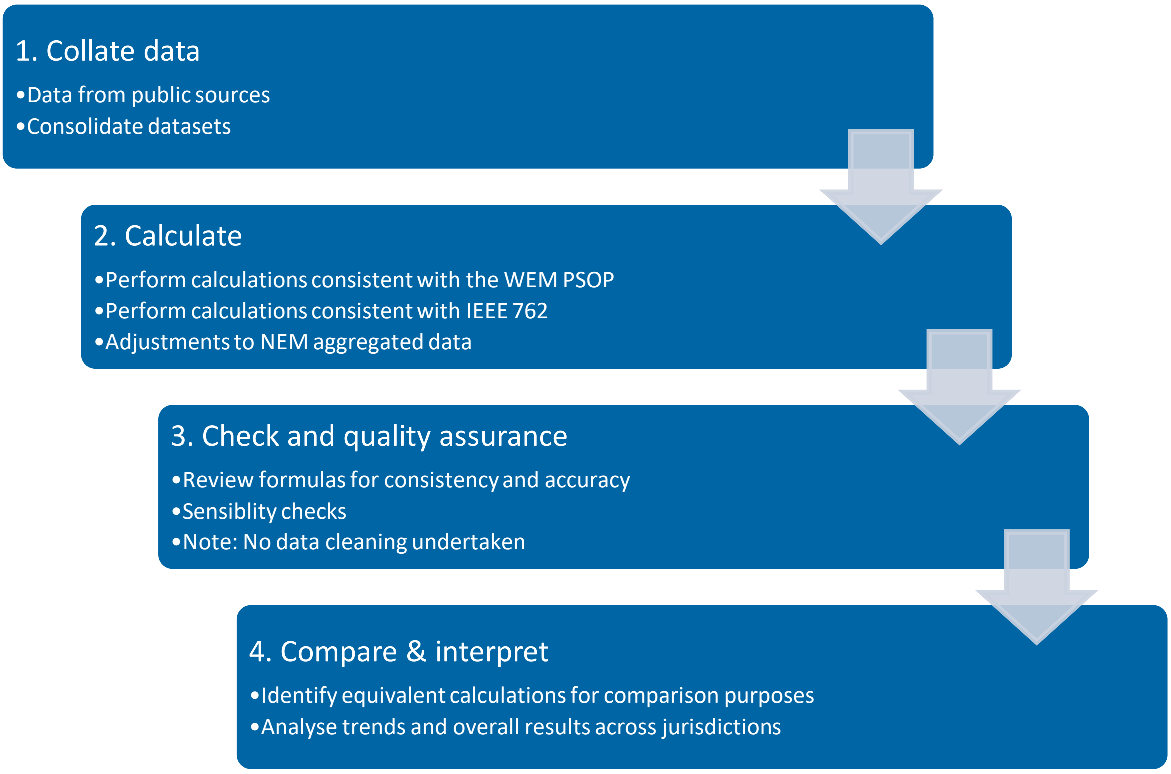
The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

2. Method & calculations

GHD followed the four-step process outlined in Figure 6 (below) to collate and analyse scheduled generator availably data for the WEM and equivalent fossil fuel generation fleets in the UK, NEM, and North America. Each step is outlined below.

Figure 6: GHD method



2.1 Data collection

GHD collated data on generator availability from both the WEM and markets selected for comparison. All data was from publicly available sources.

The data represented all scheduled generators in the WEM (i.e. wind and solar generator are excluded as they are non-scheduled) and equivalent generator fleet information in comparator markets (i.e. coal, gas, and diesel fuel type generators only).

Individual unit data was used for analysis of the WEM and UK generator fleets and, due to limits of the availability of public information, aggregated data informed the NEM and NERC analysis. We do not believe the use of aggregate data invalidates its use as a point of comparison for the WEM.

We collated 10 years of data for the WEM and used data representing the most recent five years of data for the NEM, UK and US markets. GHD considers adopting a five-year data set as the point of comparison with other jurisdictions is appropriate as across that period all of the jurisdictions included in the comparison have seen a substantial shift to renewable generation and hence changed operating conditions for existing thermal generators.

A summary of the data sources used for the purposes of this report is provided in Table 3.

Table 3: Summary of data sources

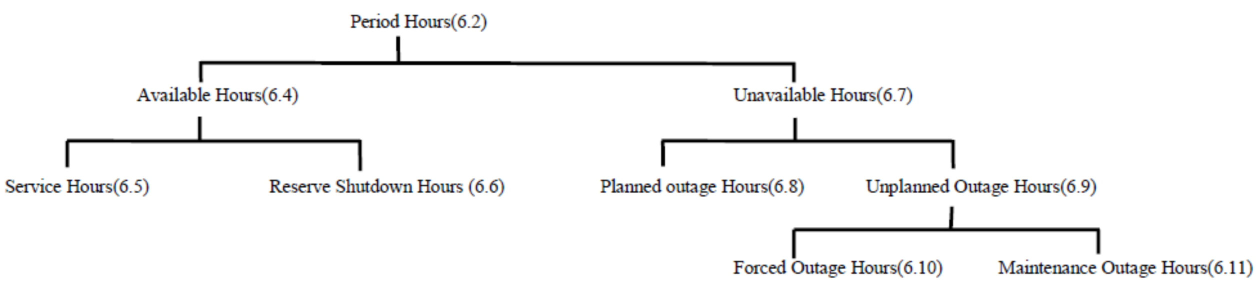
Market	Data availability	Notes on data
WEM	Individual unit data available from 2006 onwards	GHD obtained WEM outage data through the AEMO data site (http://data.wa.aemo.com.au/#outages). It is noted that outage data from AEMO for the WEM is supplied for each trading interval for the period 5 Sept 2006 onwards, with each file typically containing data for a 12 month period (from 8 AM on 1 Jan to 7.30 AM on 1 Jan the following year). Included within the data preparation will be a provision to convert outage data to align with the Capacity Years as defined under the Market Rules. Capacity Years start at 8:00 AM on 1 Oct each year and finish at the end of the 7:30 AM trading interval on 1 Oct of the subsequent year. GHD obtained unit 'in service' duration data from the AEMO data site (http://data.wa.aemo.com.au/#facility-scada). The monthly output files were collated in the same manner as above to align with Capacity Years. Capacity credit data was obtained from AEMO (https://www.aemo.com.au/energy-systems/electricity/wholesale-electricity-market-wem/wa-reserve-capacity-mechanism/assignment-of-capacity-credits). Generator fuel type and age of plant information to supplement subsequent market comparisons by type was obtained through publicly available data from AEMO.
NEM	Generator reliability data used for the ESOO available	Individual generation unit reliability data is not published for the NEM and is considered confidential information. Generator failure rates aggregated by generation class is published by AEMO as part of the ESOO data set. Six years of data sets are available on the AEMO web site (https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/forecasting-and-reliability/nem-electricity-statement-of-opportunities-esoo). As the aggregate forced outage rates per generation class have been developed using approaches aligned with the IEEE standard, the NEM data should be able to be compared with statistics for the WEM derived by applying the IEEE standard.
NERC	Aggregated data based generator type and size, available for the calendar years 2014 to 2018	GHD has obtained generator outage data from publicly available information posted by NERC (https://www.nerc.com/pa/RAPA/gads/Pages/Reports.aspx). The data available from the NERC is presented as a summary for the calendar year in of the report. Due to the aggregated nature of the data available, it is not possible to align with Capacity Years under the market rules running from 8:00 AM on 1 Oct to the end of the 7:30 AM trading period on 1 Oct of the subsequent year. Data is available over individual calendar years and 5-year averages with the first individual report available from 2014 and 5 year average of the period 2010-2014. Aggregated data within each of the reports include Available Factor calculation outputs for various capacities within different fuel types.
ENTSOE (UK)	Individual data available from 2014 onward	GHD has sourced UK outage data from the ENTSOE transparency platform available online (https://transparency.entsoe.eu/). Complete individual unit planned and unplanned (15.1a and 15.1b respectively) reports are provided for a requested period. Within data collation and cleansing steps, data has been aligned to match WEM Capacity Years. Using publicly available reports for BM unit ID's by NETA (https://www.netareports.com/data/elexon/bmu.jsp), outages have been aggregated by fuel type and capacity range to be used for the ensuing comparisons. The individual generator information within datasets provided by ENTSOE allows for specific comparisons of like-for-like generators present within the WEM, allowing for a higher resolution of availability factor at the generator level.

2.2 Calculations

To develop the final data tables and analysis, GHD undertook a series of calculations consistent with the AEMO's *WEM Rules Power System Operating Procedure: Facility Outages*[4] (the WEM PSOP) and the Institute of Electrical and Electronics Engineers Standard (IEEE) 762 – IEEE Standard Definitions for Use in Reporting Electric Generating Unit Reliability, Availability, and Productivity (IEEE 762).

The calculations each consider the amount of time units spend in various states outlined in Figure 7 with the particular calculation considering a subset of the times. The categories in Figure 7 are designed to be mutually exclusive and to cover all hours, hence Period Hours is typically set equal to the number of hours in a year (8,760)[5] for annual calculations.

Figure 7: Time spent in various states



Source: IEEE 763, Figure 3, p. 16. Numbers in brackets refer to explanatory sections of IEEE 762.

The following table summarises the equations used by GHD. In each case, GHD used equivalent calculations that consider the role of partial outages. This compares to non-equivalent calculations where a partial outage, for example, is not treated as an outage. Each of the calculations is outlined below.

Table 4: Calculations used for analysis

Calculation	Description	Comment
Equivalent outage rates	% of time that the generator is required to generate power but not able to do so due to a planned or unplanned failure	Aggregate fuel class outage rates are published by AEMO for the NEM.
Equivalent outage factor	% of time in which the generator is experiencing a full or partial outage	The same formula as the formula used for equivalent outage rates in the WEM PSOP.
Equivalent availability factor	% of time that the generator is available to generate power	
Weighted equivalent availably factor	Weighted average of the availability factors for the fleet or a particular class of generators (as specified)	Unit availability is weighted based on their proportion of capacity credits for the WEM and based on nameplate capacity for other markets.

[4] AEMO, *WEM Rules Power System Operation Procedure: Facility Outages*, version 7.0, 1 February 2020.

[5] Hours per year is 8,760 and 8,784 for leap years.

2.2.1 Equivalent Outage Rates (EOR)

For calculating the Equivalent Forced and Planned Outage Rates in the WEM, the equation shown below, which reflects IEEE 762 (equation 9.17), was used. GHD notes the difference between the EFOR and FOR as being the EFOR considers equivalent forced derated hours to include the impact of partial outages.

$$EFOR_{IEEE} = \left[\frac{\sum_{i=1}^{N} FOH_i + EFDH_i}{\sum_{i=1}^{n} FOH_i + SH_i + ERSFDH_i}\right] \times 100$$

Where:

FOH = Forced outage hours

EFDH = Equivalent forced derated hours

SH = Service hours

ERSFDH = Equivalent reserve shutdown forced derated hours (i.e. the reserve shutdown hours converted to equivalent hours. Note: Reserve shut down forced derated hours are, by definition, not during a period of demand for the unit to operate)

This equation can be extrapolated for each of the outage type flags given within each jurisdiction. For example, EFOR can be extrapolated to describe an outage rate for consequential outages within WEM outage data (ECOR), using the consequential outage hours (COH) and equivalent derated hour values (ECDH) in place of FOH and EFDH respectively.

Where Service Hour data was readily available, equivalent outage rates were calculated to be compared against one another in the following findings sections. Missing from this analysis is the inclusion of values for the UK market due to the unavailability of Service Hours.

2.2.2 Equivalent Outage Factors (EOF)

In calculating the Equivalent outage factor for a given unit in the WEM and the UK, the PSOP approach and equations were implemented. It is noted that although the PSOP defines equations given in following sections as 'rates', inspection and comparison of equivalent equations within IEEE 762 (see table below) better quantifies these values as equivalent outage factors. It is also noted that the PSOP document also does not refer to the values calculated within the given formulas as 'equivalent', comparison with IEEE standards contradicts this.

For the purpose of consistency, PSOP equations from this point forward will be referred to as their corresponding equivalent IEEE values as illustrated within Table 5(overleaf).

Table 5: Comparison of WEM PSOP Formulae with Equivalent IEEE Equations

WEM PSOP formula	IEEE 762 formula
$FOR_{WEM} = \frac{(FOH\ +\ EFDH)\ \times\ 100}{PH}$	$EFOF_{IEEE} = \left(\frac{FOH\ +\ EFDH}{PH}\right) \times 100$
$POR_{WEM} = \frac{(POH\ +\ EFDH)\ \times\ 100}{PH}$	$EPOF_{IEEE} = \left(\frac{POH\ +\ EFDH}{PH}\right) \times 100$

Where:

FOR = Forced outage rate
POR = Planned outage rate
FOH = Forced outage hours
POH = Planned outage hours
EFDH = Equivalent Forced Derated Hours
EPDH = Equivalent Planned Derated Hours
PH = Period hours
SH = Service hours

The values for components in the PSOP formulas from raw outage data are as follows:

FOH (Forced Outage Hours) = sum of all Trading Intervals

Where: Outage MW = Capacity Credit (MW) and the Outage Reason is Planned and during the period P multiplied by 0.5.

POH (Planned Outage Hours) = sum of all Trading Intervals

Where: Outage MW = Capacity Credit (MW) and the Outage Reason is Planned and during the period P multiplied by 0.5.

EFDH (Equivalent Forced Derated Hours) = sum of all trading intervals

Where: Outage MW < Capacity Credit (MW) and the Outage Reason is Forced and during the period P multiplied by 0.5 multiplied by Outage MW/Capacity Credit (in MW).

EPDH (Equivalent Planned Derated Hours) = sum of all trading intervals

Where: Outage MW < Capacity Credit (MW) and the Outage Reason is Planned and during the period P multiplied by 0.5 multiplied by Outage MW/Capacity Credit (in MW).

PH (Period hours) = where the Facility has been operating over all of period P, the number of Trading Intervals that occurred within the last 36 months, multiplied by 0.5; or where the Facility has been operating for less than period P, the number of Trading Intervals that occurred in period P after the Facility commenced operation, multiplied by 0.5.

The equations above can be extrapolated for each of the outage type flags given within each jurisdiction. For example, EFOF can be extrapolated to describe an outage factor for consequential outages within WEM outage data (ECOF), using the consequential outage hours (COH) and equivalent derated hour values (ECDH) in place of FOH and EFDH respectively.

It is also noted that AEMO uses a period of 36 months for PSOP calculations, where GHD has only included a period of 12 months, to reflect the WEM capacity year.

2.2.3 Equivalent Availability Factors (EAF)

For the WEM and the UK data, using the PSOP outage factor approach, the equivalent availability factor was calculated as 1 minus the sum of all outage factors calculated for a unit in a given jurisdiction (for example the WEM equation given below).

$$EAF_{WEM} = 1 - [EFOF_{WEM} + EPOF_{WEM} + ECOF_{WEM}]$$

$$EAF_{WEM} = 1 - \left[\frac{(FOH + EFDH) \times 100}{PH} + \frac{(POH + EPDH) \times 100}{PH} + \frac{(COH + ECDH) \times 100}{PH}\right]$$

Where:

EAF = Equivalent availability factor

EFOF = Equivalent forced outage factor

EPOF = Equivalent planned outage factor

ECOF = Equivalent consequential outage factor

FOH = Forced outage hours

POH = Planned outage hours

COH = Consequential outage hour

EFDH = Equivalent forced derated hours

EPDH = Equivalent planned derated hours

ECDH = Equivalent consequential derated hours

PH = Period hours

For the UK, a similar approach was used, however as the consequential outage data is captured within the forced and planned outage data, the equation for the equivalent availability factor is equal to 1 minus the sum of the planned and forced outages factors to the UK.

It is noted GHD's initially proposed providing the ERA with analysis based on individual unit availability factors. However, through further analysis, GHD and the ERA agreed the EAF is a more accurate measurement as partial outages are also taken into account within the supporting EOF equations in the previous section.

2.2.4 Weighted Equivalent Availability Factor (WEAF)

To better aggregate results based on the relative size and fuel type of a unit compared with other like units in analogous markets, the Weighted Equivalent Availability Factor was calculated from the equation within IEEE 762 (10.11) and is repeated below.

$$WEAF = \left(\frac{\sum_{i=1}^{n}[(AH_i\ x\ NMC_i) - (EUNDH_i + ESDH_i) \times NMC_i]}{\sum_{i=1}^{n}(PH_i \times\ NMC_i)}\right) \times 100$$

Where:

WEAF = Weighted equivalent availability factor

AH = Available hours

NMC = Net maximum capacity

EUNDH = Equivalent unit derated hours

ESDH = Equivalent seasonal derated hours

PH = Period Hours – represented as the number of hours a unit was in the active state.

The above calculation for the WEM uses the weighting factors specified in the request for quotation, namely the generator capacity credits as a proportion of the total capacity credits for scheduled generators for that capacity year. This simplifies the above formula for an individual unit to the following:

$$WEAF_{Individual\ Unit} = EAF_{Individual\ Unit} \times \frac{Unit\ Capacity\ Credits}{Total\ Scheduled\ Generator\ Capacity\ Credits}$$

Where:

WEAF = Weighted equivalent availability factor

EAF= Equivalent availability factor

In the UK case, where an equivalent capacity credit system is not implemented, GHD substituted capacity credits in the above equation with generating unit's maximum stated capacity. Likewise, the total scheduled generator capacity credits for a given year are substituted with the total fleet generation capacity in the UK market.

2.2.5 Impact of 30 minutes reporting period

In IEEE 762 the 'availability factor' of a generating unit is defined as the "fraction of a given operating period in which a generating unit is available without any outages" and the 'equivalent availability factor' is defined as the "fraction of a given operating period in which a generating unit is available without any outages and equipment or seasonal deratings".

The description in IEEE 762 suggests an analysis that considers timeframes below the 30-minute intervals at which data is available for the WEM, NEM and the UK. Given the data limitations, GHD has calculated outage statistics assuming outages present in the data persist for the full half-hour interval in which they appear.

2.2.6 NEM calculations

AEMO does not publish individual outage data statistics for the NEM, as this is considered confidential information, instead publishing outage rates and other data in its Electricity Statement of Opportunities. GHD has used this information to back-calculate a range of possible values for outage numbers and equivalent availability factors, based on IEEE 762 formulas as follows:

AEMO publishes forced full and partial outage rates, along with mean-time-to-repair values, maintenance rates and a partial outage derating factor. These values are prepared in accordance with the methodology laid out in IEEE 762. GHD used these values to calculate:

$$FFOH_{NEM} = No.of\ full\ forced\ outages \times MTTR(full)$$

$$PFOH_{\ NEM} = No.of\ partial\ forced\ outages \times MTTR(partial)$$

Where:

FFOH = Full forced outage hours

PFOH = Partial forced outage hours

MTTR = Mean-time-to-repair

The forced outage hour calculations were then used to calculate the equivalent availability factors of the generation fleet through the following equations:

$$EFOH_{\ NEM} = FFOH_{\ NEM} + PFOH_{\ NEM}$$

$$EUH_{\ NEM} = EFOH_{\ NEM} + Maintenance\ Rate_{\ NEM} \times \frac{PH}{100}$$

$$EUF_{\ NEM} = \frac{EUH_{\ NEM}}{PH}$$

$$EAF_{\ NEM} = 1 - \frac{EUH_{\ NEM}}{PH}$$

Where:

FFOH = Full forced outage hours

PFOH = Partial forced outage hours

EFOH = Equivalent forced outage hours

EUH = Equivalent unavailability hours

EUF = Equivalent unavailability factor

EAF = Equivalent availability factor

The equivalent availability factor for the NEM was calculated applying IEEE formulas. However, it was necessary to evaluate a suitable range of assumptions for the number of full and partial outages occurring on a plant.

GHD was not able to use forced outage rates to back-calculate outage hours as no service data is provided by AEMO. As such, GHD developed assumptions regarding the number of full and partial outages occurring for each evaluated type of plant. It was also necessary to evaluate a check on these outages, to determine a possible range of values for the availability factors of generation.

$$ESH_{NEM} = \frac{FFOH_{NEM} \times 100}{FFOR} - FFOH + \frac{PFOH_{NEM} \times 100}{PFOR} - PFOH$$

Where:

FFOH = Full forced outage hours

PFOH = Partial forced outage hours

ESH =Equivalent service hours

The equivalent service hours calculation was carried out consistent with the equivalent forced outage rate calculation in IEEE 762. As the ESH calculation was dependant on the FOH and POH calculations, it was, therefore, dependant on the assumption around the number of outages.

To check that GHD had made reasonable assumptions regarding the number of outages, GHD checked that the sum of the calculated ESH, EFOH and the maintenance hours specified by AEMO did not exceed the PH. This allowed GHD to identify a feasible range for the number of outages.

To arrive on a final figure for EAF it was necessary to make an assumption around the number of full and partial outages. The full outage figure was selected in the middle of the possible range of values. The partial outage figure was usually not significantly material to the availability factor, due to the low number of hours offline attributable to partial outages. After consulting with internal subject matter experts and conducting a review of a year of WEM partial outage data, GHD was able to observe that the variance in partial outages numbers were such that an average figure was difficult to predict across a fleet. However, in general, coal plants appeared more likely to suffer partial outages than gas plant. GHD has relied on advice of internal subject matter experts to select appropriate quantities for the number of forced and partial outages.

2.3 Check

Senior members of our project team reviewed all calculations for accuracy and consistency. Trends in the calculated availability factors and outage rates were reviewed to assess whether the results aligned with the expectations of our reviewers based on their experience working in the power industry.

2.4 Compare & interpret analysis

Once data for the various markets had been prepared, GHD compared the outage rates and availability factors across the markets. Our findings are presented in Chapter 3.

Due to the nature of definitions that drive reporting by generators on the underlying outage data and the various types of calculations (as described above), care is required in making comparisons. In particular, we have developed international comparisons that consider the EAF for WEM units and compare them to a WEAF for the WEM, UK, NEM and North America (as aggregated in the NERC data).

- The WEAF considers the relative contribution of individual units in the market based on their capacity credits (for the WEM) and the nameplate capacity of the unit for other jurisdictions.

- Comparisons are made using the full 10 years of data for the WEM and care has been taken to ensure plants that did not generator in a particular year are excluded from the analysis for that year even if they received capacity credits.
- Similarly, decommissioned or mothballed units have been removed from the annual data for the UK as the approach would over wise be skewed by these plants returning outages that continue for the full year.

Further, outage classifications across jurisdictions are complicated by differing definitions in different jurisdictions. GHD has worked with the classifications and definition used in the various jurisdictions and did not seek to alter these.

3. Results

This Chapter presents the results from GHD's analysis of WEM Scheduled Generator availability factors and comparisons with equivalent fossil fuel fleet in the UK, North America (as presented in NERC data) and the NEM.

3.1 WEM Scheduled Generators

Analysis presented in this section draws on the 10 years analysis period and covers changes overtime in the:

- Availability factors for scheduled generators and weighted availability factors for classes of generating units
- Contributions to capacity
- Age of units

3.1.1 Availability of Scheduled Generators

Figure 8 shows the average annual WEAF for WEM Scheduled Generators by fuel type for capacity years 2009-10 to 2018-19 and the 10-year average is summarised in Table 6.

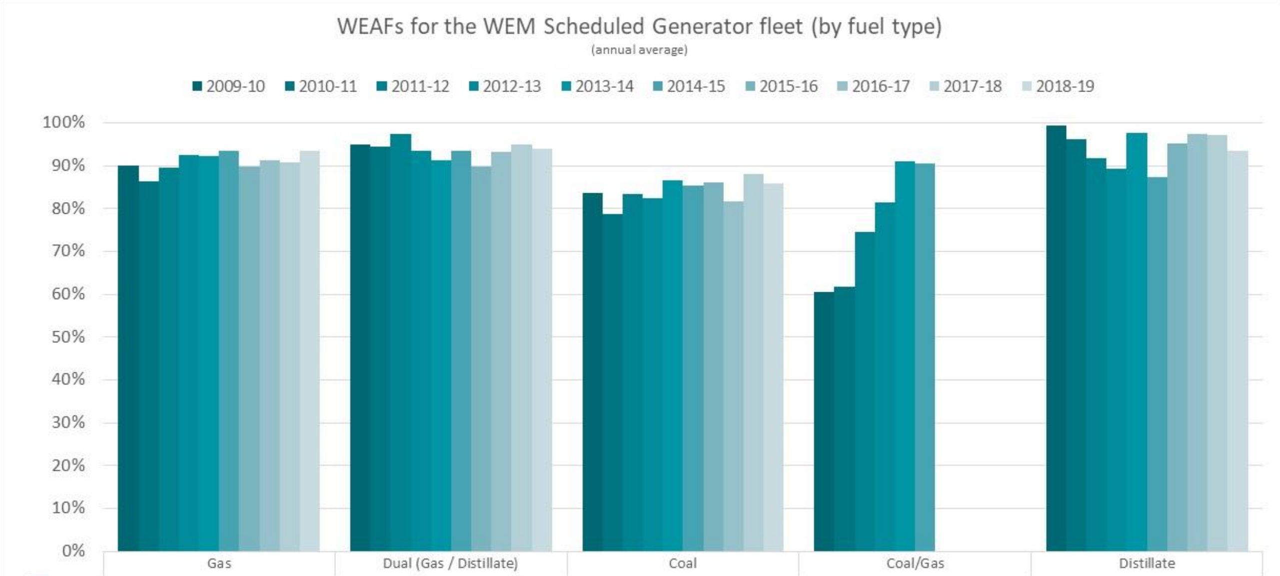
The WEAF for all Scheduled Generators in the WEM has improved slightly over the analysis period, increasing from 86 and 83 per cent in 2009-10 and 2010-11 capacity years respectively to 91 per cent for the 2017-18 and 2018-19 capacity years respectively.

Figure 8 shows the availability for most fuel classes has remained stable (dual (gas/distillate) and distillate) or increased slightly (gas, coal) over the analysis period. The exception is the coal/gas fleet, for which WEAF increased significantly from 60 per cent to 90 per cent in 2014-15 after which all the units were retired. The coal/gas units in the fleet are Kwinana G1, G3, G5 and G6.

Table 6: 10-year average WEAF for WEM Scheduled Generators

Fuel type	10-year average WEAF (%)	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19
Gas	**91%**	90%	86%	89%	92%	92%	94%	90%	91%	91%	93%
Dual (Gas / Distillate)	**94%**	95%	94%	97%	93%	91%	93%	90%	93%	95%	94%
Coal	**84%**	84%	79%	83%	82%	86%	85%	86%	82%	88%	86%
Coal/Gas	**77%**	60%	62%	74%	81%	91%	90%				
Distillate	**94%**	99%	96%	92%	89%	98%	87%	95%	97%	97%	93%
All Scheduled Generation	**89%**	**86%**	**83%**	**88%**	**89%**	**90%**	**90%**	**89%**	**89%**	**91%**	**91%**

Figure 8: Average annual WEAF for WEM Scheduled Generators (2009-10 to 2018-19) (by fuel type)



	Gas	Dual (Gas / Distillate)	Coal	Coal/Gas	Distillate
2009-10	90%	95%	84%	60%	99%
2010-11	86%	94%	79%	62%	96%
2011-12	89%	97%	83%	74%	92%
2012-13	92%	93%	82%	81%	89%
2013-14	92%	91%	86%	91%	98%
2014-15	94%	93%	85%	90%	87%
2015-16	90%	90%	86%		95%
2016-17	91%	93%	82%		97%
2017-18	91%	95%	88%		97%
2018-19	93%	94%	86%		93%

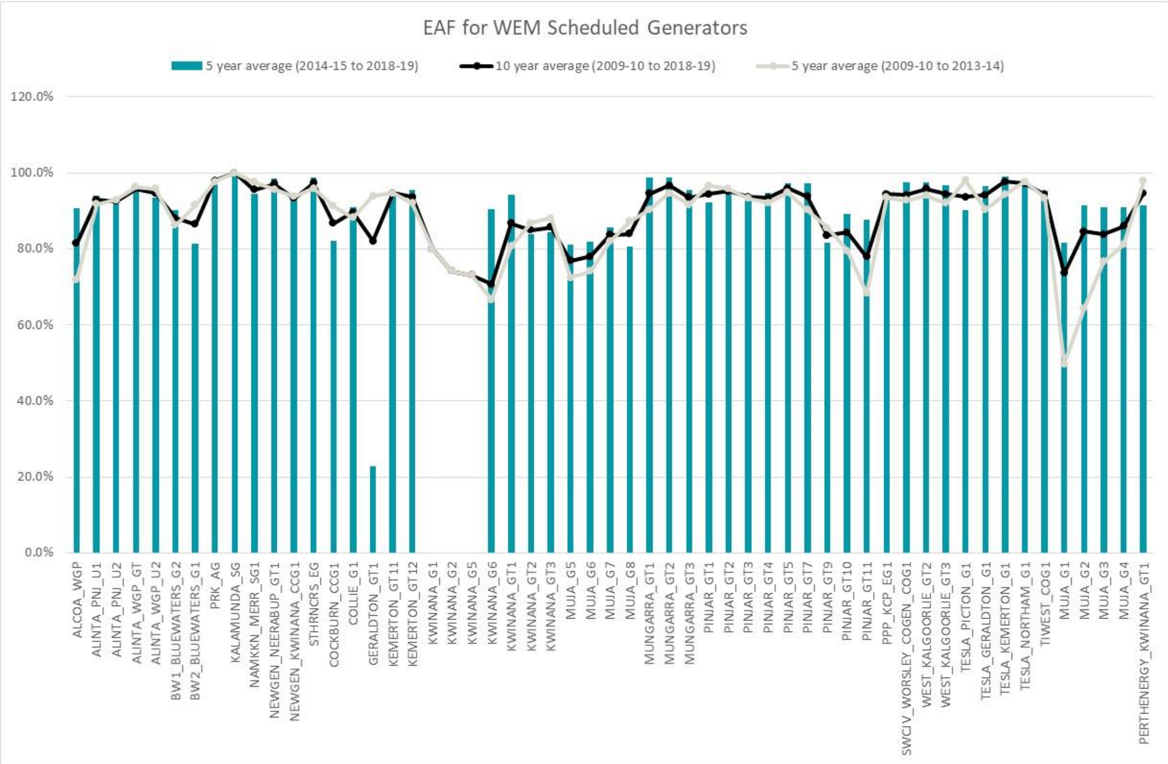
Source: GHD Advisory, 2020

3.1.2 Comparison of 5-year and 10-year average EAF

Figure 9 (below) shows the 5-year and 10-year average EAF for Scheduled Generator units in the WEM. The averages were calculated using the unit EAF data for the most recent 5 years of data (covering the period 2014-15 to 2018-19), the 10-year period (covering the period 2009-10 to 2018-19) and the initial 5 years of data for the period (covering 2009-10 to 2013-14).

As shown in the figure, a number of units that retired do not return results for the most recent 5-year period. As such, the international comparisons presented in section 3.2 are based on the 10-year average results.

Figure 9: Comparison of 5-year and 10-year average EAF for WEM Scheduled Generators



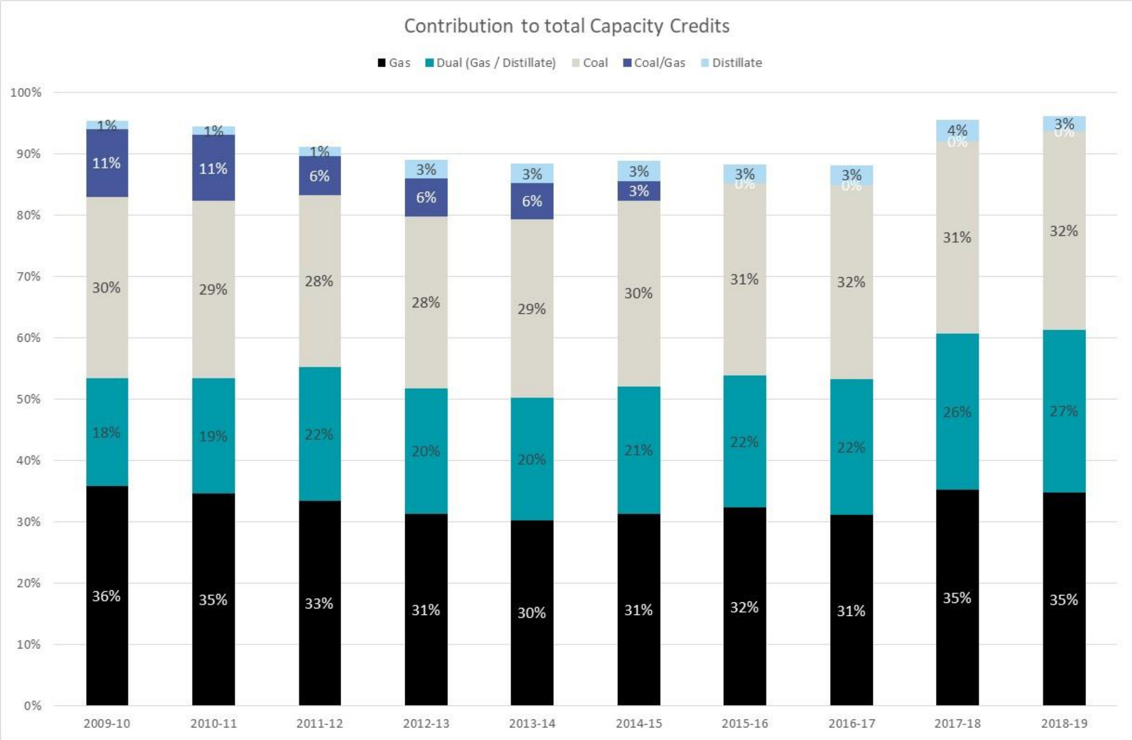
Source: GHD Advisory, 2020

3.1.3 Contributions to capacity

Figure 10 and Figure 11 (below) show the contribution of Scheduled Generators in the WEM to total capacity and total Scheduled Generation capacity respectively, as indicated by relative quantitates of capacity credits to total capacity credits or total Scheduled Generation capacity credits.

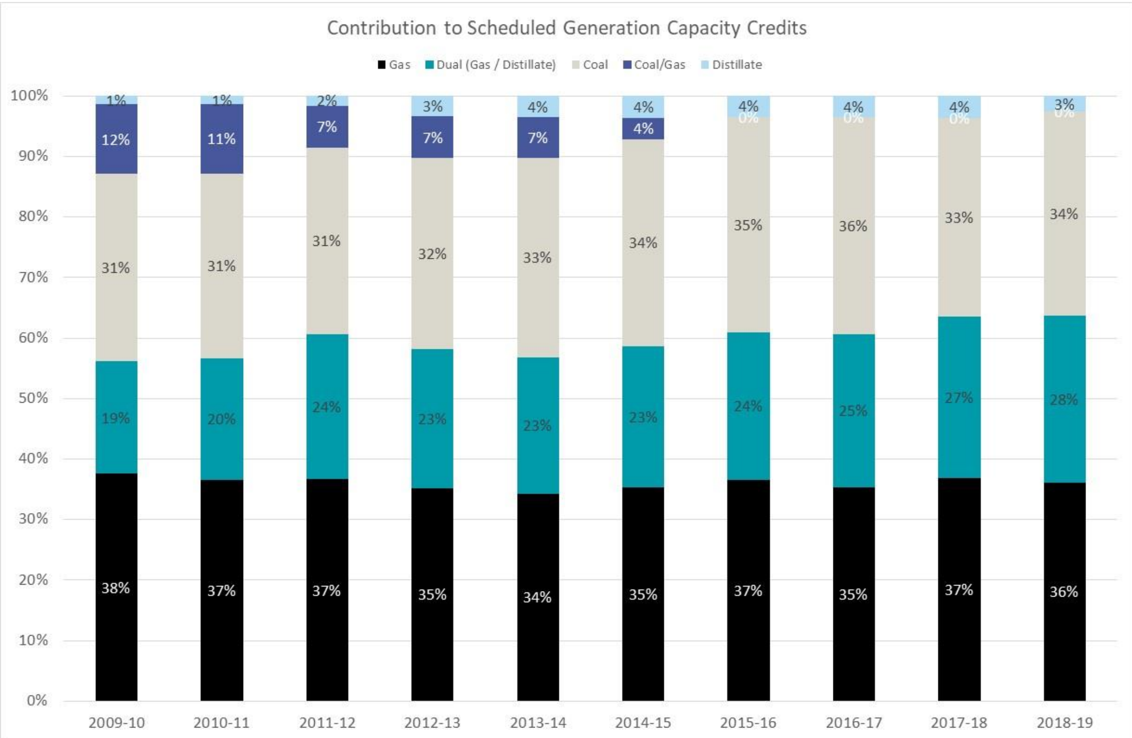
Changes in the WEM fleet that received capacity credits are evident in both figures. It is noted that the capacity credits represent a subsection of the generation available in the WEM at any point in time, further Figure 11 considers only Scheduled Generators' Capacity Credits, and as such excludes wind, solar, biomass and landfill gas units.

Figure 10: Annual contribution to total capacity credits (2009-10 to 2018-19)



Source: GHD Advisory, 2020

Figure 11: Annual contribution to Scheduled Generation capacity credits (2009-10 to 2018-19)



Source: GHD Advisory, 2020

3.1.4 Average age of units

Publicly available data on the commissioning dates for WEM units is not complete. As AEMO typically publishes this data only for the current fleet, the age of retired generators is unknown. Units that were retired during the analysis period have therefore been excluded from the following analysis.

Units excluded from the age analysis are Geraldton GT1, Kwinana G1, G2, G5, G6 and GT1, Mungarra GT2, SWCJV Worsley Cogen COG1, and Muja G1, G2, G3, G4.

Figure 12 (overleaf) shows the average age of WEM Scheduled Generators by fuel type over the period. The ages are calculated as a straight average (based on the number of units with Capacity Credits). Figure 13 (overleaf) shows the weighted average age of the WEM Scheduled Generators. However, data shown in this figure weights the age of each unit by the unit's contribution to capacity credits in the relevant fuel class. Note: there is no data shown for the Coal/Gas fleet as age data was not available for these units.

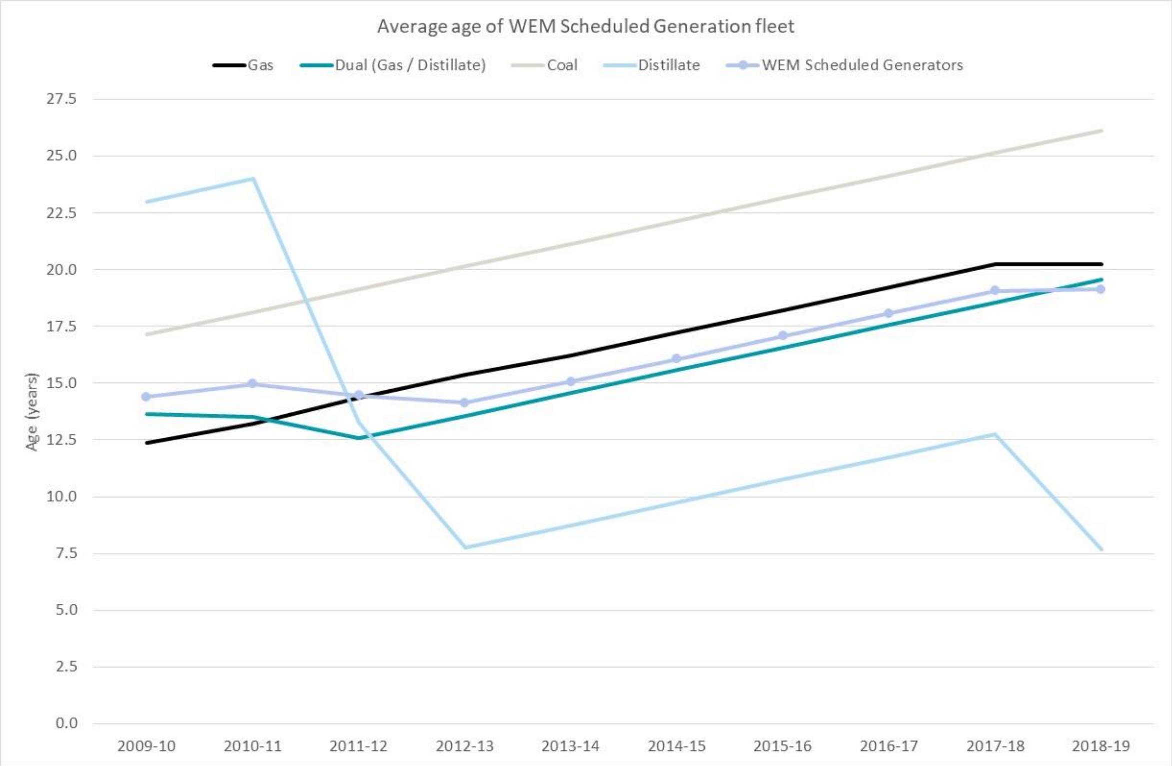
For most fuel types, the average age of the unit increased over the analysis period, consistent with the passing of time. However, the average age of distillate plants reduced between the 2009-10 and 2012-13 capacity year. This is due to the entrance of Kalamunda SG (1.3 MW) in 2010, Merredin SG1 (92.6 MW) in 2011, and Tesla's Picton G1 (9.9 MW), Geraldton G1 (9.9 MW), and Kemerton G1 (9.9 MW) units in 2011 and the Tesla Northam G1 (9.9 MW) unit in 2012.

The oldest units still active in the WEM are:

- Alcoa's Wagerup Gas (26 MW) commissioned in 1981
- Muja G5 (195.8 MW), G6 (193.6 MW), G7 (212.6 MW), and G8 (212.6 MW) coal units commissioned in 1981 (G5 and G6) and 1986 (G7 and G8)
- West Kalgoorlie GT2 (41.2 MW) distillate unit commissioned in 1984

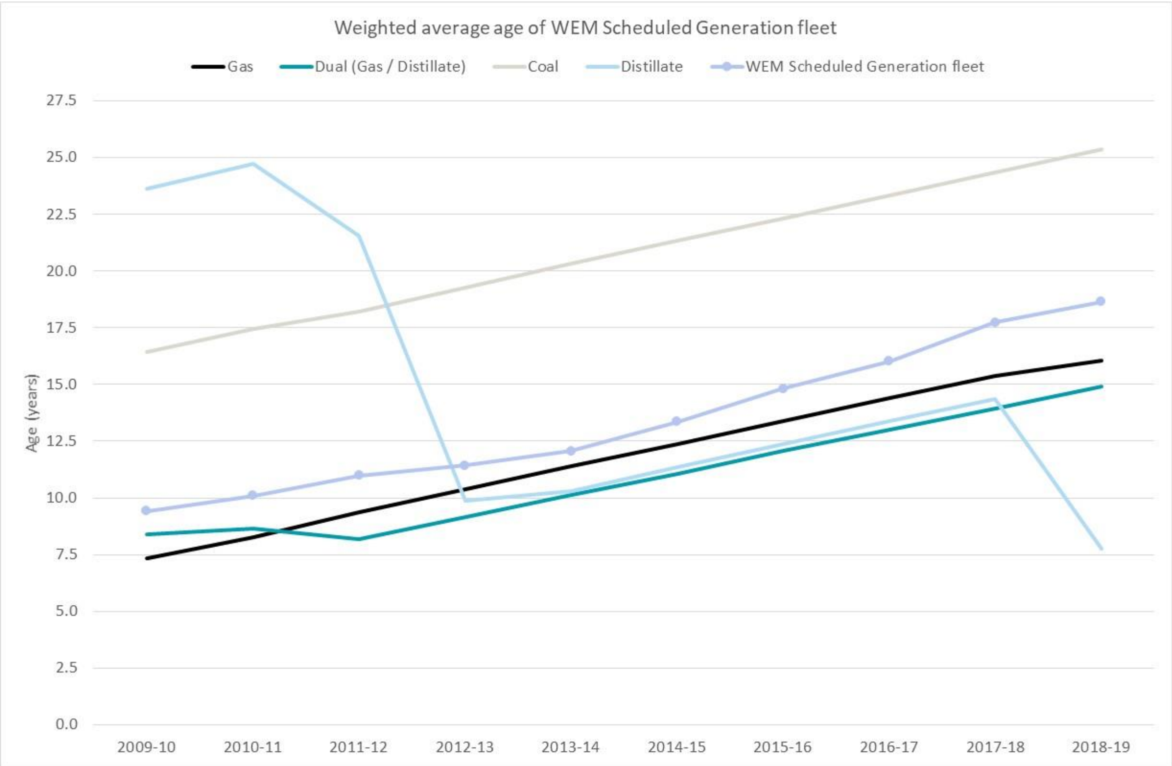
The newest units in the WEM were commissioned in 2010, 2011 and 2012. These include the distillate units outlined above, as well as the Perth Energy Kwinana G1 (116.0 MW) dual (gas / distillate) unit commissioned in 2010 and the Kwinana G2 (103.2 MW) and G3 (103.2 MW) dual (gas/ distillate) units commissioned in 2011.

Figure 12: Average age of WEM Scheduled Generators (active units only)



Source: GHD Advisory, 2020

Figure 13: Weighted average age of WEM Scheduled Generators (active units only)



Source: GHD Advisory, 2020

3.2 International comparison

The results in this section present a comparison of the WEM Scheduled Generator unit availability factors with comparative generator fleets in the UK, North America (as aggregated in the NERC data) and the NEM.

The following comparisons are provided:

- All fossil fuel units
- Gas fleet
- Coal fleets

The figures presented use the 10-year average EAF for scheduled generator units in the WEM and a five-year average WEAF for equivalent generator fleets in the UK, North America (as aggregated in the NERC data). A three-year average representing seven years of outage data is used for the NEM. AEMO updates generator reliability data each year, publishing aggregate availability statistics which are the average of the data captured across the previous four years.

3.2.1 All fossil fuel generators

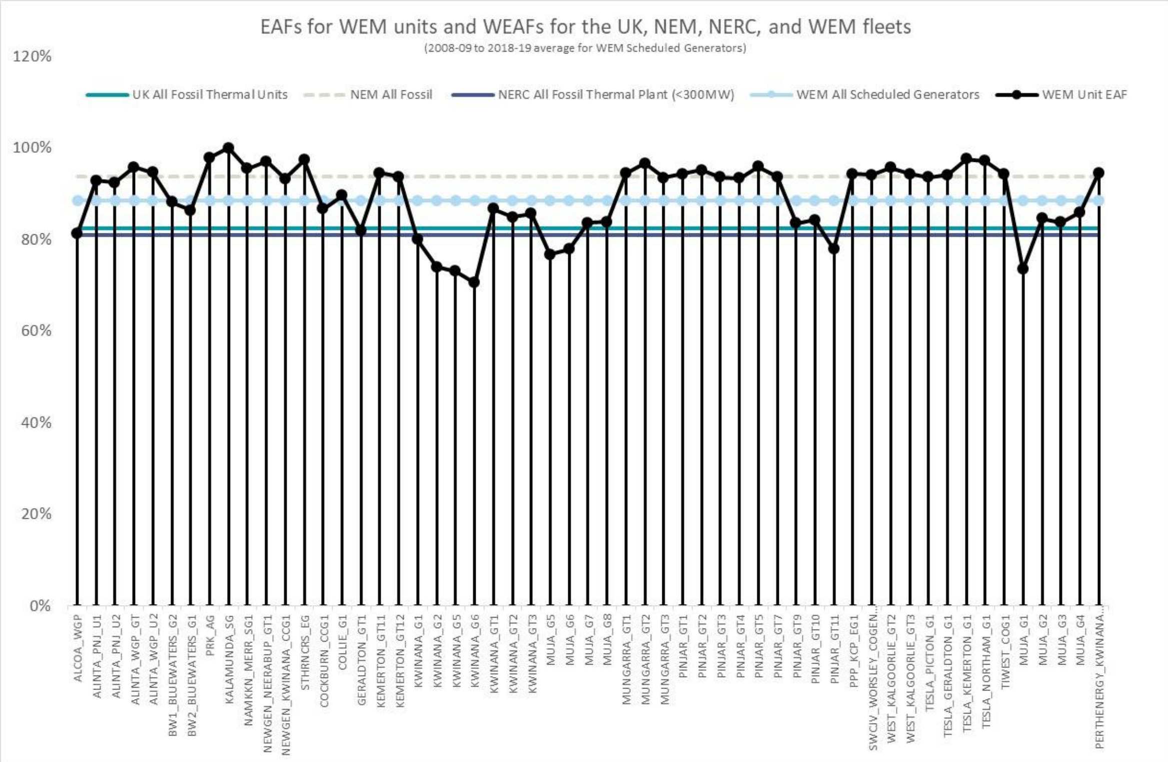
Figure 14 (below) provides a comparison of the 10-year average EAF for all Scheduled Generation units in the WEM, the WEAF for the WEM Scheduled Generator fleet and WEAFs for equivalent fossil fuel fleets in other jurisdictions.

The scheduled generation units in the WEM have an average WEAF of 89 per cent. Data indicates the units are, on average, more available than comparable fossil fuel fleets in the UK (83 per cent) and based on NERC data (80 per cent for units <300 MW), however they are less available than the equivalent fleet in the NEM (94 per cent).

Several of the generators with lower than average availability retired during the analysis period. Units that retired during the period are Geraldton GT1, Kwinana G1, G2, G5, G6 and GT1, Mungarra GT2, SWCJV Worsley Cogen COG1, and Muja G1, G2, G3, G4.

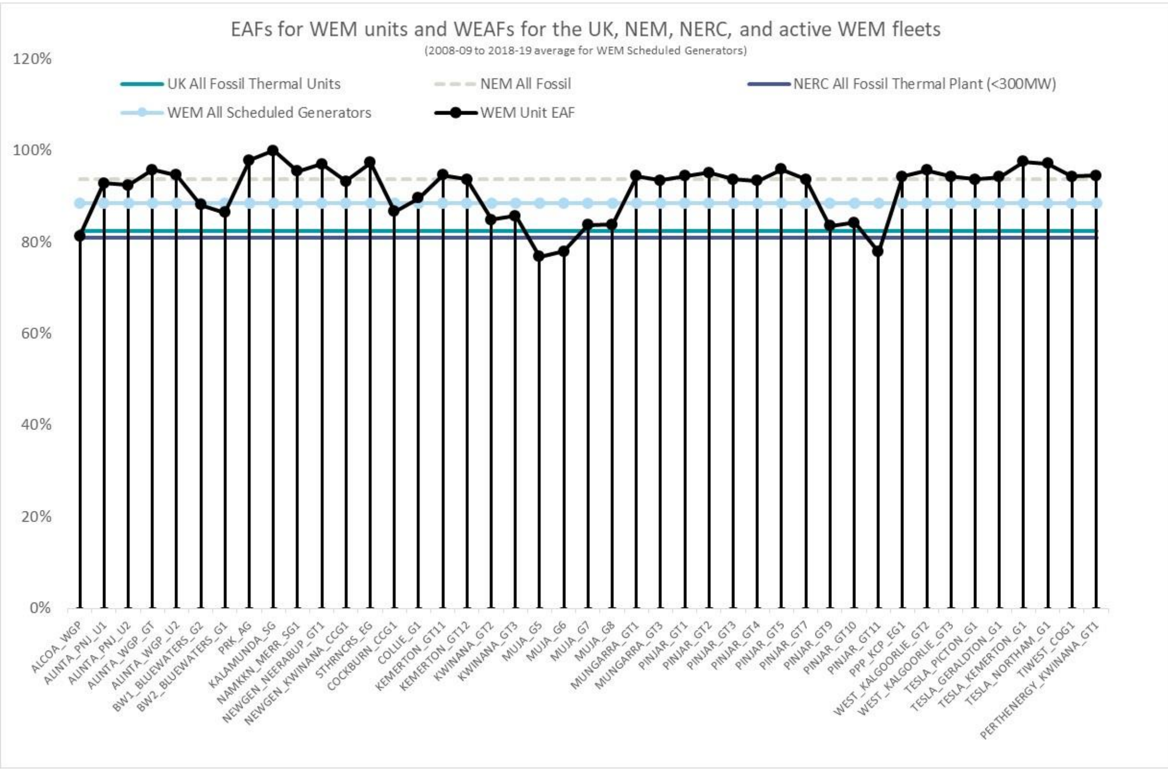
Figure 15 provides the same information as Figure 14, however retired units have been removed from the EAF unit representations.

Figure 14: Comparison of WEM Scheduled Generators with equivalent fossil fuel fleets



Source: GHD Advisory, 2020

Figure 15: Comparison of active WEM Scheduled Generators with equivalent fossil fuel fleets



Source: GHD Advisory, 2020

3.2.2 Gas fleet

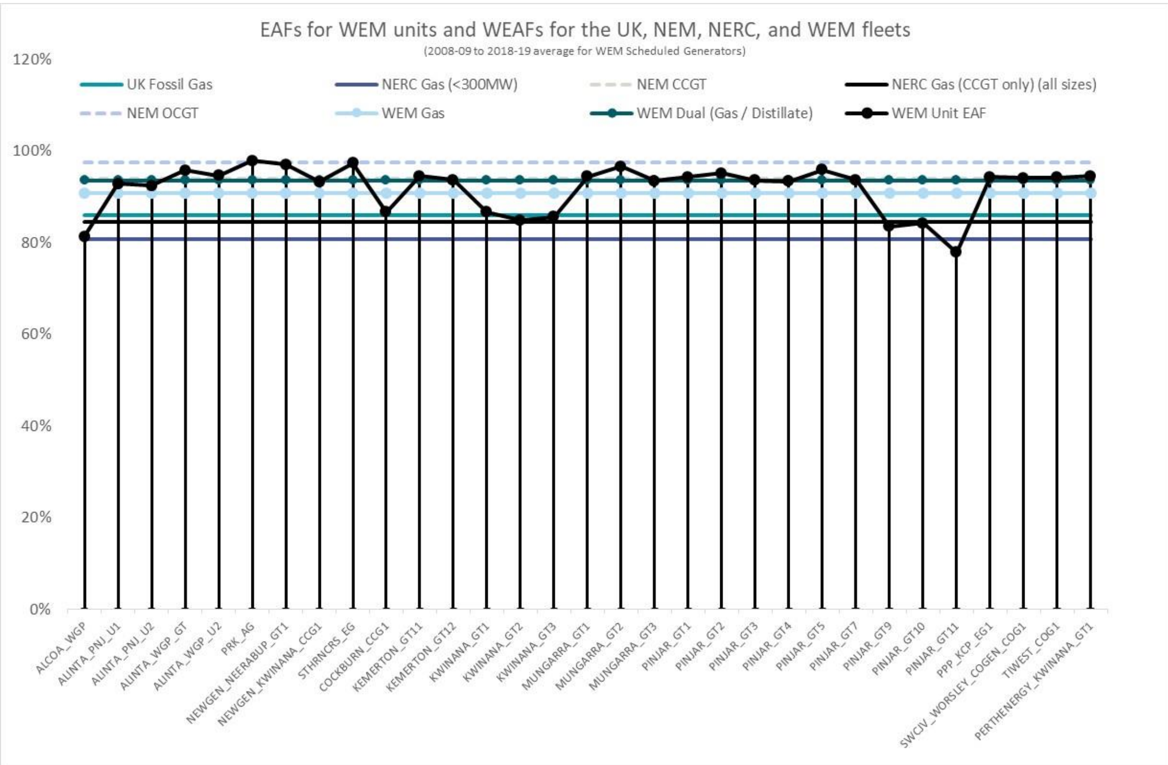
Figure 16 (below) provides a comparison of the 10-year average EAF for gas Scheduled Generation units[6] in the WEM, the WEAF for the WEM Scheduled Generator gas fleet and WEAFs for equivalent gas fleets in other jurisdictions. The figure includes both gas and dual (gas/distillate) units. Dual gas/coal units are reported on in section 3.2.3 which covers coal.[7]

The scheduled gas generation units in the WEM have an average WEAF of 91 per cent. Data indicates the units are, on average, more available than comparable gas fleets in the UK (86 per cent) and based on NERC data (81 per cent for gas units < 300 MW and CCGT only (all sizes)), however they are less available than the equivalent fleet in the NEM (94 per cent for CCGT and 98 per cent for OCGT).

The scheduled dual gas/distillate generation units in the WEM have an average WEAF of 84 per cent.

A number of the gas generators in the WEM fleet that were retired during the period of analysis have lower than average EAFs (for example, the Kwinana G1, G2, G5 and G6 units). Pinjar GT9, GT10 and GT11 also have lower than average EAFs.

Figure 16: Comparison of WEM Scheduled Generators with equivalent fossil fuel fleets (gas only)



Source: GHD Advisory, 2020. Note: NEM CCGT and WEM Dual (Gas/Distillate) fleets have the same WEAF (94 per cent) so the line for NEM CCGTs is not visible on the above graph.

[6] The gas Scheduled Generation units includes units classified by AEMO as Gas, Dual (Gas/Distillate), and Coal/Gas.

[7] We have assumed dual fuel units run predominantly on the cheaper of the two fuel types and reported on these units in the cheaper fuel unit group accordingly.

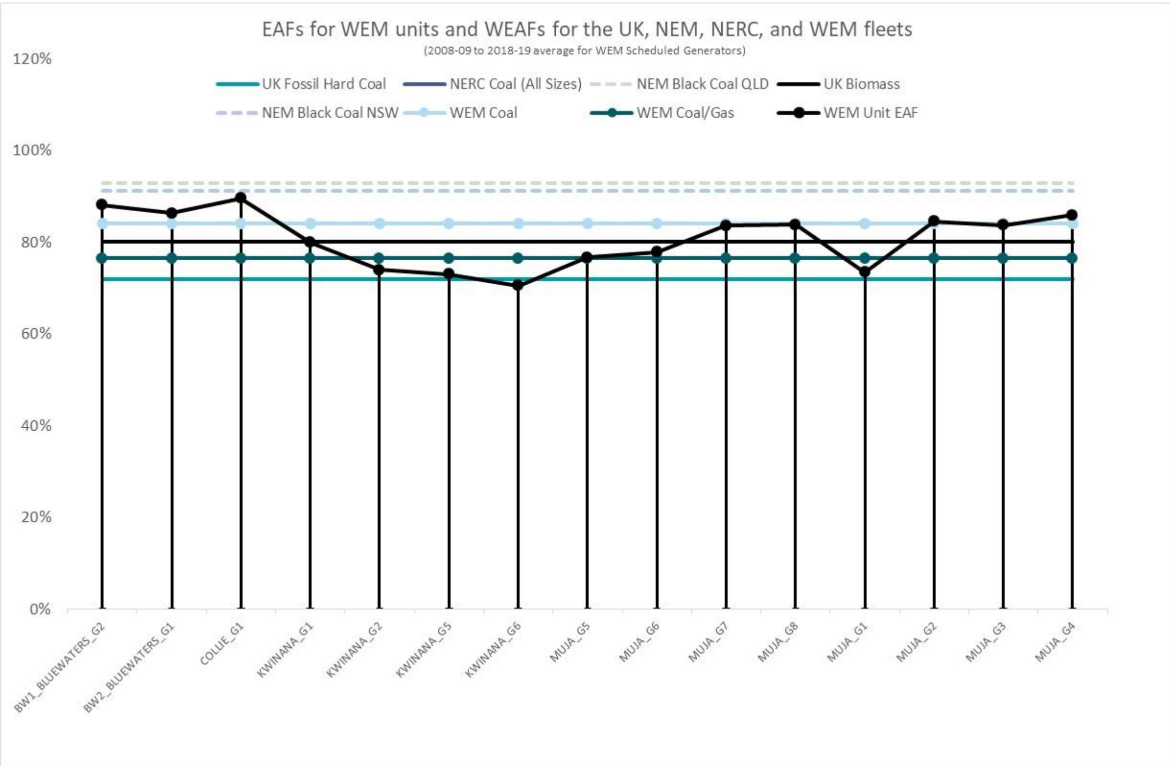
3.2.3 Coal fleet

Figure 17 (below) provides a comparison of the 10-year average EAF for coal Scheduled Generation units[8] in the WEM, the WEAF for the WEM Scheduled Generator coal fleet and WEAFs for equivalent coal fleets in other jurisdictions. The figure includes dual (coal/gas) units on the basis that these unit are likely to have been run predominately on coal while in service.[9]

The scheduled coal generation units in the WEM have an average WEAF of 84 per cent and coal/gas units have an average WEAF of 76.6 per cent. Data indicates the coal units are, on average, more available than comparable the coal fleet in the UK (72 per cent for hard coal and 80 per cent for biomass[10]) and based on NERC data (81 per cent for coal units < 300 MW), however the coal units are less available than the equivalent fleet in the NEM (93 per cent for black coal in Qld and 91 per cent for black coal in NSW).

Several of the WEM units with lower than average EAF values were retired during the analysis period. Units that were retired during the analysis period include Muja G1, G2, G3, and G4, and Kwinana G1, G2, G5 and G6.

Figure 17: Comparison of WEM Scheduled Generators with equivalent fossil fuel fleets (coal only)



Source: GHD Advisory, 2020. Note: NERC Coal (all sizes) and UK Biomass fleets have the same WEAF (80 per cent) so the line for NERC is not visible on the above graph.

[8] Coal Scheduled Generation units includes units classified by AEMO as Coal and Coal/Gas.

[9] We have assumed dual fuel units run predominantly on the cheaper of the two fuel types and reported on these units in the cheaper fuel unit group accordingly.

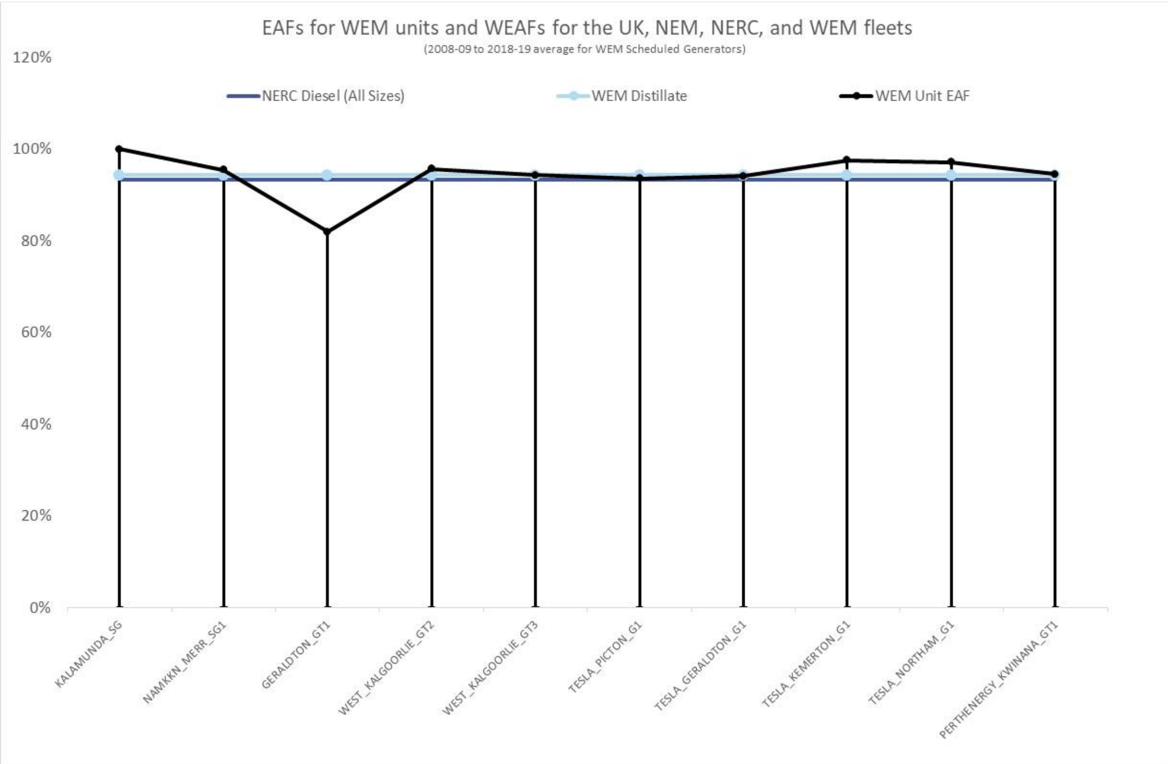
[10] Biomass is included in the UK fossil fuel fleet as a number of coal fired generation plants in the UK have been converted to biomass.

3.2.4 Distillate fleet

Figure 18 (below) provides a comparison of the 10-year average EAF for distillate Scheduled Generation units in the WEM, the WEAF for the WEM Scheduled Generator dual and distillate fleet and WEAFs for the equivalent diesel fleet in North America.[11] Dual gas/distillate units are reported on in section 3.2.2 which covers gas.[12]

The scheduled distillate fuel generation units in the WEM have an average WEAF of 94 per cent. Data indicates the units are, on average, have equivalent availability to comparable fleets based on NERC data for diesel units (93 per cent).

Figure 18: Comparison of WEM Scheduled Generators with equivalent fossil fuel fleets (distillate only)



Source: GHD Advisory, 2020.

[11] Comparator data was not available from other jurisdictions.

[12] We have assumed dual fuel units run predominantly on the cheaper of the two fuel types and reported on these units in the cheaper fuel unit group accordingly.

3.3 Comparison of WEM and UK WEAFs over time

Figure 19 (overleaf) shows changes in the WEM Scheduled Generator WEAF's over the most recent 5 year period (2014-15 to 2018-19) and Figure 20 (overleaf) shows equivalent fossil fuel generators in the UK. The note that follows provides background on changes in the UK market to assist with an analysis comparing trends across the two jurisdictions.

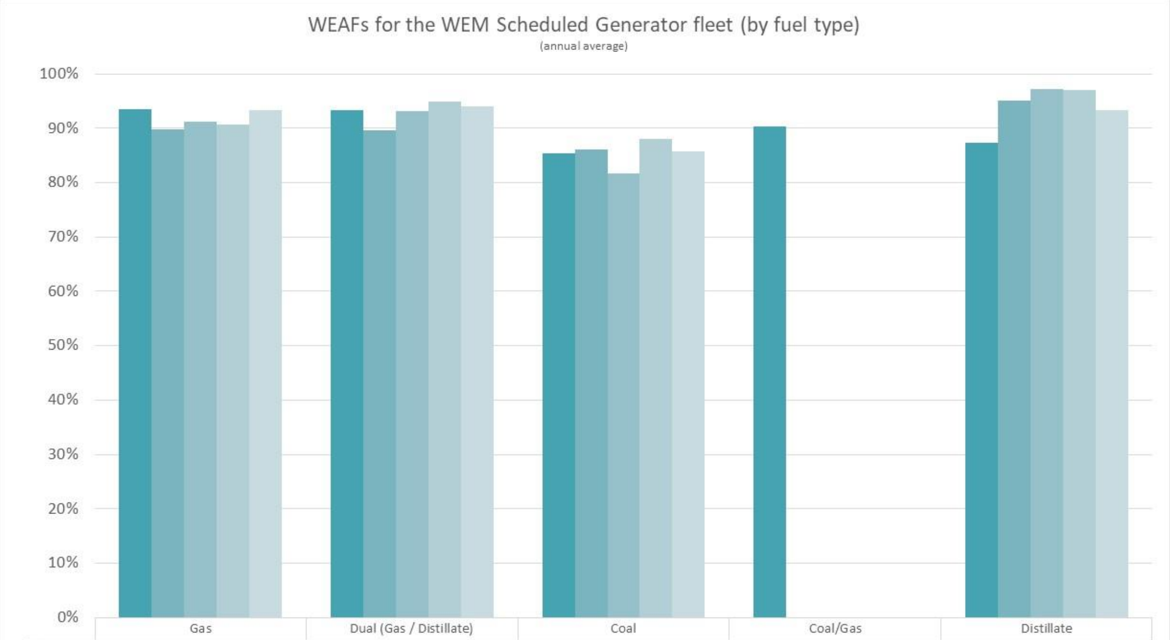
3.3.1 Trends in UK electricity generation

The UK's electricity generation mix has changed significantly over the past 40 years. Base-load generation in the UK has historically been dominated by coal and nuclear power stations. A brief move towards more oil-fired generators prompted by low and declining oil prices before the 1970's was immediately stopped due to the OPEC oil crisis, with many oil-fired plants undergoing conversion to dual fire with coal. The liberalisation of the natural gas market in the European Union, combined with the exploitation of new natural gas resources in the North Sea led to a "dash for gas" with coal-fired power stations surpassed by lower capital cost CCGT's. Carbon pricing and UK government policy have made coal an unattractive investment, with no coal-fired power stations commissioned in the UK since the 1980s.

Over the ten years considered for the WEM analysis, the UK's coal fleet has been aging, and more turbulent wholesale market prices have made it more difficult for the coal fleet primarily built in the 1970s to operate in its primary role as base-load. A significant number have undergone conversions to dual-fuel arrangements with biomass, with the largest (Drax Power Station) converting almost entirely to biomass in the last few years. It is therefore unsurprising that the availability of these units is significantly reduced compared to more modern units in Australia and across North America. Combined cycle gas turbines, which in the UK are all less than 30 years old, unsurprisingly have a significantly higher availability factor.

The trends experienced by the UK generation fleet are extreme examples of trends experienced to some extent in North America and Australia, where carbon pricing has not been set as high, but market forces have nonetheless lead to increasing average age of coal-fired generation, forced the conversion of oil-fired power plants, and have led to natural gas burned in CCGT's and OCGT's becoming the majority of modern fossil fuel power stations being built. While plant age is not the sole determinant of reliability and availability, these trends have undoubtedly played a role in the significant differences observed in the international comparison.

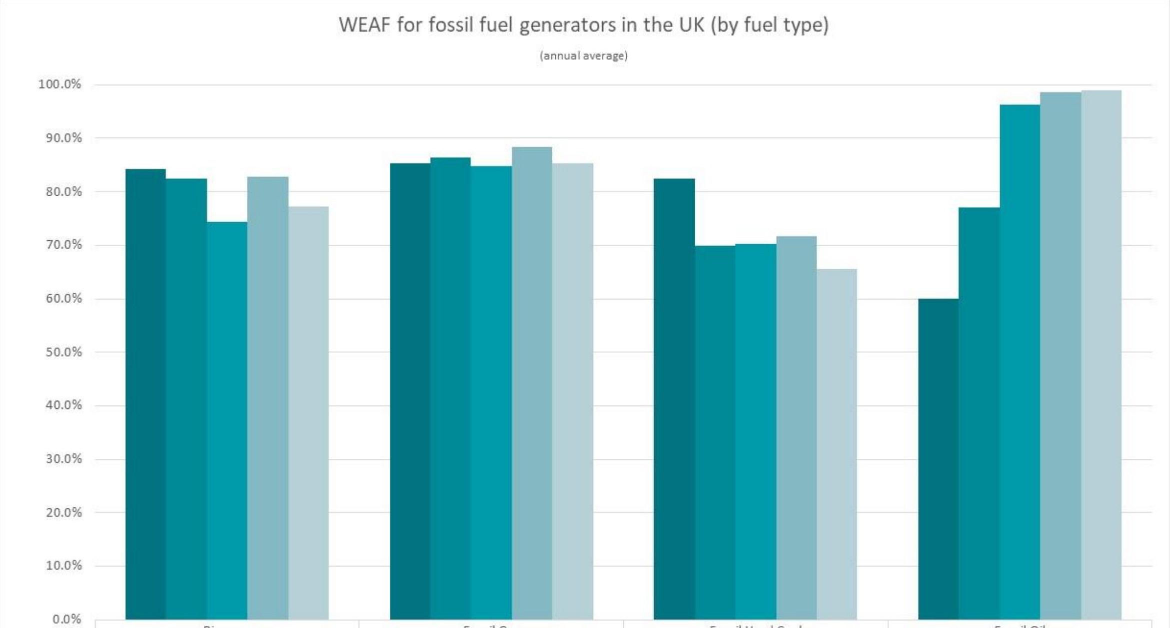
Figure 19: Average annual WEAF for WEM Scheduled Generators (2014-15 to 2018-19) (by fuel type)



	Gas	Dual (Gas / Distillate)	Coal	Coal/Gas	Distillate
2014-15	94%	93%	85%	90%	87%
2015-16	90%	90%	86%		95%
2016-17	91%	93%	82%		97%
2017-18	91%	95%	88%		97%
2018-19	93%	94%	86%		93%

Source: GHD Advisory, 2020

Figure 20: Average annual WEAF for UK fossil fuel generators (2014-15 to 2018-19) (by fuel type)



	Biomass	Fossil Gas	Fossil Hard Coal	Fossil Oil
2014-15	84.3%	85.3%	82.4%	60.0%
2015-16	82.4%	86.4%	69.8%	77.1%
2016-17	74.4%	84.7%	70.2%	96.3%
2017-18	82.9%	88.3%	71.7%	98.6%
2018-19	77.3%	85.3%	65.6%	99.0%

Source: GHD Advisory, 2020

Appendices

Appendix A List of acronyms

The following acronyms, terms and abbreviations have been used in this report.

Acronym / term / abbreviation	Meaning
AEMO	Australian Energy Market Operator
AH	Available hours
CCGTs	Combined cycle gas turbines
COH	Consequential outage hours
EAF	Equivalent availability factor
ECDH	Equivalent consequential derated hours
ECOF	Equivalent consequential outage factor
ECOR	Equivalent consequential outage rate
EFDH	Equivalent forced derated hours
EFDR	Equivalent forced derated hours
EFOF	Equivalent forced outage factor
EFOH	Equivalent forced outage hours
EFOR	Equivalent forced outage rate
EOR	Equivalent outage rate
EPDH	Equivalent planned derated hours
EPOF	Equivalent planned outage factor
ERA	Economic Regulation Authority
ERSFDH	Equivalent reserve shutdown forced derated hours
ESDH	Equivalent seasonal derated hours
ESH	Equivalent service hours
ESOO	Electricity Statement of Opportunities
EUF	Equivalent unavailability factor
EUH	Equivalent unavailable hours
EUH	Equivalent
EUH	Equivalent unavailability hours
EUNDH	Equivalent Unit derated hours
FFOH	Full forced outage hours
FOH	Forced outage hours
FOR	Forced outage rate

Acronym / term / abbreviation	Meaning
GHD	GHD Pty Ltd
IEEE	Institute of Electrical and Electronics Engineers
Market Rules	Wholesale Electricity Market Rules
MTTR	Mean-time-to-repair
MW	Megawatt
MWh	Megawatt hour
NEM	National Electricity Market
NER	National Electricity Rules
NERC	North American Electric Reliability Corporation
NMC	Net maximum capacity
OCGT	Open cycle gas turbine
PFOH	Partial forced outage hours
PH	Period Hours
POH	Planned outage hours
POR	Planned outage rate
SH	Service hours
WEAF	Weighted equivalent availability factor
WEM	Wholesale Electricity Market

Level 10 999 Hay Street Perth WA 6000 Australia
PO Box 3106 Perth WA 6832 Australia

61 8 6222 8222
permail@ghd.com

In addition to the author and reviewers below GHD acknowledges the contributions from Paul Espie, Luke Hyett and Ciara Ritson-Courtney.

Rev. No.	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
Final	H. Burns	L. O'Brien		D. Bones		13/07/2020

GHD Advisory