ROAM CONSULTING
ENERGY MODELLING EXPERTISE

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Report (WEP00015) to

westernpower

Appendix B:Results of analysis of future curtailment of wind generation - Cost-reflective DMO

Public report

23 November 2009

VERSION HISTORY

Version History					
Revision	**Date Issued**	**Prepared By**	**Approved By**	**Date Approved**	**Revision Type**
0.5	2009-06-03	Jenny Riesz			Input assumptions
1	2009-06-26	Jenny Riesz Joel Gilmore	Matthew Holmes	2009-06-26	Report
1.1		Jenny Riesz Joel Gilmore			Updated Report
1.2	2009-09-08	Joel Gilmore			Additional Scenarios - Draft
1.25	2009-09-20	Joel Gilmore			Additional Scenarios – Final
1.3	2009-10-08	Joel Gilmore			Cost based merit order scenarios

This report shows the results of analysis performed by ROAM Consulting for System Management. It should be read in conjunction with the System Management report entitled *Effects of increased penetration of intermittent generation in the SWIS*. Note:

- Two versions of the Dispatch Merit Order (DMO) are considered, and the ROAM report detailing the other DMO should be considered.
- Scenarios 1 and 3, which were variants of scenario 2, have been discarded.

1) Scenarios 2 and 6 Results (Cost DMO)

1.1) Input assumptions

All cogen plant is "must run", and therefore is the last plant to be decommitted. This includes the following plant:

- Worsley Cogen
- TiWest
- Alcoa Wagerup
- Alinta Pinjara
- Kwinana E
- Alinta Wagerup (once converted)
- Kwinana Cogen Project (PPP_KCP)
- Mungarra GT1 (must run for voltage support)

All biomass plant is must run.

Selected thermal facilities are also considered must-run:

- Muja 6
- Muja 7
- Muja 8
- Muja A G2
- Muja B
- Collie Power Station
- Bluewaters 1
- Bluewaters 2
- Coal 2 Unit 1
- Coal 1

The above means that 1 out of 4 thermal units are cycled. Therefore the following facilities are cycled (as required):

- All Kwinana thermal units (this is currently occurring)
- Muja A G1
- Muja 5
- Coal 2 Unit 2

Unit bids and merit order was provided by Western Power.

1.1.1) Commissioning Schedule

Table 1.1 – Wind farm commissioning schedule

Year Commissioned	Location	Capacity (MW)	Source data
2010	Merredin	200	BOM data (60min data available) 2007-08
2011	East of Albany	100	Albany wind farm 2007-08
	Albany	100	Albany wind farm 2007-08
2012	Emu Downs	100	Emu Downs wind farm 2007-08
2013	Walkaway	100	Walkaway wind farm 2007-08
2014	Albany	100	Albany wind farm 2007-08
2015	Emu Downs	100	Emu Downs wind farm 2007-08
2016	Walkaway	100	Walkaway wind farm 2007-08
2017	Albany	100	Albany wind farm 2007-08
2018	Emu Downs	100	Emu Downs wind farm 2007-08
2019	Walkaway	100	Walkaway wind farm 2007-08

Table 1.2 – Thermal plant commissioning / retirement schedule – same as Case 2

Year	Plant name	Market Participant	Fuel type	Change in status
2011	Kwinana D	Perth Energy	Gas	Commission (1x120MW)
	Blue Waters 2	Griffin Power 2 Pty Ltd	Coal	Commission (1x200MW)
	Muja A	Verve Energy	Coal	Re-commission (2x60MW)
	Muja B	Verve Energy	Coal	Re-commission (2x60MW)
	Kwinana B – LMS100	Verve Energy	OCGT- Gas	Commission (2x100MW)
2012	Kwinana A	Verve Energy	Thermal	Retire (2x100MW)
2013	OCGT convert to cogen	IPP	Gas/Liquid	Convert OCGT to cogen (2x180MW)
2014	OCGT 1	-	OCGT- Gas	Commission (1x180MW)
2015	Kwinana E	-	Cogen- OCGT-Gas	Commission (2x180MW)
	Kwinana C	Verve Energy	Thermal	Retire (2x200MW)
2016	Coal 1	-	Coal	Commission (2x200MW)

Table 1.2 – Thermal plant commissioning / retirement schedule – same as Case 2				
Year	**Plant name**	**Market Participant**	**Fuel type**	**Change in status**
2017	Coal 2	-	Coal	Commission (2x200MW)
2018	New OCGT 1	-	OCGT-Gas/Liquid	Commission (1x180MW)
2019	New OCGT 2	-	OCGT-Gas/Liquid	Commission (1x180MW)

1.2) WIND CURTAILMENT

Wind curtailment is significantly higher when "must run" coal plant is included. Curtailment is slightly lower than in the original scenario 2 case because of the revised merit order.

Table 1.3 – Wind Curtailment			
Year	**Total Installed Wind (MW)**	**% of Annual wind energy curtailed**	
		Scenario 2C	**Scenario 6C**
2010-11	391	0.0%	0.0%
2011-12	591	0.0%	0.7%
2012-13	691	0.0%	1.1%
2013-14	791	0.0%	11.2%
2014-15	891	0.1%	18.0%
2015-16	991	1.0%	28.8%
2016-17	1091	2.9%	42.6%
2017-18	1191	3.9%	48.8%
2018-19	1291	9.3%	56.4%
2019-20	1391	14.9%	61.5%

Curtailment by time of day

Wind farms in overnight periods are completely constrained off, due to demand being met by load following gas plant and must run coal plant. However, even some of the "must run" coal plant is forced to cycle during overnight periods due to the large quantity of load following gas plant online (demonstrated below for Coal IPP and Muja A).

Figure 1.1 – Wind curtailment in 2019-20 (Scenario 2C) – moderate curtailment

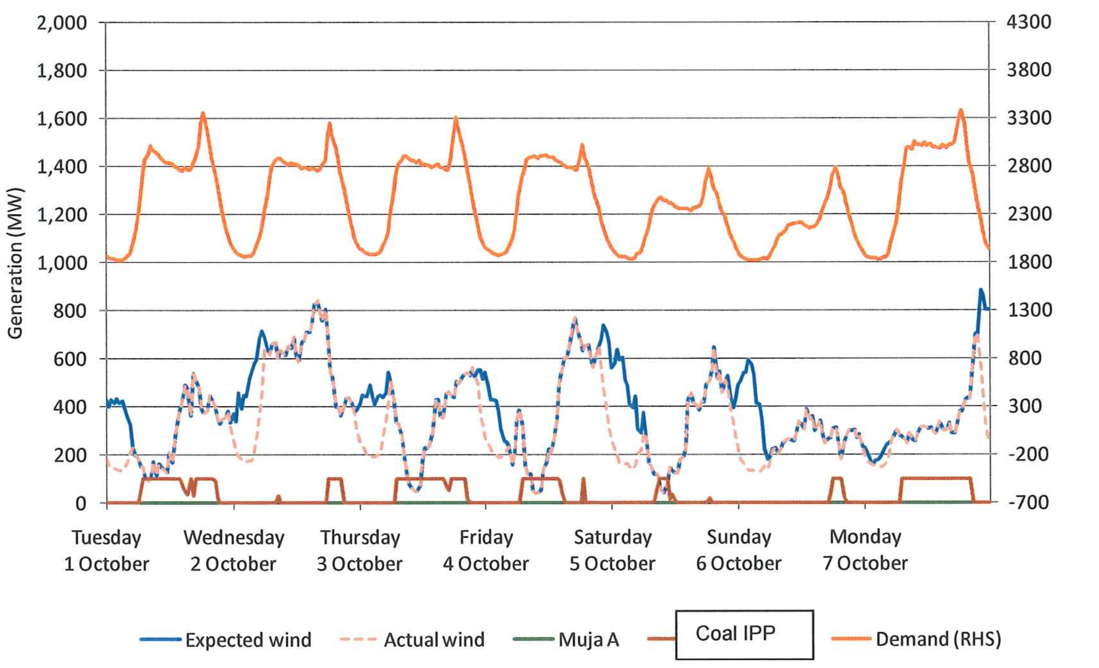
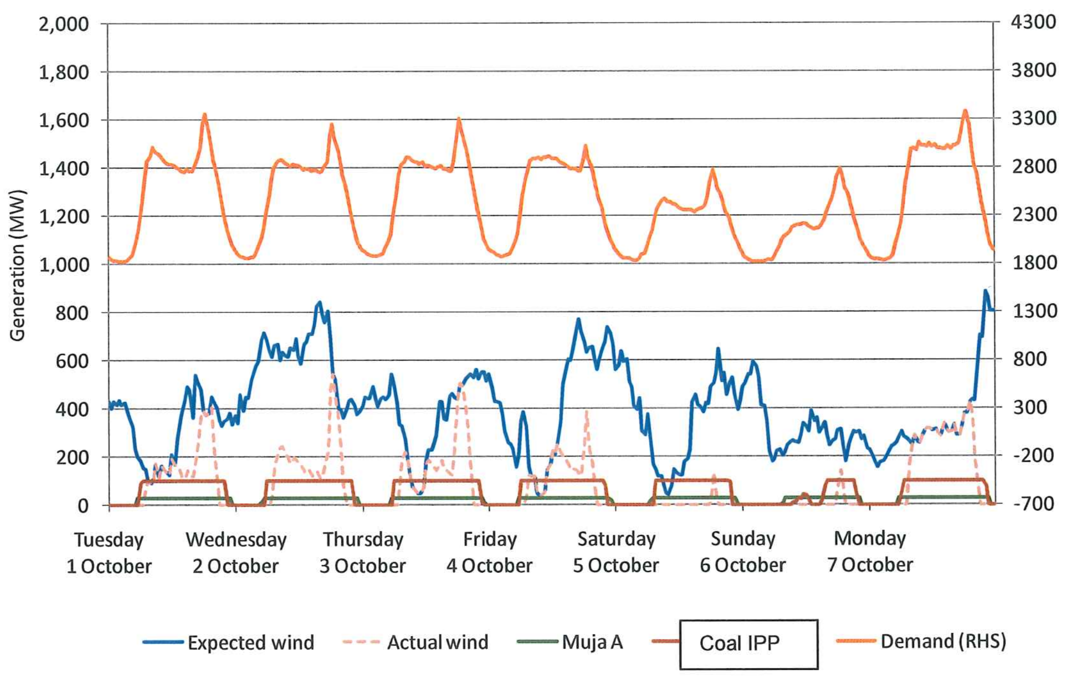
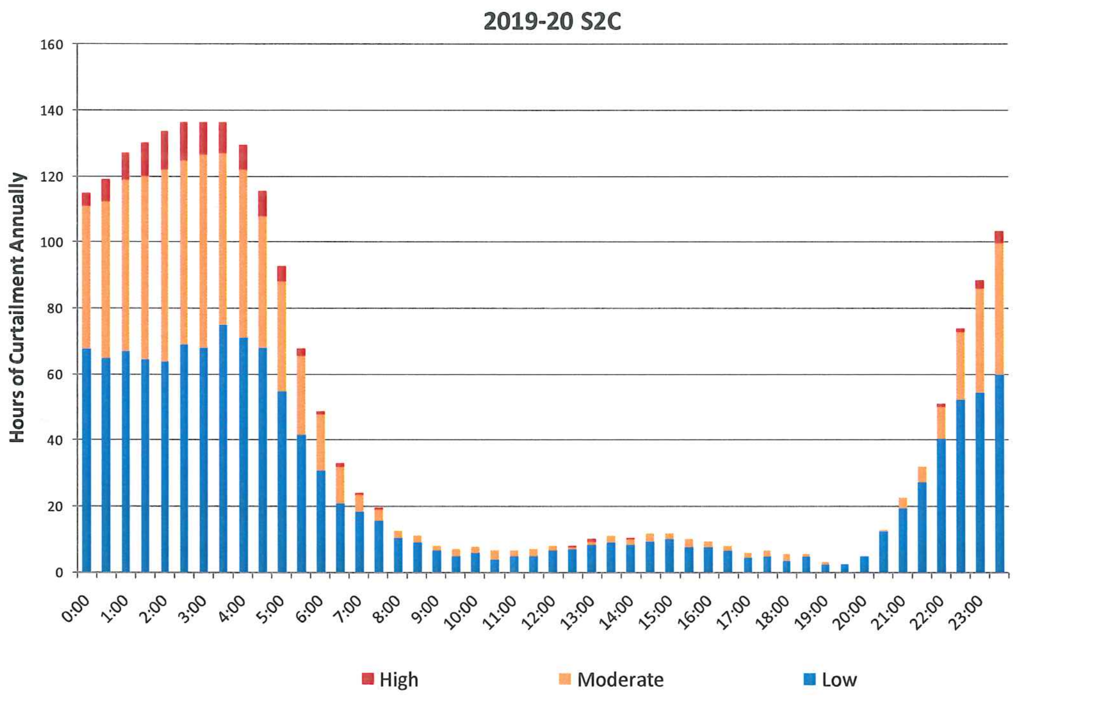


Figure 1.2 – Wind curtailment in 2019-20 (Scenario 6C) – high curtailment



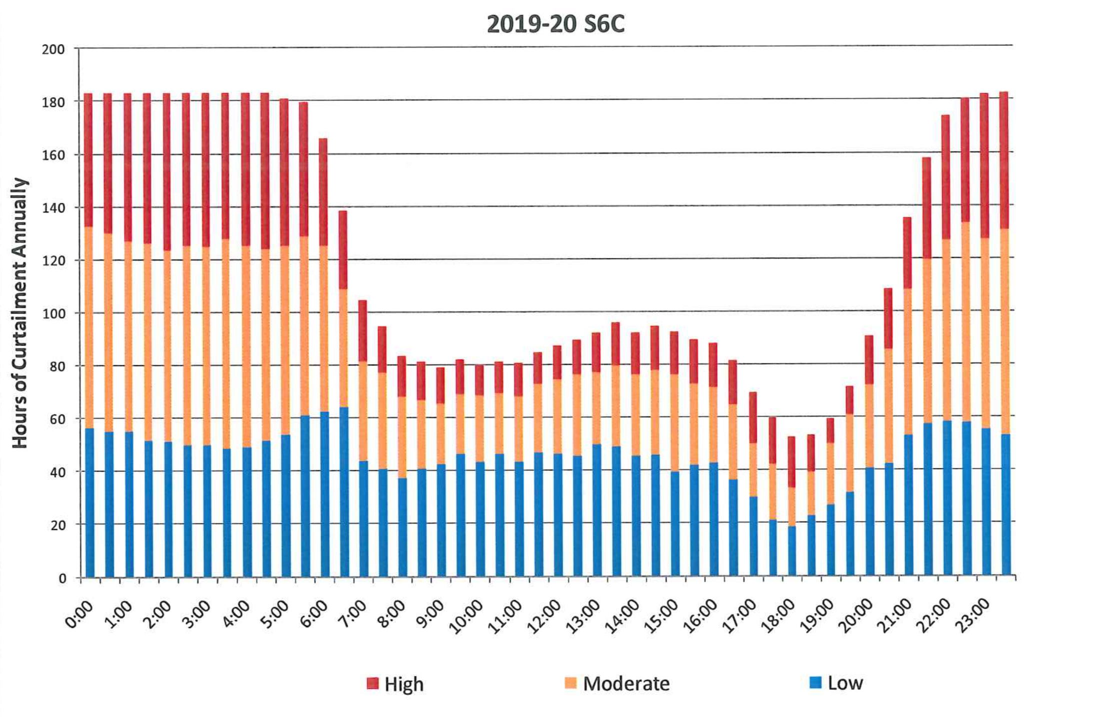
Significant curtailment in overnight periods, and moderate curtailment in daytime periods, is now observed.

Figure 1.3 – Hours of curtailment by time of day (Scenario 2C, 2019-20)



High – More than 50% of the wind capacity was curtailed
Moderate – Between 25% and 50% of the wind capacity was curtailed
Low – Between 0% and 25% of the wind capacity was curtailed

Figure 1.4 – Hours of curtailment by time of day (Scenario 6C, 2019-20)



High – More than 50% of the wind capacity was curtailed
Moderate – Between 25% and 50% of the wind capacity was curtailed
Low – Between 0% and 25% of the wind capacity was curtailed

1.3) Generation

Figure 1.5 – Energy production in the SWIS (Scenario 2C)

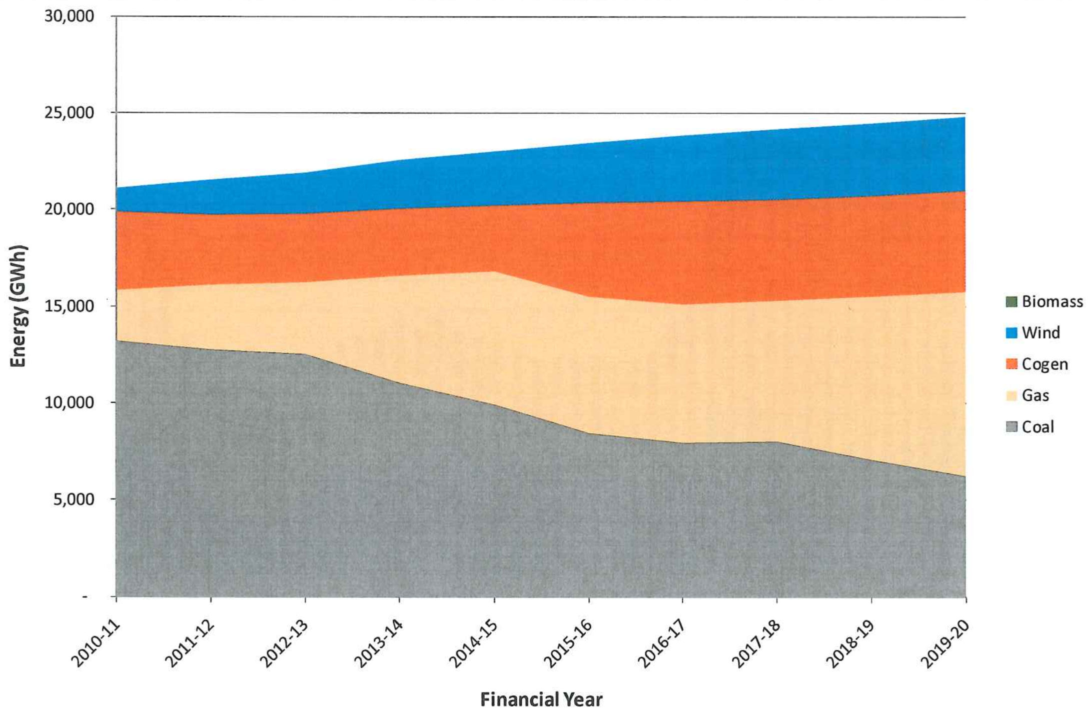
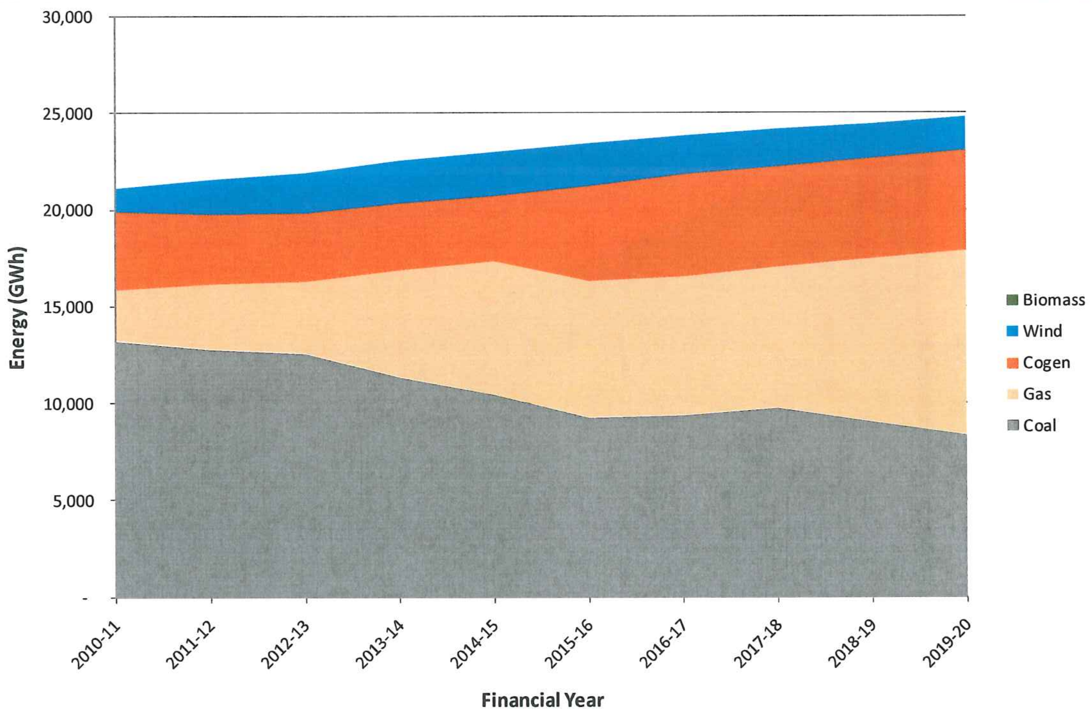


Figure 1.6 – Energy production in the SWIS (Scenario 6C)



1.4) GREENHOUSE EMISSIONS

Figure 1.7 – Greenhouse emissions from the SWIS (Scenario 2C)

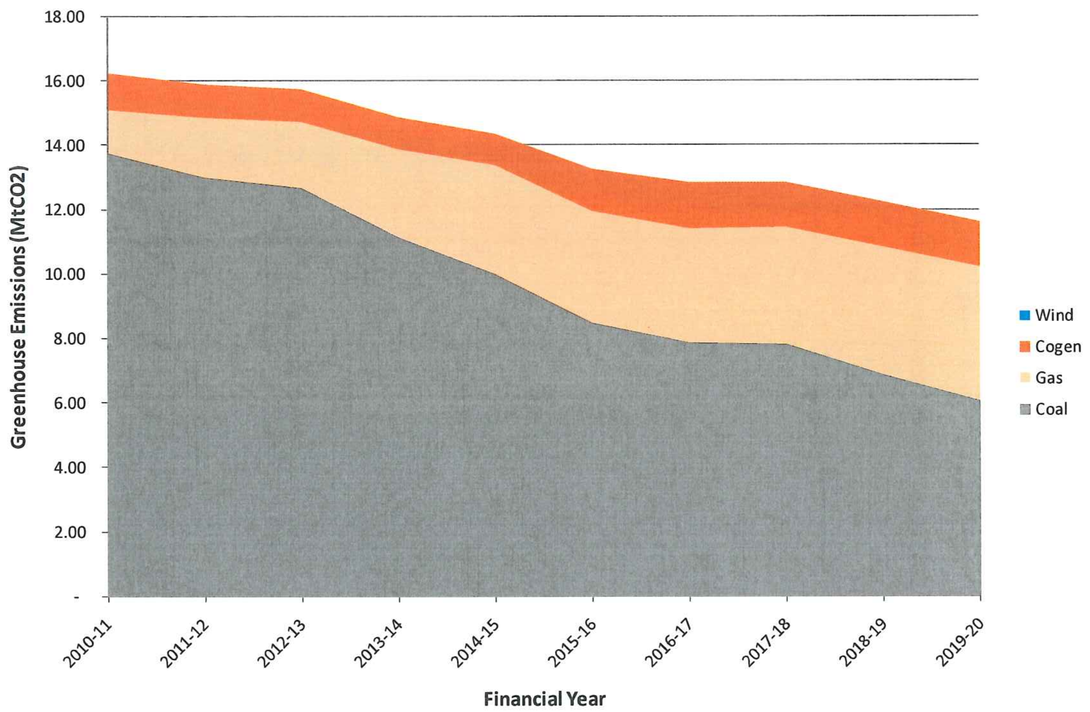
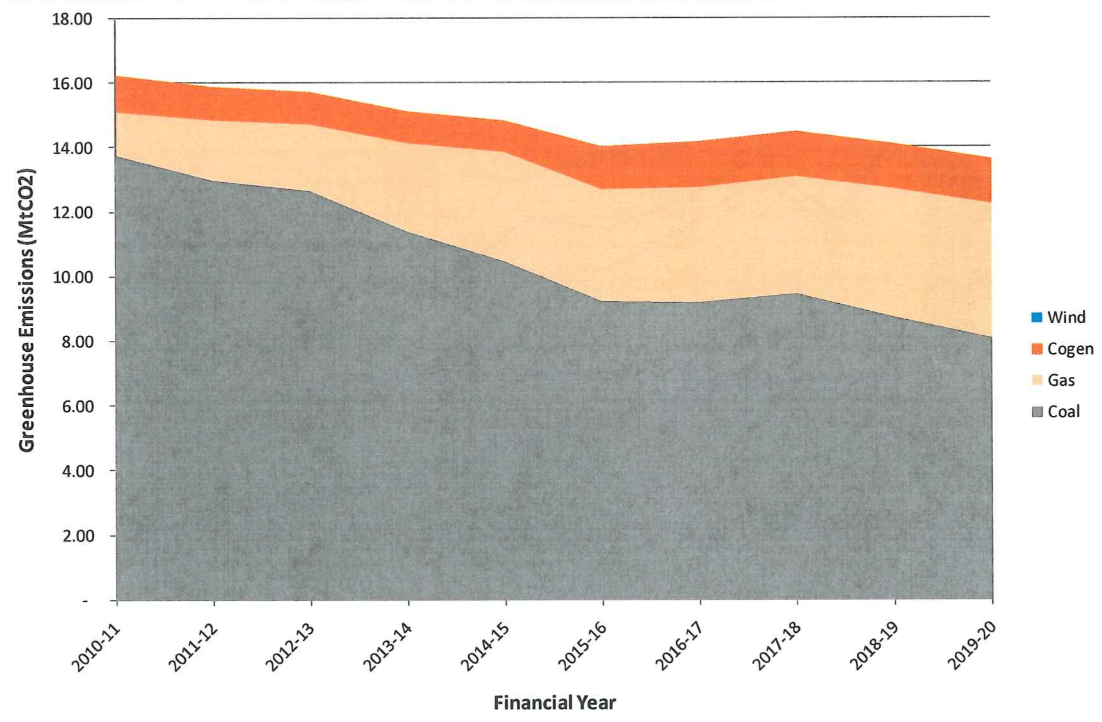
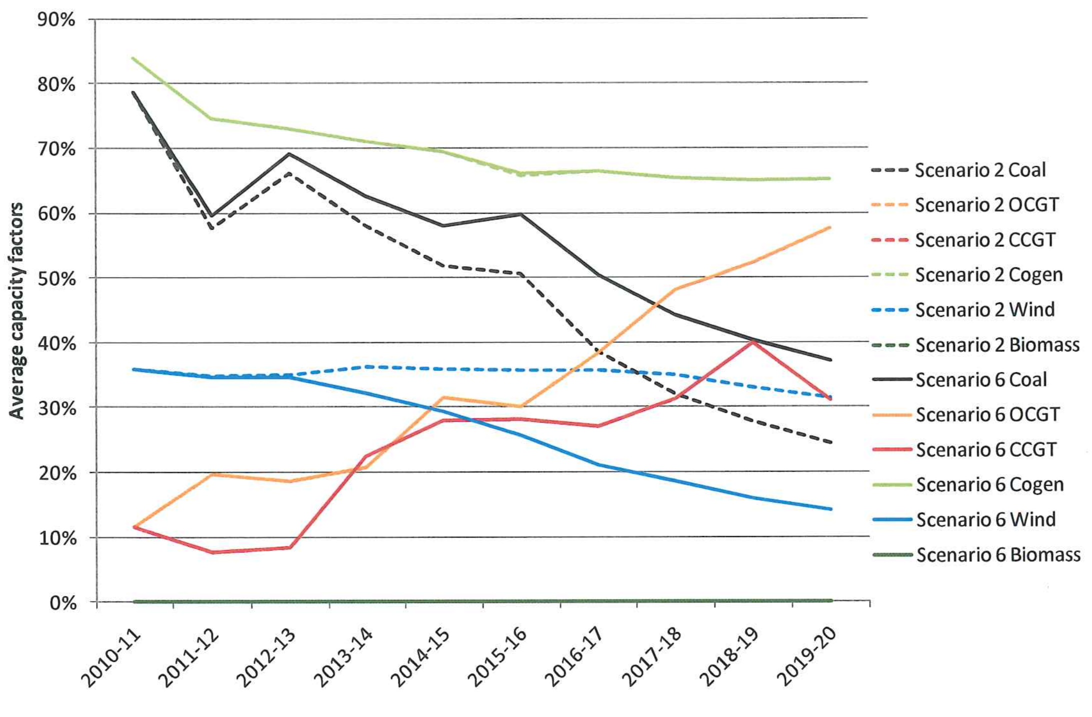


Figure 1.8 – Greenhouse emissions from the SWIS (Scenario 6C)



1.5) OPERATIONAL MODES OF PLANTS

Figure 1.9 – Capacity Factors of plants in the SWIS, cost based merit order



Coal fired plant increases generation at the expense of wind and OCGT plant. Capacity factors for load following plant remain relatively unchanged from the original study (Scenarios 1-3).

Plant cycling

The figures below show periods in both Scenario 2 and Scenario 6 where cycling of coal plants occur. In Scenario 2, cycling occurs on a regular basis.

Figure 1.10 – Time-sequential generation of coal-fired plant in 2019-20 (Scenario 2C)

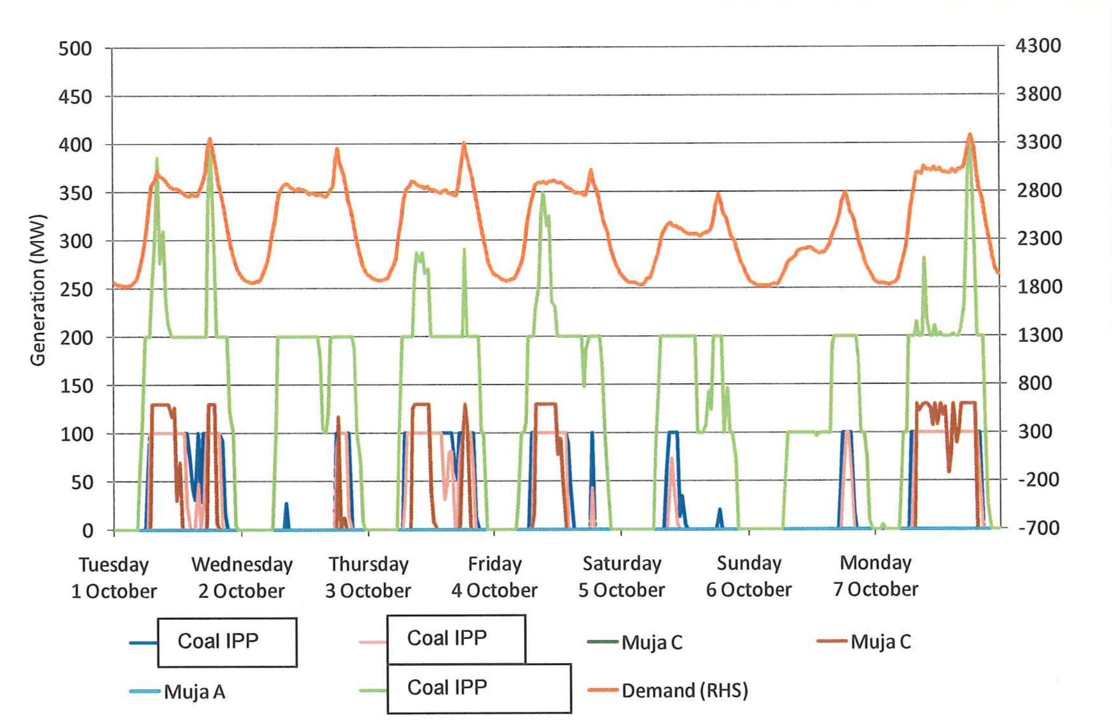
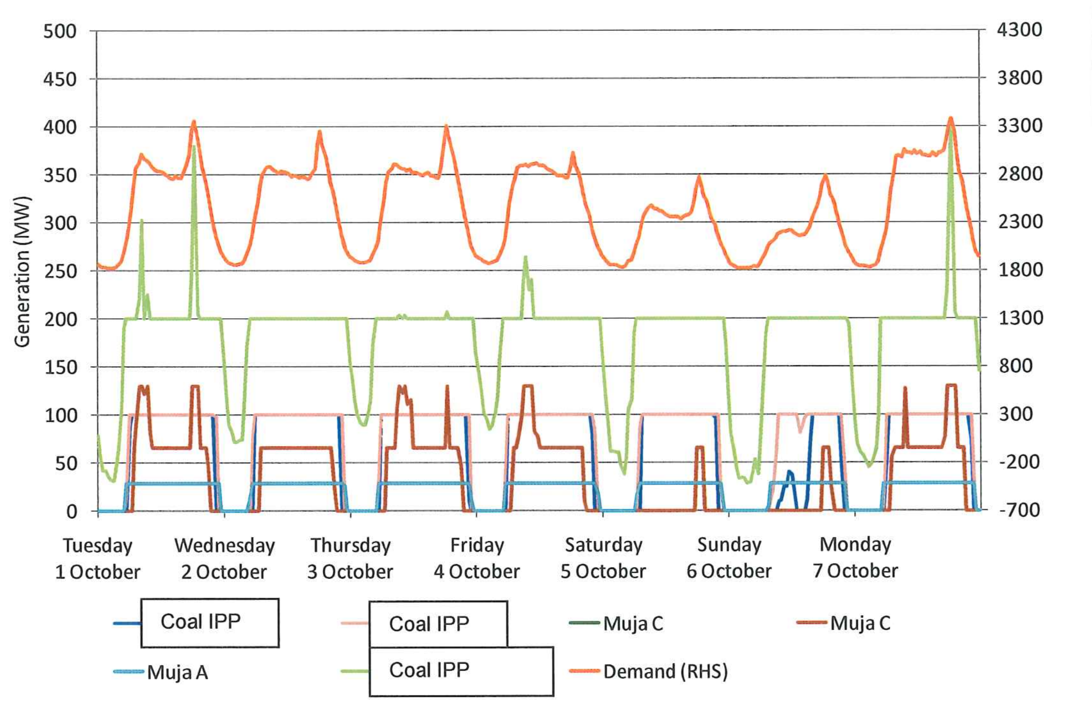


Figure 1.11 – Time-sequential generation of coal-fired plant in 2019-20 (Scenario 6C)



In Scenario 6, several coal power stations are still required to cycle despite their "must-run" status, during periods of high wind/low demand. The large amount of wind combined with the correspondingly large amount of load following gas plant exceeds demand on a regular basis.

2) Scenarios 4 and 5 Results

2.1) Input Assumptions

All cogen plant is "must run", and therefore is the last plant to be decommitted. This includes the following plant:

- Worsley Cogen
- TiWest
- Alcoa Wagerup
- Alinta Pinjara
- Kwinana Cogen Project (PPP_KCP)
- Mungarra GT1 (must run for voltage support)

All biomass plant is must run.

In Scenario 5, selected thermal facilities are also considered must-run:

- Muja 6
- Muja 7
- Muja 8
- Muja A G2
- Muja B
- Collie Power Station
- Bluewaters 1
- Bluewaters 2

The above means that 1 out of 4 thermal units are cycled. Therefore the following facilities are cycled (as required):

- All Kwinana thermal units (this is currently occurring)
- Muja A G1
- Muja 5

2.1.1) Commissioning Schedule

Table 2.1 – Plant commissioning / retirement schedule

Year	Plant name	Market Participant	Plant type	Change in status
2009	Newgen Neerabup	Newgen	OCGT- gas	Commission (2x165MW)
2009	Kwinana Power Station A G1	Verve Energy	Thermal	Reduce maximum capacity from 111.5 to 94.5 MW (ie reduction of 17MW)
2009	Blue Waters 2	Griffin Power 2 Pty Ltd	Coal	Commission (1x200MW)
2010	Kwinana D	Perth Energy	OCGT- gas	Commission (1x120MW)
2011	WA Biomass	WA Biomass	Biomass	Commission (1x40MW)
2011	Merriden WF	Collgar	Wind farm	Commission (1x200MW)
2011	Muja A	Verve Energy	Coal	Re-commission (2x50MW)
2011	Muja B	Verve Energy	Coal	Re-commission (2x60MW)
2011	Kwinana B – LMS100	Verve Energy	OCGT- gas	Commission (2x90MW)
2011	Kwinana A	Verve Energy	Thermal	Retire (2x100MW)
2012	Biomass 1	IPP	Biomass	Commission (1x25MW)
2012	OCGT 1	IPP	OCGT- liquid	Commission (2x125MW)
2013	Albany WF2	Verve Energy	Wind farm	Commission (1x100MW)
2013	OCGT 2	IPP	OCGT- liquid	Commission (2x150MW)
2014	OCGT 3	IPP	OCGT- liquid	Commission (1x100MW)
2014	Pinjar 2	Verve Energy	OCGT	Reduce maximum capacity from 37.2 to 20 MW (ie reduction of 17MW)
2015	Biomass 2	IPP	Biomass	Commission (2x25MW)

Table 2.1 – Plant commissioning / retirement schedule				
Year	**Plant name**	**Market Participant**	**Plant type**	**Change in status**
2015	EDWF2	IPP	Wind farm	Commission (1x100MW)
2015	OCGT 4	Verve Energy	OCGT- gas	Commission (1x150MW)
2016	Kwinana C	Verve Energy	Thermal	Retire (2x200MW)
2016	Renewable 1	IPP	Biomass	Commission (1x20MW)
2016	WWF 2	Alinta	Wind farm	Commission (1x100MW)
2016	Albany WF 3	IPP	Wind farm	Commission (1x100MW)
2016	EDWF WF 3	IPP	Wind farm	Commission (1x105MW)
2016	OCGT 4	IPP	OCGT- liquid	Commission (4x150MW)
2016	OCGT 5	IPP	OCGT- liquid	Commission (1x50MW)
2016	Pinjar 9	Verve Energy	OCGT	Retire (1x116MW)
2016	Pinjar 1	Verve Energy	OCGT	Retire (1x37.2MW)
2017	OCGT 6	IPP	OCGT- liquid	Commission (2x100MW)
2018	WWF 3	IPP	Wind farm	Commission (1x55MW)
2018	OCGT 7	IPP	OCGT- liquid	Commission (1x150MW)
2019	OCGT 8	IPP	OCGT- liquid	Commission (2x100MW)

2.1.2) Assumptions: DMO

A dispatch merit order was created that reflected the perceived short-run marginal cost of each facility ie all OCGT facililties (for both Verve and IPP's) were curtailed and decommitted before coal facilities (for both Verve and IPP's) were curtailed.

2.1.3) Assumptions: minimum capacity

- Removed

Table 2.2 – Scenarios 4 and 5 load following requirements	
	Load following required (MW)
2010-11	62.7
2011-12	89.0
2012-13	89.0
2013-14	105.1
2014-15	105.1
2015-16	125.3

2016-17	198.1
2017-18	196.1
2018-19	206.2
2019-20	206.2

2.2) WIND CURTAILMENT

Limited wind curtailment is observed, even when the must run coal plant is included.

Table 2.3 – Wind Curtailment

Year	Total Installed Wind (MW)	% of Annual wind energy curtailed	
		Scenario 4	Scenario 5
2010-11	190.7	0.0%	0.0%
2011-12	390.7	0.0%	0.0%
2012-13	390.7	0.0%	0.0%
2013-14	490.7	0.0%	0.0%
2014-15	490.7	0.0%	0.0%
2015-16	590.7	0.0%	0.2%
2016-17	895.7	0.0%	5.0%
2017-18	895.7	0.0%	4.5%
2018-19	950.7	0.0%	5.4%
2019-20	950.7	0.0%	4.6%

Curtailment by time of day

Wind farms exhibit no constraints under this planting schedule in Scenario 4. Coal plants are forced to cycle due to the wind and the lower bidding biomass plant. Under Scenario 5, with the coal must-run plant, short periods of wind constraints are observed during early morning periods.

Figure 2.1 – Wind curtailment in 2019-20 (Scenarios 4)

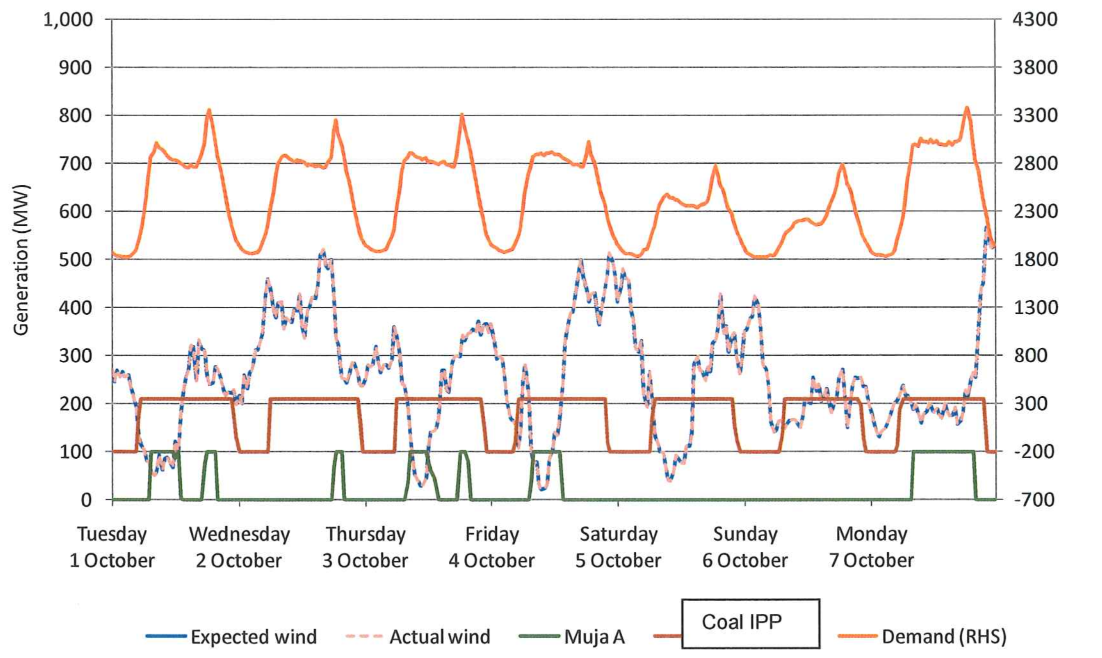
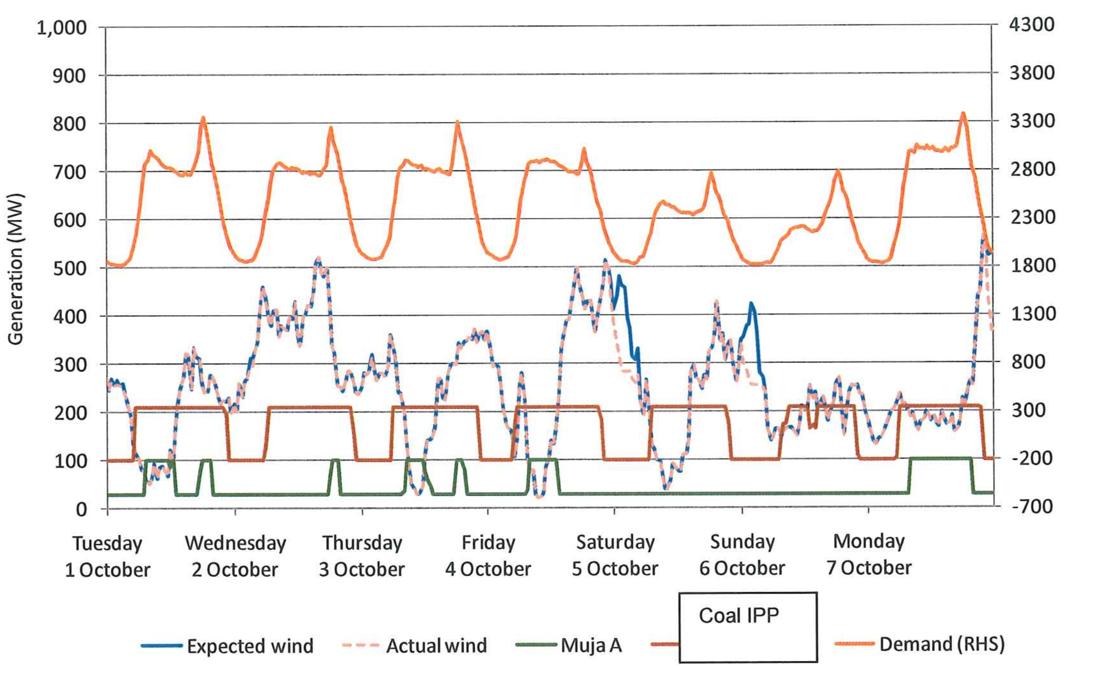
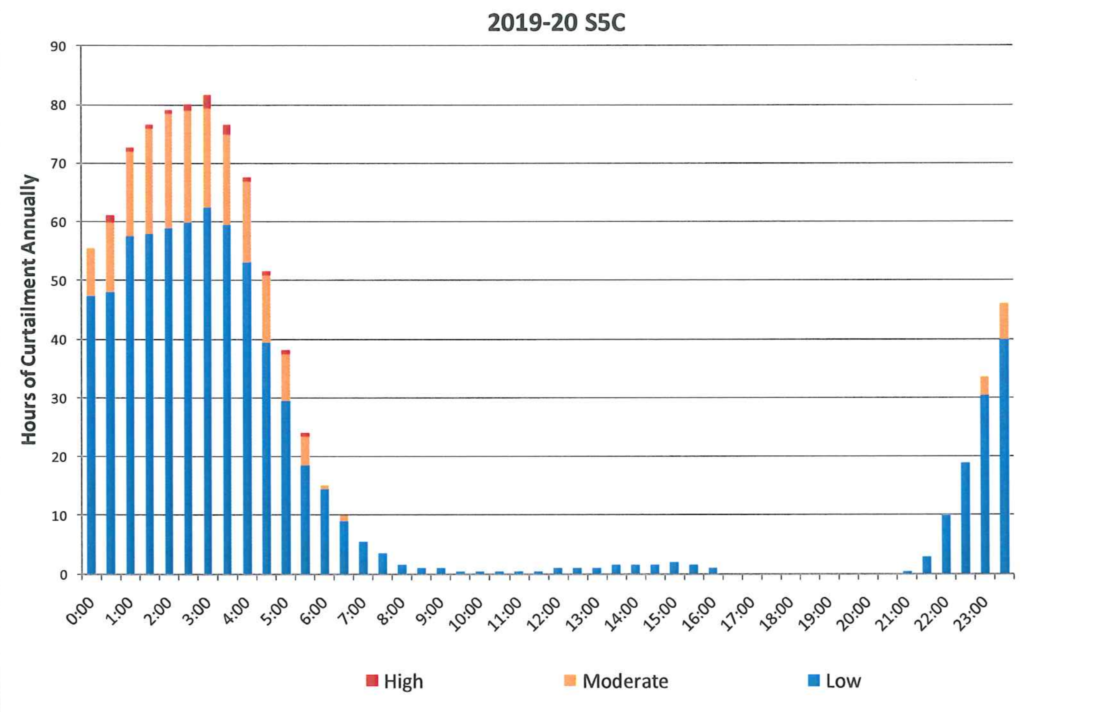


Figure 2.2 – Wind curtailment in 2019 (Scenarios 5)



The figure below shows the level of curtailment for each period of the day for Scenario 5. Note, however, that the curtailment level is as a proportion of total wind installed and the chart therefore has a different scale than the Scenario 1-3 and 6 results. Note that Scenario 4 exhibits no wind constraints.

Figure 2.3 – Hours of curtailment by time of day (Scenario 5, 2019-20)



High – More than 50% of the wind capacity was curtailed
Moderate – Between 25% and 50% of the wind capacity was curtailed
Low – Between 0% and 25% of the wind capacity was curtailed

2.3) GENERATION

Figure 2.4 – Energy production in the SWIS (Scenario 4C)

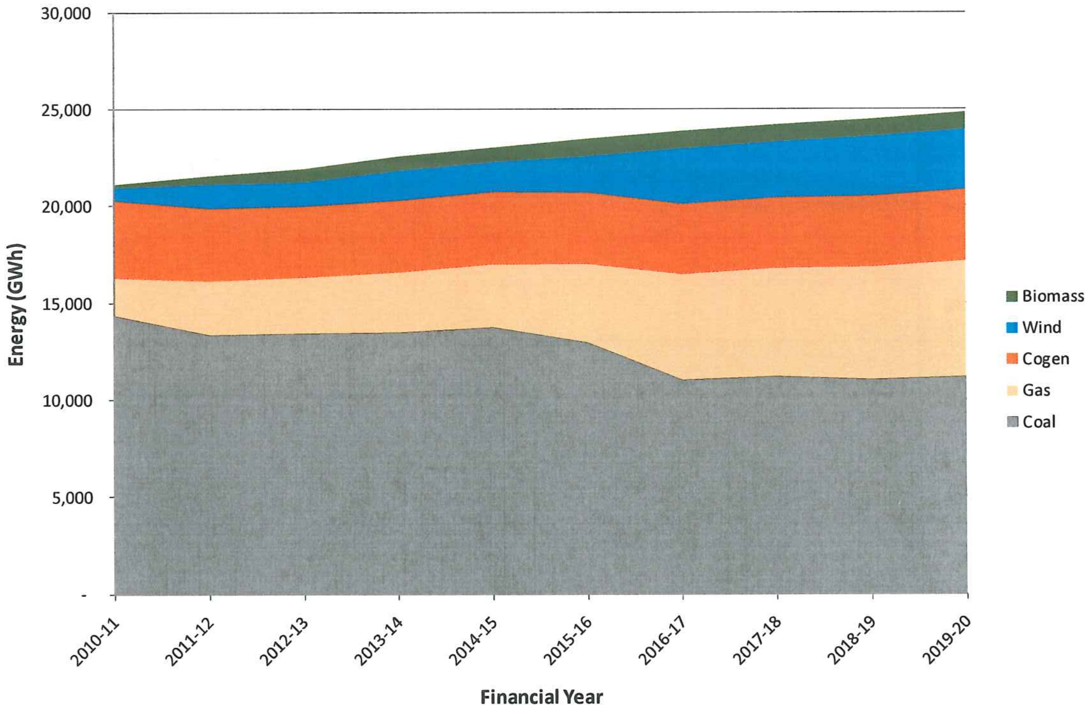
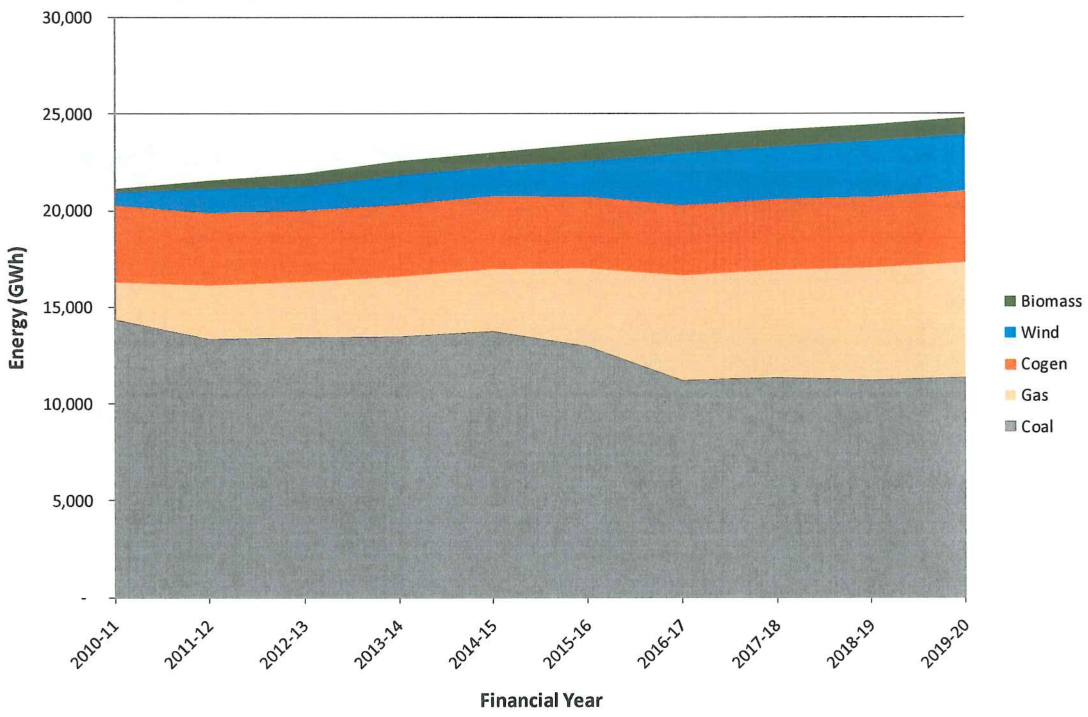


Figure 2.5 – Energy production in the SWIS (Scenario 5C)



2.4) Greenhouse emissions

Emissions are similar in both scenarios, remaining relatively constant over the duration of the study.

Figure 2.6 – Greenhouse emissions from the SWIS (Scenario 4C)

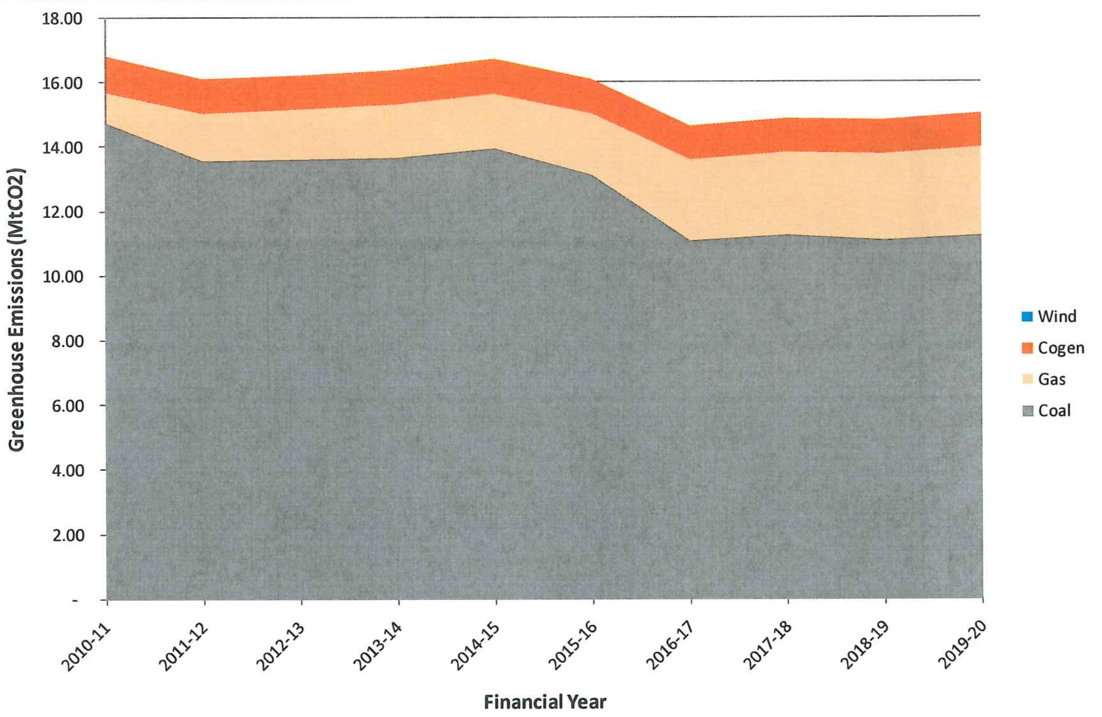
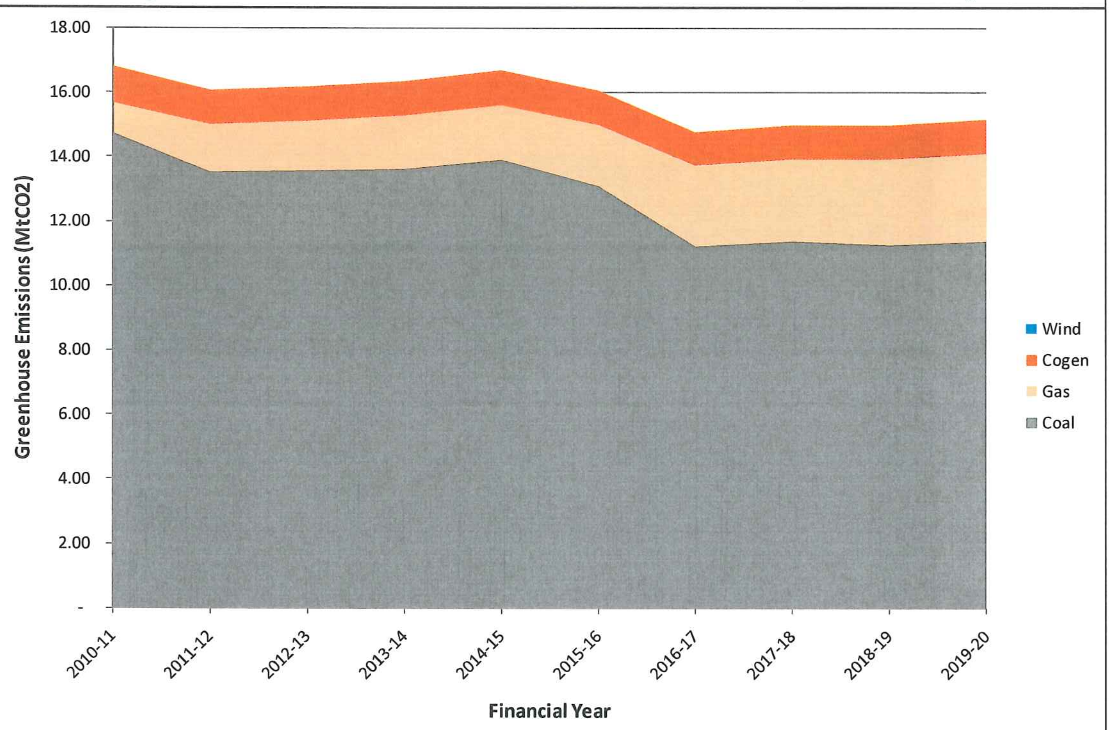
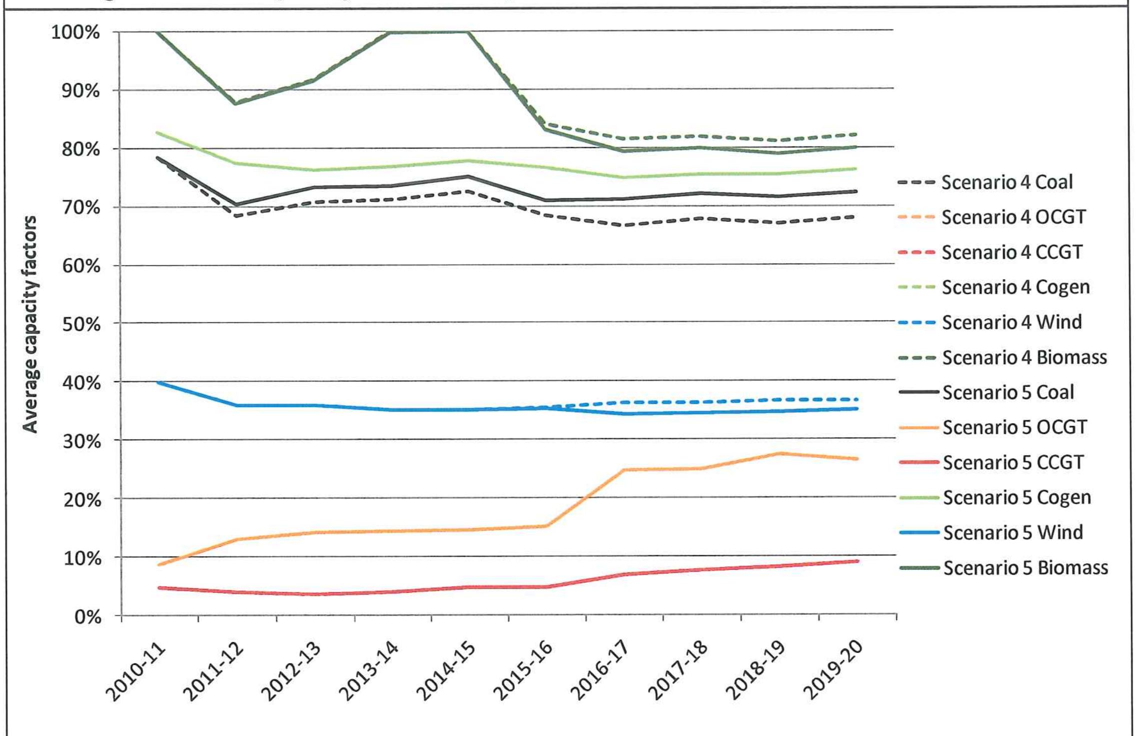


Figure 2.7 – Greenhouse emissions from the SWIS (Scenario 5C)



2.5) OPERATIONAL MODES OF PLANTS

Figure 2.8 – Capacity Factors of plants in the SWIS (Scenarios 4C and 5C)



Generators maintain fairly constant capacity factors over the life of the study, with the exception of biomass due to the low quantity of installed capacity.

Plant cycling

Figure 2.9 – Time-sequential generation of coal-fired plant (Scenario 4C)

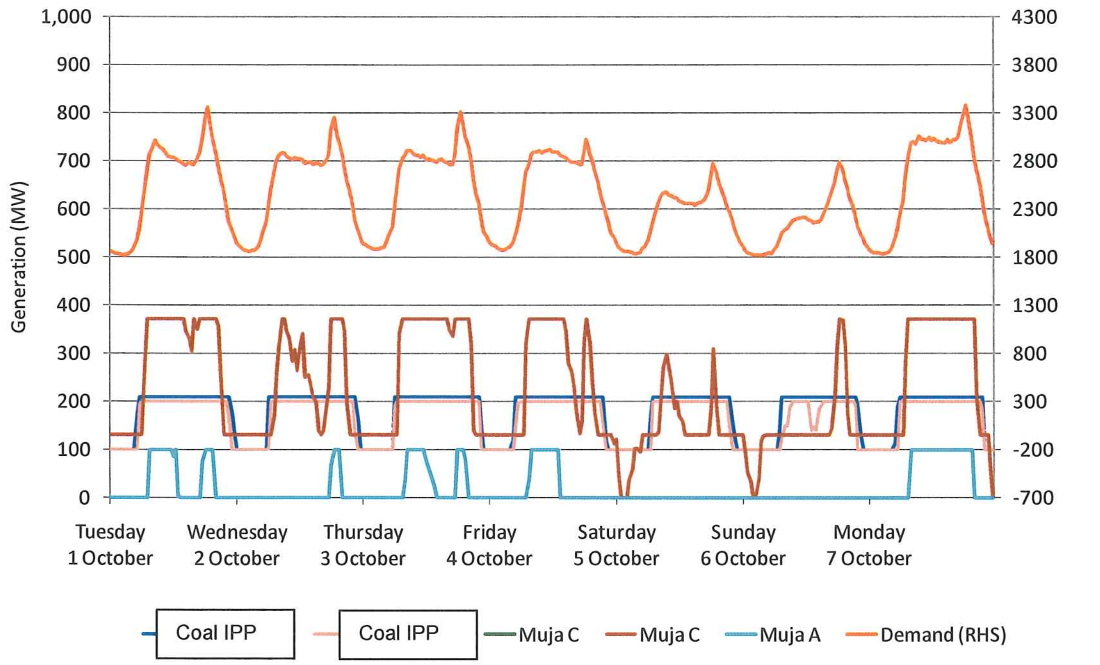
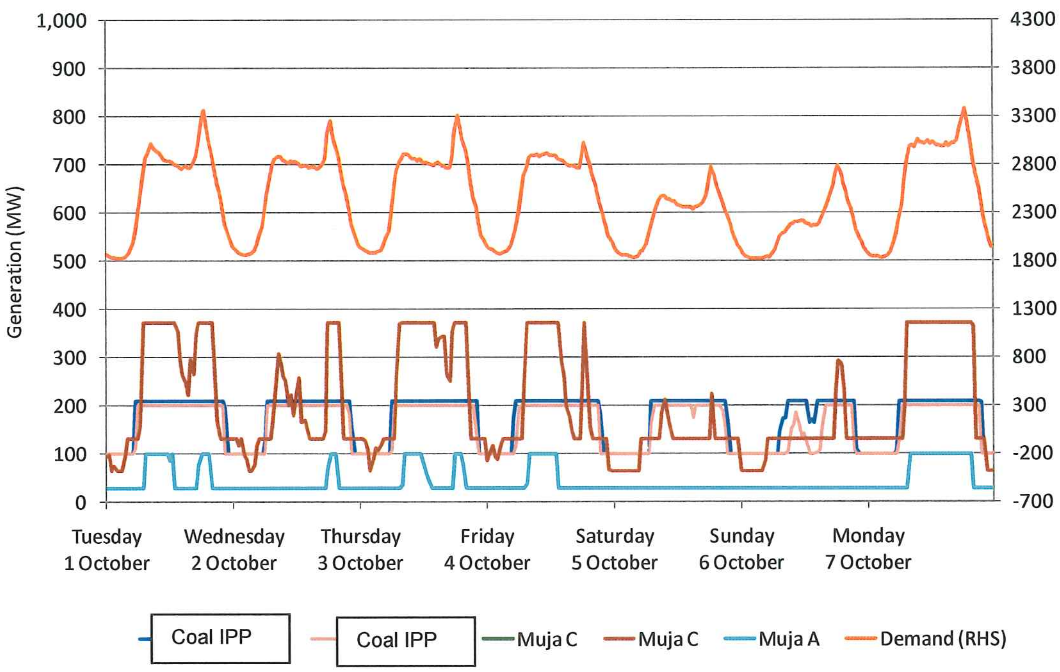


Figure 2.10 – Time-sequential generation of coal-fired plant (Scenario 5C)



In Scenario 4, coal fired plant is required to cycle occasionally (as in the case of Muja A above, shown for both Scenario 4 and Scenario 5 for comparison). In Scenario 5, the wind is curtailed first in every period and no cycling occurs. However, coal plants that are not listed as "must run" may do worse, due to the change in merit order (such as Muja C above).

3) Fuel Usage

ROAM has estimated the fuel usage for each year of each scenario. ROAM has determined best estimates for heat rates for plants in the SWIS and has calculated fuel usage accordingly (in petajoules). The figures below refer to fuel used during operation at typical levels and do not include fuel required for plant start-ups, e.g., for cycling coal plant. As such, these figures may be underestimates of true SWIS fuel usage.

Figure 3.1 – Fuel usage (PJ)

		2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20
Scen. 4C	Gas	29	33	33	36	37	45	55	56	58	59
	Liquid	0.1	0.3	0.3	0.4	0.5	0.5	1.0	1.3	1.5	1.8
	Coal	146	140	142	142	145	137	119	121	120	121

Scen. 5C	Gas	29	33	33	36	37	45	55	56	58	59
	Liquid	0.1	0.3	0.3	0.4	0.5	0.5	1.0	1.3	1.5	1.8
	Coal	146	141	142	143	145	138	122	123	122	123
Scen 2C	Gas	39	41	41	40	47	47	49	51	53	51
	Liquid	0.6	0.3	0.6	0.3	0.4	0.5	0.2	0.0	10.2	23.9
	Coal	133	133	133	117	106	91	84	83	73	65
Scen 6C	Gas	39	41	41	40	47	47	49	51	53	51
	Liquid	0.6	0.3	0.6	0.3	0.4	0.5	0.2	0.0	10.2	23.9
	Coal	133	133	134	121	112	100	100	102	94	87

As expected, requiring coal plants to be must-run significantly increases the coal fuel usage, generally at the expense of wind generation so that gas and liquid usage is not significantly affected.

Figure 3.2 – Fuel usage (Scenario 2 vs Scenario 6)

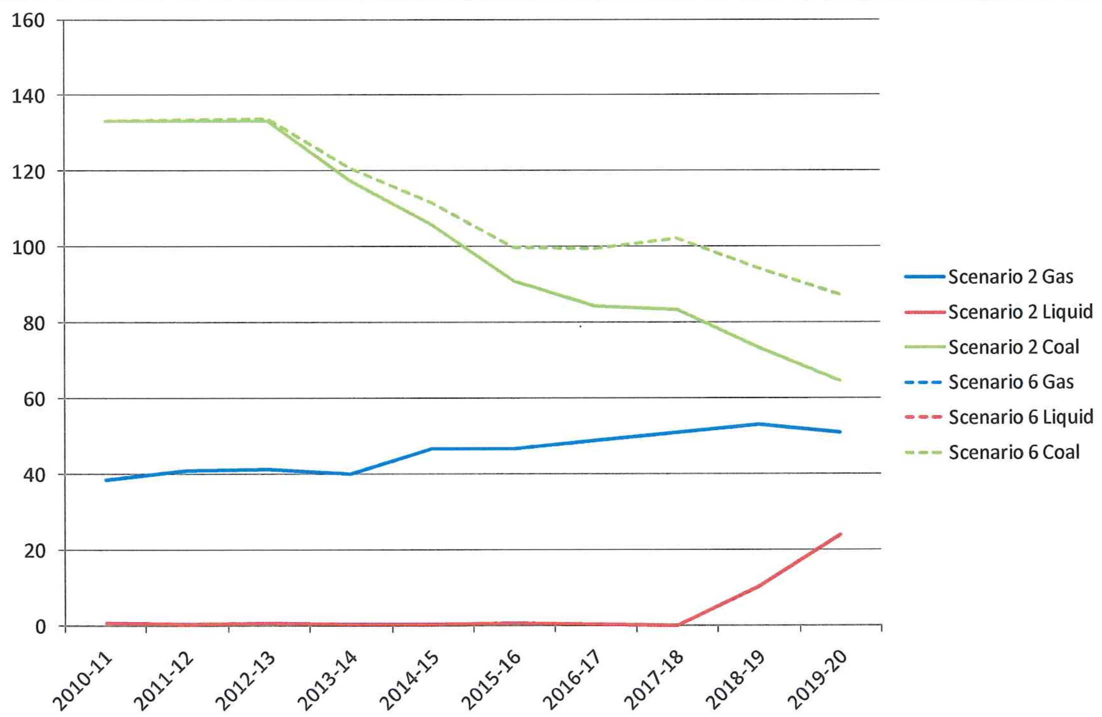


Figure 3.3 – Fuel usage (Scenario 4 vs Scenario 5)