Sensitivity of Electricity Prices to a Carbon Price on the South West Interconnected System

Sustainable Energy Now Inc.

PO Box 341

West Perth WA 6872

contact@sen.asn.au

http://www.sen.asn.au/

Authors: Len Bunn, Dr Rob Phillips

Contributors: Humphrey Boogaerdt, Steve Gates, Alastair Leith

Proofreading: Tanya Marwood

Sustainable Energy Now (SEN) is a voluntary group of some 200 members and associates, many of whom are professionals in the engineering, science, educational, business and IT fields. Its goal is to promote renewable energy in Western Australia.	Contact details: PO Box 341 West Perth, WA 6872 contact@sen.asn.au www.sen.asn.au

Executive Summary

In early 2019, the State government announced an 'Energy Transformation Strategy' [1], *"to ensure the delivery of secure, reliable, sustainable and affordable electricity to Western Australian's for years to come"*, and established an Energy Transformation Taskforce, including an Energy Transition Implementation Unit (ETIU) tasked with the development of a Whole of System Plan (WoSP). These functions have now been rolled into an organisation called Energy Policy WA (EPWA).

Due to the uncertain status of a carbon price in Australia, EPWA has not yet included a treatment of it in the base inputs and assumptions for its WoSP modelling.

SEN considers that the likelihood of a carbon price within the next 5-10 years is very high, and the impact of a carbon price on modelling outcomes and transition plans is significant.

Given that EPWA is not explicitly modelling a carbon price, inclusion of a sensitivity analysis of a carbon price over possible ranges is prudent as a risk mitigation measure, in line with the WoSP Implementation Unit's intentions. SEN has developed this document to inform EPWA about the impact of a price on carbon on modelled electricity prices.

We have provided two alternative measures of carbon-price-sensitivity: modelled results based on 2016 figures for Levelised Cost of Electricity (LCOE); and an approach based on emissions intensity for various generation technologies, calculated at various carbon price values. The 2016 modelling showed that a $30/tonne carbon price increased the LCOE of coal generation from $91 to$109 – an increase of approximately 20%.

The substantive part of this work is a Carbon Price Sensitivity Analysis. This approach comprised four steps:

1. Determine the Scope 1 & 2 emissions intensity of various fossil fuel and renewable energy generation technologies using widely-accepted Australian (BREE AETA) and International (IPCC) sources.
2. Identify the international and national range of existing and sanctioned carbon prices.
3. Estimate the probability that a particular carbon price will be applied in Western Australia in the medium term. This sensitivity analysis considers the likelihood and consequent impact of a particular carbon price. Probabilities are expressed as P_n.

   That is, there is a probability that the actual carbon price will be equal to or greater than the associated price within the next decade, where n is a positive percentage in the range [0% - 100%].
4. Combines this information to estimate the impact on electricity prices at various probabilities.

In the Australian context, SEN asserts that in the next 5 to 10 years there is a:

- Near certainty (100%) of a carbon price of at least $17.50 (expressed as P100)
- Very high (90%) likelihood of a carbon price of at least $30 (expressed as P90)
- Significant (50%) likelihood of a carbon price of at least $60 (expressed as P50)

The sensitivity analysis for the impact of various carbon prices on Levelised Cost of Electricity for each technology is summarised in Table 6.

It is clear from Table 6 that even relatively low, but high probability, carbon prices will have a substantial impact on the LCOE of electricity generation modelled by the WoSP Implementation Unit. Even at P90 and P100 levels, the price impact on the relative LCOEs for coal and gas is significant with the P90 adding $19-$27/MWh.

A $60 carbon price (P50 sensitivity) is not unreasonable by 2030, Such a carbon price on coal and gas will add $39 to $54/MWh to the LCOE.

Given the 20-30 year operational lifetime of generation assets, it is important that the right investment decisions are made, based on all relevant information. Modelling and decision making which does not include consideration of a carbon price is flawed, given the size of the effect indicated by this sensitivity analysis.

This can have the following implications:

- A carbon price will increase the economic competitiveness of renewables over new fossil generation.
- The timing of economic arguments to switch from coal/gas to renewable energy will be heavily influenced by a carbon price.
- The profitability of Synergy's fossil fuel assets will be directly affected by a carbon price with limited ability to pass on cost increases.
- There is a major risk of stranded assets, as they become uneconomic earlier than expected.
- There is a major risk of 'regret spending' on new fossil fuel generation and repairs and enhancements like new control systems for existing coal units that may become obsolete or unnecessary within the next decade.
- There is a major risk that the long lead-times required for network infrastructure upgrades will delay a transition to renewables.
- There is a major risk of 'regret spending' by entering into or renewing inappropriate fuel supply contracts for coal and gas that do not include sufficient flexibility to accommodate rapid and early changes in fuel requirements.

SEN is of the view that this sensitivity analysis highlights the importance of the influence of a potential carbon price on electricity generation costs in WA.

Introduction

Background

In early 2019, the State government announced an 'Energy Transformation Strategy' [1], *"to ensure the delivery of secure, reliable, sustainable and affordable electricity to Western Australian's for years to come"*, and established an Energy Transformation Taskforce, including an Energy Transition Implementation Unit (ETIU) tasked with the development of a Whole of System Plan (WoSP). These functions have now been rolled into an organisation called Energy Policy WA.

The Terms of Reference of the Energy Transformation Taskforce [2] state that:

> *This Strategy is designed to help deliver the Government's overarching objectives for the energy sector, which are to:*
>
> - *maintain a secure and reliable electricity supply;*
> - *ensure affordable electricity for households and businesses;*
> - ***reduce energy sector emissions****;*
> - *transition affected workers in the Collie region from the move away from coal; and*
> - *promote local jobs and growth.*

The third point implies that emissions reduction should be explicitly part of taskforce plans. However, the Whole of System Plan modelling scenarios [3] draw back from this provision, stating:

> *As there is currently no explicit climate or emissions reduction policy targeted at the electricity sector at either the State or Federal level other than the existing Commonwealth Renewable Energy Target (RET), only the Large-Scale RET will be explicitly modelled in the WOSP. However, the modelling will provide a view of the different emissions outcomes that may result over the 20-year horizon under the different scenarios*

Energy Policy WA has not included a carbon price in its WoSP modelling due to its uncertain status in Australia. However, State governments are bound by the National Climate Resilience and Adaptation Strategy [4] to manage "risks and impacts to public assets (including natural assets) and infrastructure owned and managed by the State or Territory Government" [5]. SEN argues that the absence of a price on carbon in the WoSP modelling goes against climate risk principles and the Terms of Reference of the Energy Transformation Taskforce.

SEN considers that the likelihood of a carbon price within the next 5-10 years is very high. The introduction of a price on carbon is essential to combat GHG emissions and is supported by many economists [6]. Industry is expecting that a carbon price will come into force in Australia, referring to the *"Australian Government's evolving climate change framework"* [7]. Industry is also increasingly factoring a carbon price into investment decisions (e.g. Woodside Petroleum is assuming $40 per tonne CO_2-e [8]). Similarly, the Australian Securities and Investments Commission requires companies to factor climate change risks into their activities [9]. Furthermore, carbon pricing is high on the agenda in international negotiations, although agreement was not reached at the recent COP25 conference [10].

Furthermore, the European Commission is signalling that the EU will impose carbon border tariffs on imports from nations not pricing carbon [11]. The border tariffs are likely to be similar or higher than an equivalence to the floating carbon price in the EU Emissions Trading Scheme. China has been trialling an internal price on carbon in several provinces and is working towards a national scheme. Given the large volumes of trade Australia has with China and Europe, the international implications of carbon pricing will be unavoidable for Australia.

SEN considers that the impact of a carbon price on modelling outcomes and transition plans is significant. Given that EPWA is not explicitly modelling a carbon price, inclusion of a sensitivity analysis of a carbon price over possible ranges is prudent as a risk mitigation measure, in line with EPWA's intentions. EPWA needs to ensure that designs and plans in the WoSP are robust and able to accommodate various levels of carbon pricing. SEN has developed this document to inform EPWA about the impact of a price of carbon on modelled electricity prices. This work is indicative only, because SEN does not have access to the range of accurate information that the WoSP Implementation Unit does.

We have provided two alternative measures of carbon-price-sensitivity: modelled results based on 2016 figures for Levelised Cost of Electricity (LCOE); and an approach based on emissions intensity for various generation technologies, calculated at various carbon price values.

Modelling Approach

In 2016, SEN made a submission to the Senate Inquiry "Retirement of Coal-fired Power Stations" [12], based on detailed modelling of the South West Interconnected System [13]. The relevant results here are shown in Table 1, which explores different renewable scenarios with different carbon pricing mechanisms.

Table 1: Results of SEN's modelling of transitional scenarios. Derived from [12], page 15.

Scenario / Assumptions	BAU existing C=100%	Close Muja ABCD power stations C=71.6%	Close Muja ABCD and Collie power stations C=50.3%	No coal power, no storage, increase Wind, PV C=38.7%
Zero C price and zero RET	$91	$99	$109	$109
$30/t Carbon Price	$109	$112	$119	$116
$55 LGC price, 20% RET target; excess LGC's sold	$98	$96	$100	$98

Table 1 shows modelled LCOE as coal-fired generation is phased out (columns 2-5) with no subsidies, a $30/tonne carbon price and Renewable Energy Target Large-scale Generation Certificates (Rows 2-4). The relevant figures here are in Column 2, the Business-as Usual (BAU) scenario in 2016, where all Coal generators were in service. The LCOE figure of $91 rises to $109 when a $30/ tonne CO_2-e price is applied. Thus, approximately 20% of the LCOE comes from a carbon price. Any modelling of the future electricity system needs to factor in such a large impact.

This modelling was performed in 2016. Since then, prices of renewables have continued to reduce, and the Muja A/B coal generators have been mothballed. While some of the assumptions in this work may no longer be accurate, the general finding of an approximate 20% impact is still valid.

This finding has prompted SEN to perform a different, more fundamental, analysis of carbon price impact on electricity prices, described below. That is, an approach based on emissions intensity for various generation technologies, calculated at various carbon price values.

Carbon Price Sensitivity Analysis

Our approach comprised three steps:

1. Determine the Scope 1 & 2 emissions intensity of various fossil fuel and renewable energy generation technologies.
2. Identify the international and national range of existing and sanctioned carbon prices.
3. Estimate the probability that a particular carbon price will be applied in Western Australia in the medium term.

The analysis combines this information to estimate the impact on electricity prices at various probabilities. Some other background information is provided in the following subsections.

Emissions' Scope

The Western Australian Environmental Protection Authority defines Scope 1,2 & 3 GHG emissions [14] as:

> *Scope 1 GHG emissions are the emissions released to the atmosphere as a direct result of an activity, or a series of activities at a facility level. Scope 2 GHG emissions are the emissions from the consumption of an energy product. Scope 3 emissions are indirect GHG emissions other than scope 2 emissions that are generated in the wider community.*

This analysis considers Scope 1 emissions on their own, and both Scope 1 & Scope 2 emissions together. Scope 3 emissions are not included here, as they are part of general electricity grid user emissions.

The electricity generation sector uses these definitions of Scope 1 & 2 emissions.

- Scope 1 - direct CO_2 emissions from combustion exhaust gases. Scope 1 should also include emissions from general plant operations including transport, maintenance, heating/cooling etc., but these are normally minor when compared with combustion emissions.
- Scope 2 - Upstream emissions from activities that produce and deliver energy inputs to the scope 1 activities. This includes mining, processing, transport and fugitive emissions, among others.

Sensitivity Analysis

The Sensitivity analysis considers the likelihood and consequent impact of a particular Carbon Price. Probabilities are expressed as P_n. That is, there is a *n* % probability that the actual carbon price will be equal to or greater than the nominated price within the next decade.

In the Australian context, SEN asserts that in the next 5 to 10 years there is:

- Almost certainty (100%) that there will be a carbon price of at least \$17.50 (expressed as P100)
- A very high (90%) likelihood of a carbon price of at least \$30 (expressed as P90)

- A significant (50%) likelihood of a carbon price of at least $60 (expressed as P50)

A prudent sensitivity analysis to understand, and therefore minimise, the risks associated with an introduced carbon price would typically consider probabilities from P100 to P30. Given the critical nature of the infrastructure being considered, and potential large impact, the analysis could even consider a P10 sensitivity (10% probability of occurrence).

Global Warming Potential

Methane is a substantially more potent greenhouse gas than carbon dioxide, and is responsible for as much as a third of the anthropogenic global warming that has occurred to date [15, 16].

Global Warming Potential (GWP) is an *"index measuring the radiative forcing following an emission of a unit mass of a given substance, accumulated over a chosen time horizon, relative to that of the reference substance, carbon dioxide (CO_2). The GWP thus represents the combined effect of the differing times these substances remain in the atmosphere and their effectiveness in causing radiative forcing"* [17, page 124].

However, using different time horizons (periods of observation) for greenhouse gas impact changes the observable warming effect in comparison to other GHGs [18]. Methane has a high radiative forcing (RF), but its atmospheric life is around 10 years (half life ~7yrs),

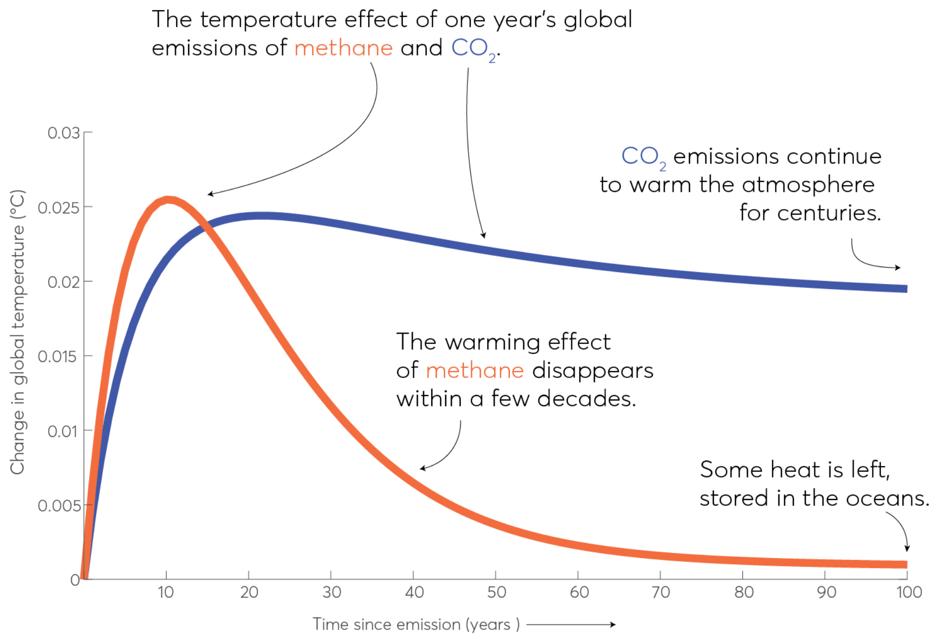

Figure 1. Methane and CO_2 decay curves in the atmosphere.

because chemical reactions in the atmosphere convert it to other gases, mostly CO_2, which has a much lower radiative forcing (RF) impact than methane. Warming from methane decreases sharply after 10 years, as shown in Fig. 1, taken from [19]. If methane were a once-off pulse emission and humanity had decades to address climate change, then the concern would be low. Unfortunately, the atmospheric stock of methane has continued to grow since preindustrial times, much more rapidly than CO_2 in fact, and scientific opinion is that we have one decade left to rapidly reduce GHG emissions to half or less than current global emissions [20].

Two methods of Global Warming Potential are commonly used: whether methane should be compared with CO_2 in the atmosphere over 100 years (GWP_{100}) or 20 years (GWP_{20}). The lower-impact GWP_{100} was used historically in government and quasi-government evaluations, before the rapid rate of change of climate was widely understood, but there has been a recent move to use of GWP_{20} to better reflect the timeframes available for realistic action.

For example, the Kyoto Protocol is based on GWP_{100}. At the time it was signed, methane was indexed at 25 times the warming potential of carbon dioxide [21]. On the other hand, the latest IPCC figure for methane using GWP_{20} uses values between 72 and 105 times the potency of CO_2 over 20 years [22]. In other words, GWP_{100} values substantially reduce the estimated global warming potential of methane compared to GWP_{20} values over the short (10-20 year) timeframes that are now being considered for effective climate change action.

The IPCC has continually discussed various indices for comparing GHG warming effects, and while Global Warming Potential has been seen as a compromise between ease of application and accuracy, the IPCC has always listed estimates for both GWP_{100} and GWP_{20}, even though GWP_{100} has seen the greater adoption in UNFCCC negotiations and legislative frameworks around the world. This is largely due to the almost exclusive focus of world negotiations on CO_2 over other GHGs.

Since a global spike in methane emissions in recent years after a temporary flattening, and the concurrent emergence of unconventional gas mining in recent years, more attention has been focused on methane and the inappropriateness of the reductions within the GWP_{100} index.

For example, in June 2019, the state of New York passed wide-ranging legislation that methane emissions both inside and outside state boundaries will be assessed using the GWP_{20} index [23].

In line with more recent understanding of climate change time frames, SEN advocates for the use of the GWP_{20} approach for methane reporting and accounting, and advises the WA State Government to do the same.

In this work, based on the IPCC findings, SEN has used a factor of 84 for GWP_{20} (section 8.7.1.4 Table 8.7 of [22]), and 28 for GWP_{100} (section 3.9.6 Page 251 of [24]), because this is a more realistic measure of the effect of methane in these particularly critical near-term years of global warming.

CO_2 Intensities

CO_2-e emission intensities for each of the key generation technologies used in the SWIS were researched using widely-accepted Australian (BREE AETA)[25] and International sources (IPCC) [24, 26]. Both Scope 1 & Scope 2 emissions are shown in Table 2.

The BREE AETA [25] data includes only Scope 1 emissions intensities, but includes all technologies used in the SWIS, including OCGT (column 3).

The IPCC data [24, 26] includes both Scope 1 and 2 emissions intensities (columns 2 & 5), but does not include Open Cycle Gas Turbine (OCGT) data. The OCGT equivalent Scope 2 emissions were derived from the Scope 2 emissions for CCGT on the basis that the ratio of Scope 1 to Scope 2 emissions from both OCGT and CCGT are the same. All are proportional to the amount of fuel used.

The BREE AETA figures for coal were taken from Table 3.1.1 of [25]. CCGT and OCGT figures were taken from Table 3.2.1 of [25]. Figures were converted from kg/MWh to tonnes/MWh.

The Scope 1 values for coal and Combined Cycle Gas Turbines (CCGT) are similar in both the IPCC and AETA datasets, and an average value was taken (column 4). The similarity in these figures lends confidence that the AETA OCGT data (column 3) are justifiable.

The IPCC figures [26] for emissions intensity shown in Table 2 were modified to account for: the low embedded methane levels of WA coal compared to world and Australian averages; and to convert the Global Warming Potential from GWP100 to GWP20. Details are provided in Appendix A.

An average was taken of the two estimates of Scope 1 emissions, shown in Column 4. The Scope 2 values (column 5 of Table 2) were derived from the sum of columns 3 to 5 of Table A.2 in Appendix A. The final column of Table 2 shows the combined Scope 1 and Scope 2 emissions used in this analysis.

Table 2. Emission Intensities of Generation Technologies, in units of either gCO_2-e / kWh or $kgCO_2$-e / MWh.

	Scope 1			Scope 2	Scope 1 & 2
Commercial Technologies	IPCC WG3 AR5* [26]	BREE AETA [25]	Average	IPCC WG3 AR5* [26]	Used for Analysis
Coal (pulverised coal, sub-critical)	760	783	772	52	824
Gas – combined cycle	370	369	370	275	645
Gas – OCGT	n. a.	515	515	383	898
Biomass – dedicated	0	0	0	237	237
Solar PV utility	0	0	0	29	29
Solar PV rooftop	0	0	0	42	42
Conc. Solar thermal	0	0	0	66	66
Wind onshore	0	0	0	15	15
Wind offshore	0	0	0	17	17

* GWP_{20} for Methane

CO_2 Prices

A review was carried out of carbon pricing schemes in various jurisdictions, as shown in Table 3. All prices have been converted to Australian dollars. Note that Table 3 shows various carbon pricing mechanisms under the Type column, but these are largely irrelevant to this analysis. Table 3 also shows, where relevant and known, expected future values every two years until 2040.

The trading price of Australian Carbon Credit Units (ACCU) [27] was one Australian measure used (row 2). The price has trended up in 2018-19.

Rows 3 & 4 correspond to two scenarios provided by AETA [25, Figure 2.2.1]: the Strong Growth, Low Pollution (SGLP), based on limiting emissions at 550 ppm of CO_2 by 2050; and the High Price Scenario based on limiting emissions at 450 ppm of CO_2 by 2050. This is now closer to the base scenario for world climate change action.

International prices are shown in the remaining rows of Table 3. These are derived from the World Bank Carbon Pricing Dashboard [28] for various countries and states/ provinces. Footnotes to Table 3 provide specifics.

Table 3. Carbon Price Schemes in various jurisdictions with expected future values every two years until 2040. All prices have been converted to Australian dollars.

Jurisdiction	Type	Commenced	Exchange	2019	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
Australian Auction Price [27]	ACCUs	2015	$1.00	$17.50											
AETA SGLP Core [25, Figure 2.2.1]	Non specific	2012	$1.00		$35	$39	$43	$47	$52	$57	$63	$70	$77	$85	$94
AETA High Price Scenario [25, Figure 2.2.1]	Non specific	2012	$1.00		$74	$82	$90	$99	$110	$121	$133	$147	$162	$178	$197
British Columbia (Canada) [28]	Carbon price & dividend	2008	$1.11		$50	$56									
Canada[1] [28]	ETS	2019	$1.11		$33	$56									
Sweden[2] [28]	Carbon tax	1991	$1.48		$188	$188	$188	$188	$188	$188	$188	$188	$188	$188	$188
UK[3] [28]	ETS	2013	$1.81		$29	$29									
Europe[4] [28]	ETS	2005	$1.63	$47.27	$47	$47	$47	$47	$47	$47	$47	$47	$47	$47	$47
California[5] [28]	ETS	2012	$1.48	$23.12	$24	$27	$30	$33	$36	$40	$44	$48	$53	$58	$64

[1] Overarching federal Emissions Trading Scheme to pick up any regions that haven't already implemented their own scheme to the same level. Started at $20 in 2019 and rising $10/year to $50 in 2022

[2] Will be adjusted annually to include inflation.

[3] Floor price in case BREXIT completes to provide confidence.

[4] Emissions Trading Scheme with floating value due to market dynamics

[5] Emissions Trading Scheme Values noted here are the set minimum prices. Prices can trade substantially above these levels. Increase in the minimum of 5% per year plus inflation.

Carbon prices currently vary from $17.50 (Australian Auction Price) to $188 (Sweden). The bulk of the 2020 values cluster between $30 and $50, with the exception of $74 for the AETA High Price Scenario. However, given the long-term nature of the technology investments being modelled, it is prudent to examine future projections of carbon prices. In 2040, the AETA High Price Scenario is approaching $200, and the AETA SGLP value is $94.

Given the ranges shown in Table 3, we have applied heuristics to estimate the probability of various carbon prices being applied in Australia. These are shown in Table 4. Other values could be chosen for the various probabilities, but these are sufficient for the general nature of this analysis.

Table 4. Probabilities of various carbon prices.

Probability	Price	Notes
P100	$17.50	Current ACCU price in Nov 2019, so the probability is 100%
P90	$30	Minimum of the range of 2019 comparable country forecasts and legislated prices
P70	$45	Towards the upper end of 2019 comparable country forecasts and legislated prices
P50	$60	AETA SGLP in 2030 [25]
P30	$100	AETA SGLP in 2040 [25]
P10	$150	Approaching Sweden and the AETA High Price Scenario [25, Figure 2.2.1].

Impact of CO_2 Price on LCOE

The sensitivity analysis combines the CO_2 intensity of a range of technologies from Table 2, with probabilities of various carbon prices from Table 4 to calculate the impact on the Levelised Cost of Electricity of each technology at each probability point. Table 5 provides this matrix for Scope 1 emissions (Column 4 of Table 2), while Table 6 does the same for combined Scope 1 & 2 emissions (Column 6 of Table 2).

Note that Tables 5 & 6 only show the *change* in LCOE for each technology. This will need to be added to the LCOE modelled by the WoSP Implementation Unit. Such modelling is out of scope here, but our 2016 work indicated that overall generation (and storage as applicable) combined LCOE is in the order of $100 /MWh. Note also that there are no Scope 1 emissions for renewable technologies.

For Scope 1 coal generation (Table 5), P100 and P90 add $14 and $23 to the LCOE, respectively. At P50, a carbon price of $60 adds ca. $50 to the LCOE. The impact of a carbon price on Scope 1 emissions for both types of gas generation is approximately 30% - 50% less than for coal generation.

However, combined Scope 1 & 2 emissions are a more appropriate measure, because these include methane emissions and other production factors. The following discussion therefore considers Table 6.

Because Table 6 also includes Scope 2 emissions, the LCOE of renewable generation technologies is also increased, generally by a small amount compared to fossil-fuel generation. Once Scope 2 emissions are included, the impact of a carbon price is roughly equivalent for coal and OCGT generation. CCGT generation is approximately 20% less than OCGT.

Table 5. Sensitivity analysis for impact of various carbon prices on Levelised Cost of Electricity for each technology. Scope 1 emissions, in \$/MWh.

	CO_2-e Intensity		Carbon Price (\$/tonne CO_2-e)					
			P100	P90	P70	P50	P30	P10
Technology	g/kWhr	tonne/MWhr	\$17.50	\$30	\$45	\$60	\$100	\$150
Coal (pulverised coal, sub-critical)	772	0.772	\$14	\$23	\$35	\$46	\$77	\$116
Gas – combined cycle	370	0.37	\$6	\$11	\$17	\$22	\$37	\$56
Gas – OCGT	515	0.515	\$9	\$15	\$23	\$31	\$52	\$77
Biomass – dedicated	0	0	\$0	\$0	\$0	\$0	\$0	\$0
Solar PV – utility	0	0	\$0	\$0	\$0	\$0	\$0	\$0
Solar PV – rooftop	0	0	\$0	\$0	\$0	\$0	\$0	\$0
Conc. Solar thermal	0	0	\$0	\$0	\$0	\$0	\$0	\$0
Wind onshore	0	0	\$0	\$0	\$0	\$0	\$0	\$0
Wind offshore	0	0	\$0	\$0	\$0	\$0	\$0	\$0

Even at P90 and P100 levels, the price impact on the relative LCOEs for coal and gas is significant with the P90 adding \$19-\$27/MWh.

At the P50 level, the price impact on coal and gas adds \$39 to \$54/MWh to the LCOE (in the order of 40-50%).

Table 3 indicates that a carbon price of \$60 /tonne CO_2-e (P50) is at the low range of what AETA predicts for 2030. Under the AETA High Price Scenario scenario, a carbon price of \$120 /tonne CO_2-e can be expected by 2030 (P30).

Because the effect of GWP_{20} compared to GWP_{100} may affect the sensitivity analysis, Appendix B shows analogous results to Table 6 under a scenario where GWP_{100} was used. P90 results for coal, combined-cycle gas and open-cycle gas fall from \$25, \$19 and \$27 to \$24, \$14 & \$19 respectively with GWP_{100}. While GWP_{100} has less effect than GWP_{20}, there is still a significant sensitivity effect. This does not change the outcomes of this work.

Table 6. Sensitivity analysis for impact of various carbon prices on Levelised Cost of Electricity for each technology. Combined Scope 1 & 2 emissions, in \$/MWh.

	CO_2-e Intensity		Carbon Price (\$/tonne CO_2-e)					
			P100	P90	P70	P50	P30	P10
Technology	g/kWhr	tonne/MWhr	\$17.50	\$30	\$45	\$60	\$100	\$150
Coal (pulverised coal, sub-critical)	824	0.824	\$14	\$25	\$37	\$49	\$82	\$124
Gas – combined cycle	645	0.645	\$11	\$19	\$29	\$39	\$65	\$97
Gas – OCGT	898	0.898	\$16	\$27	\$40	\$54	\$90	\$135
Biomass – dedicated	237	0.237	\$4	\$7	\$11	\$14	\$24	\$36
Solar PV – utility	29	0.029	\$1	\$1	\$1	\$2	\$3	\$4
Solar PV – rooftop	42	0.042	\$1	\$1	\$2	\$3	\$4	\$6
Conc. Solar thermal	66	0.066	\$1	\$2	\$3	\$4	\$7	\$10
Wind onshore	15	0.015	\$0	\$0	\$1	\$1	\$2	\$2
Wind offshore	17	0.017	\$0	\$1	\$1	\$1	\$2	\$3

Conclusion

In the Australian context, SEN asserts that in the next 5 to 10 years there is a:

- Near certainty (100%) of a carbon price of at least $17.50 (expressed as P100)
- Very high (90%) likelihood of a carbon price of at least $30 (expressed as P90)
- Significant (50%) likelihood of a carbon price of at least $60 (expressed as P50)

It is clear from Table 6 that even relatively low, but high probability, carbon prices will have a substantial impact on the LCOE of electricity generation modelled by the WoSP Implementation Unit. Even at P90 and P100 levels the price impact on the relative LCOEs for coal and gas is significant with the P90 adding $19-$27/MWh.

A $60 carbon price (P50 sensitivity) is not unreasonable by 2030. Such a carbon price on coal and gas will add $39 to $54/MWh to the LCOE.

SEN's 2016 modelling summarised in Table 1 indicates that a $30 carbon price causes a $18 increase in LCOE across the entire generation mix (at that time 94% fossil-fuelled). This is relatively consistent with the range of P90 values in Table 6 ($19-27), and provides a cross check on validity.

Given the 20-30 year operational lifetime[1] of generation assets, it is important that the right investment decisions are made, based on all relevant information. Modelling which does not include consideration of a carbon price is flawed, given the size of the effect indicated by this sensitivity analysis.

This can have the following implications:

- A carbon price will increase the economic competitiveness of renewables over new fossil generation.
- The timing of economic arguments to switch from coal/gas to renewable energy will be heavily influenced by a carbon price.
- The profitability of Synergy's fossil fuel assets will be directly affected by a carbon price with limited ability to pass on cost increases.
- There is a major risk of stranded assets, as they become uneconomic earlier than expected.
- There is a major risk of 'regret spending' on new fossil fuel generation and repairs and enhancements like new control systems for existing coal units that may become obsolete or unnecessary within the next decade.
- There is a major risk that the long lead times required for network infrastructure upgrades will delay a transition to renewables.
- There is a major risk of 'regret spending' by entering into or renewing inappropriate fuel supply contracts for coal and gas that do not include sufficient flexibility to accommodate rapid and early changes in fuel requirements.

SEN is of the view that this sensitivity analysis highlights the importance of the influence of a potential carbon price on electricity generation costs in WA. If it is not currently possible to include carbon pricing in the WoSP modelling, SEN recommends the development of a risk analysis of the type used in Section 7 of SEN's Clean Energy WA Study [13].

[1] More than 50 years for pumped hydro.

Appendix A. Details of Modification of Emissions Components

The IPCC figures [26] for emissions intensity were broken down into components: Direct Emissions (Scope 1); Infrastructure and supply chain emissions; Biogenic CO_2 emissions and albedo effect; and Methane emissions. See Table A.1.

The CO_2 equivalence for methane emissions (column 5) was derived from use of a GWP_{100} for Methane of 28 (See section 3.9.6 Page 251 of [26]).

Table A.1. Emission Intensities of Generation Technologies. Extract from [26] [14, P. 1335] based on GWP_{100}, in units of either gCO_2-e / kWh or $kgCO_2$-e / MWh.

	Scope 1	**Scope 2**			**Lifecycle emissions (incl. albedo effect) - Median**
Options	**Direct Emissions (Scope 1) - Median**	**Infrastructure and supply chain emissions**	**Biogenic CO_2 emissions and albedo effect**	**Methane emissions**	
Coal - PC	760	9.6	0	47	820
Gas - Combined Cycle	370	1.6	0	91	490
Biomass - dedicated	n. a.	210	27	0	230
Concentrated Solar Thermal	0	29	0	0	27
Solar PV - rooftop	0	42	0	0	41
Solar PV - utility	0	66	0	0	48
Wind Onshore	0	15	0	0	11
Wind offshore	0	17	0	0	12

Two modifications were made to the methane emissions intensity, and these are shown in Table A.2.

The IPCC emissions intensity for methane was based on GWP100. However, since SEN's calculations were based on the more appropriate GWP20, CO_2 equivalent methane values were converted from GWP100 to GWP20 by a simple ratio of 84/28, using 84 for GWP20 and 28 for GWP100.

Fugitive methane emissions for coal have been reduced by 70% as the WA coal used for generation has low embedded methane levels compared to world and Australian averages. Actual fugitive emissions were not readily available to confirm this assumption.

The figures in column 5 of Table 2 were derived from the sum of columns 3 to 5 of Table A.2.

Table A.2. Emission Intensities of Generation Technologies. Modified Table A.1, using GWP_{20} for Methane of 84 (no feedbacks) and reduced coal emissions, in units of either gCO_2-e / kWh or $kgCO_2$-e / MWh.

Options	**Direct Emissions (Scope 1) - Median**	**Infrastructure and supply chain emissions**	**Biogenic CO_2 emissions and albedo effect**	**Methane emissions**	**Lifecycle emissions (incl. albedo effect) - Median**
Coal - PC	760	9.6	0	42.3	815.3
Gas - Combined Cycle	370	1.6	0	273	672
Biomass - dedicated	n. a.	210	27	0	230
Concentrated Solar Thermal	0	29	0	0	27
Solar PV - rooftop	0	42	0	0	41
Solar PV - utility	0	66	0	0	48
Wind Onshore	0	15	0	0	11
Wind offshore	0	17	0	0	12

Appendix B. Sensitivity Analysis with GWP_{100}

Appendix B investigates the effect of GWP_{20} compared to GWP_{100} on the sensitivity analysis. Table 6 was recalculated under a scenario where GWP_{100} was used instead of GWP_{20}. See Table B.1. P90 results for coal, combined-cycle gas and open-cycle gas fall from $25, $19 and $27 to $24, $14 & $19 respectively with GWP_{100}.

Similarly, under P50, results for coal, combined-cycle gas and open-cycle gas fall from $49, $39 and $54 to $48, $28 & $39 respectively with GWP_{100}. GWP_{100} has a larger impact on gas prices, because Western Australian coal has relatively low levels of embedded methane.

While GWP_{100} has less effect than GWP_{20}, there is still a significant sensitivity effect. This does not change the outcomes of this work.

Table B.1. Sensitivity analysis under GWP_{100} for impact of various carbon prices on Levelised Cost of Electricity for each technology. Combined Scope 1 & 2 emissions, in $/MWh.

	CO_2e Intensity		Carbon Price ($/tonne CO_2e)					
			P100	P90	P70	P50	P30	P10
Technology	g/kWhr	tonne/MWhr	$17.50	$30	$45	$60	$100	$150
Coal (pulverised coal, sub-critical)	796	0.796	$14	$24	$36	$48	$80	$119
Gas – combined cycle	463	0.463	$8	$14	$21	$28	$46	$69
Gas – OCGT	644	0.644	$11	$19	$29	$39	$64	$97
Biomass – dedicated	237	0.237	$4	$7	$11	$14	$24	$36
Solar PV utility	29	0.029	$1	$1	$1	$2	$3	$4
Solar PV rooftop	42	0.042	$1	$1	$2	$3	$4	$6
Conc. Solar thermal	66	0.066	$1	$2	$3	$4	$7	$10
Wind onshore	15	0.015	$0	$0	$1	$1	$2	$2
Wind offshore	17	0.017	$0	$1	$1	$1	$2	$3

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