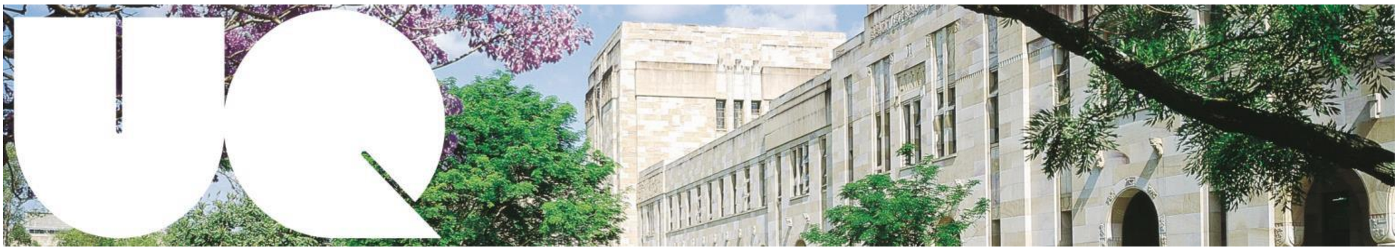

The effect of increasing the number of wind turbine generators on carbon dioxide emissions in the Australian National Electricity Market from 2014 to 2025

EEMG Working Paper 5-2015 - Version 13

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Infigen
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University of Newcastle

As part of the project:

ARC Linkage Project (LP110200957, 2011-2014) - An investigation of the impacts of increased power supply to the national grid by wind generators on the Australian electricity industry

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Preface

This report investigates *'The effect of increasing the number of wind turbine generators on carbon dioxide emissions in the Australian National Electricity Market (NEM) from 2014 to 2025'*. The report is part of research project titled: *An investigation of the impacts of increased power supply to the national grid by wind generators on the Australian electricity industry: ARC Linkage Project (LP110200957, 2011-2014).*

The aim of the project is to discover the most economical and effective way to accommodate large increases in wind power into the national grid and to understand the effects on the national electricity market. This is crucial to ensure stability of electricity supply and affordable prices in the transition towards a low carbon economy.

Significant increases in Australian power generation using wind are planned for the coming years. This project answers urgent questions concerning the capability of the existing power grid to cope with a volatile source of supply, required grid modifications, impacts on the national electricity market (NEM), the optimal placement of wind farms and the Large-scale Renewable Energy Target (LRET). This is, necessarily, an interdisciplinary project involving economists, electrical engineers and climate scientists with very strong support from the wind generators. A coherent government policy to phase in renewable energy in a cost effective manner will not be possible without high quality research of this kind.

The project's electricity market modelling tool is the *Australian National Electricity Market (ANEM) model version 1.10 (Wild et al. 2015).* Wild et al. (2015) provide extensive details of the version of the ANEM model used in this project. Table 1 provides a list of the project's publications.

Table 1: The project's publications

Journal publications:

Bell, WP, Wild, P, Foster, J, and Hewson, M (2015), Wind speed and electricity demand correlation analysis in the Australian National Electricity Market: Determining wind turbine generators' ability to meet electricity demand without energy storage, *Economic Analysis & Policy*, Vol. In Press, doi:10.1016/j.eap.2015.11.009

Wild, P, Bell, WP and Foster, J, (2015) Impact of Carbon Prices on Wholesale Electricity Prices and Carbon Pass-Through Rates in the Australian National Electricity Market. *The Energy Journal*, *36* 3: doi:10.5547/01956574.36.3.pwil

Final reports:

Wild, P, Bell, WP, Foster, J, and Hewson, M (2015), *Australian National Electricity Market Model version 1.10*, EEMG Working Paper 2-2015, The University of Queensland, Brisbane, Australia.

Bell, WP, Wild, P, Foster, J, and Hewson, M (2015), *The effect of increasing the number of wind turbine generators on transmission line congestion in the Australian National Electricity Market from 2014 to 2025*, EEMG Working Paper 3-2015, The University of Queensland, Brisbane, Australia.

Bell, WP, Wild, P, Foster, J, and Hewson, M (2015), *The effect of increasing the number of wind turbine generators on wholesale spot prices in the Australian National Electricity Market from 2014 to 2025*, EEMG Working Paper 4-2015, The University of Queensland, Brisbane, Australia.

Bell, WP, Wild, P, Foster, J, and Hewson, M (2015), *The effect of increasing the number of wind turbine generators on carbon dioxide emissions in the Australian National Electricity Market from 2014 to 2025*, EEMG Working Paper 5-2015, The University of Queensland, Brisbane, Australia.

Bell, WP, Wild, P, Foster, J, and Hewson, M (2015), *The effect of increasing the number of wind turbine generators on generator energy in the Australian National Electricity Market from 2014 to 2025*, EEMG Working Paper 6-2015, The University of Queensland, Brisbane, Australia.

Bell, WP, Wild, P, Foster, J, and Hewson, M (2015), *NEMLink: Augmenting the Australian National Electricity Market transmission grid to facilitate increased wind turbine generation and its effect on transmission congestion*, EEMG Working Paper 9-2015, The University of Queensland, Brisbane, Australia.

Bell, WP, Wild, P, Foster, J, and Hewson, M (2015), *NEMLink: Augmenting the Australian National Electricity Market transmission grid to facilitate increased wind turbine generation and its effect on wholesale spot prices*, EEMG Working Paper 10-2015, The University of Queensland, Brisbane, Australia.

Interim reports:

Wild, P, Bell, WP and Foster, J (2014*), Impact of Transmission Network Augmentation Options on Operational Wind Generation in the Australian National Electricity Market over 2007-2012*, EEMG Working Paper 11-2014, School of Economics, The University of Queensland

Wild, P, Bell, WP and Foster, J (2014)*, Impact of increased penetration of wind generation in the Australian National Electricity Market,* EEMG Working Paper 10-2014, School of Economics, The University of Queensland

Wild, P, Bell, WP and Foster, J (2014), *Impact of Operational Wind Generation in the Australian National Electricity Market over 2007-2012*. EEMG Working Paper 1-2014, School of Economics, The University of Queensland.

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Abstract

This report investigates the effect of increasing the number of wind turbine generators on carbon dioxide emission in the Australian National Electricity Market's (NEM) existing transmission grid from 2014 to 2025. This report answers urgent questions concerning the capability of the existing transmission grid to cope with significant increases in wind power and aid emissions reductions. The report findings will help develop a coherent government policy to phase in renewable energy in a cost effective manner.

We use a sensitivity analysis to evaluate the effect of five different levels of wind penetration on carbon dioxide emissions. The five levels of wind penetration span Scenarios A to E where Scenario A represents 'no wind' and Scenario E includes all the existing and planned wind power sufficient to meet Australia's 2020 41TWh Large Renewable Energy Target (LRET). We also use sensitivity analysis to evaluate the effect on carbon dioxide emissions of growth in electricity demand over the projections years 2014 to 2015 and weather over the years 2010 to 2012. The sensitivity analysis uses simulations from the 'Australian National Electricity Market (ANEM) model version 1.10' (Wild et al. 2015).

We find increasing wind power penetration decreases carbon dioxide emissions but retail prices fail to reflect the decrease in carbon dioxide emissions. We find Victoria has the largest carbon dioxide emissions and of the states in the NEM Victoria's emissions respond the least to increasing wind power penetration. Victoria having the largest brown coal generation fleet in the NEM explains this unresponsiveness. Wind power via the merit order effect displaces the more expensive fossil fuel generators first in the order gas, black coal and brown coal. However, brown coal has the highest carbon dioxide emissions per unit of electricity. This is suboptimal for climate change mitigation and the reintroduction of a carbon pricing mechanism would adjust the relative costs of fossil fuels favouring the fuels with the lower emissions per unit of electricity.

We find that uncertainty in electricity demand and the renewable energy target are hindering the deployment of wind power. Electricity demand uncertainty stems from permanent structural changes such as downward pressure on demand from the decline in manufacturing, price sensitivity, technological efficiency and meeting electricity demand behind the meter via solar PV and solar water heating. Electricity demand uncertainty also stems from cyclical uncertainty of the El Niño Southern Oscillation (ENSO). The recent reduction of the LRET from the 41 TWh to 20% of demand reflects both permanent and cyclic changes. Both the recent reduction and the annual review of the RET induces investment uncertainty for wind power generators. Introducing a 100% RET and making the percent a moving average of the demand of the last 10 years would encourage retailers to purchase the LRET certificates, help reduce investment uncertainty and accommodate the structural changes in electricity demand.

We find transmission congestion is reducing wind power's ability to reduce emissions. This is particularly noticeable in South Australia (SA) where there are negative wholesale prices inducing spillage of wind power. Factors causing this situation are SA large wind deployment and relatively small demand base plus interconnectors between SA and VIC that quickly exceed their maximum capacity.

In further research, we (Bell et al. 2015b, 2015c) investigate augmenting the NEM's transmission grid to reduce carbon dioxide emissions across the NEM and address the price differential between states under increasing wind power penetration.

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Abbreviations

ABS	Australian Bureau of Statistics
AC	Alternating Current
ACF	Annual Capacity Factor
AEMC	Australian Electricity Market Commission
AEMO	Australian Energy Market Operator
AGL	Australian Gas Limited
ANEM	Australian National Electricity Market Model (from EEMG)
ARENA	Australian Renewable Energy Agency
BREE	Bureau of Resources and Energy Economics
CCGT	Combined Cycle Gas Turbine
CER	Clean Energy Regulator
DC OPF	Direct Current Optimal Power Flow
EEMG	Energy Economics and Management Group (at UQ)
ESO	Electricity Statement of Opportunities
GHG	Green House Gas
GJ	Gigajoule
ISO	Independent System Operator
LCOE	Levelised Cost of Energy
LMP	Locational Marginal Price
LNG	Liquid Natural Gas
LRET	Large-scale Renewable Energy Target
LRMC	Long Run Marginal Cost
LSE	Load Serving Entity
MVA	Megavoltamperes
MW	Megawatt
MWh	Megawatt hour
NEFR	National Electricity Forecast Report

NEM	National Electricity Market
NSP	Network Service Provider
NSW	New South Wales
NPV	Net Present Value
OCGT	Open Cycle Gas Turbine
PPA	Power Purchase Agreement
PV	Photovoltaic
QLD	Queensland
SA	South Australia
SRMC	Short Run Marginal Cost
LRMC	Long Run Marginal Cost
TAS	Tasmania
$tC0_2$	Unit of Carbon Dioxide Measurement: Tonnes of Carbon Dioxide
TMM	Typical Meteorological Month
TMY	Typical Meteorological Year
UQ	University of Queensland
VIC	Victoria
VO&M	Variable Operation and Maintenance
VOLL	Value-of-Lost-Load
WTG	Wind Turbine Generator

1 Introduction

This report's primary aim is to investigate *'The effect of increasing the number of wind turbine generators on carbon dioxide emissions in the Australian National Electricity Market from 2014 to 2025'.* The report is part of the research project titled *'An investigation of the impacts of increased power supply to the national grid by wind generators on the Australian electricity industry'.* The sensitivity analysis in this report uses simulations from the *'Australian National Electricity Market (ANEM) model version 1.10' (Wild et al. 2015)* to model the effect of five different levels of wind penetration on carbon dioxide emissions. The five levels of wind penetration span Scenarios A to E where Scenario A represents 'no wind' and Scenario E includes all the existing and planned wind power sufficient to meet Australia's 2020 41TWh Large Renewable Energy Target. Wild et al. (2015) provide a comprehensive explanation of the both the ANEM model and the five levels of wind penetration.

Bell et al. (2015d) analyses wind speed and electricity demand correlation to determine the ability of wind turbine generators to meet electricity demand in the Australian National Electricity Market (NEM) without the aid of energy storage. They find the most advantage from the lack of correlation between wind speed between the NEM's peripheral states including QLD, SA and TAS. Additionally, the correlation between electricity demand and wind speed is strongest between these states. Similarly, they find the most advantage from the lack of correlation between electricity demands in each of these states. However, the NEM requires sufficient transmission capacity through VIC and NSW to maximise the benefit of wind power in the peripheral states and the NEM generally. To that end, this report examines the reduction in emissions induced by higher penetrations of wind power displacing fossil fuel generation and any potential transmission constraints through VIC and NSW as well as between other States impeding fossil fuel displacement.

Section 2 discusses the methodology for the sensitivity analysis and provides an extremely brief outline of the *ANEM model (Wild et al. 2015).* Section 3 presents the results from the sensitivity analysis. Section 4 discusses the results and Section 5 concludes the report.

2 Methodology: a sensitivity analysis using five levels of wind penetration

Wild et al. (2015) provides a detailed description of the ANEM model, justification for the five levels of wind power penetration and the incrementing of the baseline electricity demand profile years 2010 to 2012 to form three demand projections from 2014 to 2025. This section provides a brief outline of the ANEM model, the five levels of wind power penetration and the demand profiles before presenting the sensitivity analysis results in the next section.

2.1 Australian National Electricity Market Model

The following description provides a simplified computer input-output overview of the ANEM model.

The inputs of the ANEM model are:

- half hourly electricity “total demand” for 50 nodes in the NEM;
- parameter and constraint values for 68 transmission lines and 330 generators, albeit incorporating the de-commissioning of generation plant occurring over the period 2007-2014;
- carbon price, which is assumed zero in this project;
- fossil fuel prices; and
- network topology of nodes, transmission lines and generators.

The outputs of the ANEM model are:

- wholesale spot price at each node (half hourly),
- energy generated by each generator (half hourly),
- energy dispatched (sent out) by each generator (half hourly),
- power flow on each transmission line (half hourly), and
- carbon dioxide emissions for each generator (daily).

2.2 Five levels of wind penetration

We group existing and planned windfarms into five levels of wind power penetration.

a. No wind generation
b. Operational and under construction
c. Advanced planning *(+all the windfarms above)*
d. Less advanced planning *(+all the windfarms above)*
e. Least advanced planning *(+all the windfarms above)*

Details of the windfarms within the five groups are in the project report *‘ANEM model version 1.10’* (Wild et al. 2015, tbls. 4 & 5).

2.3 Baseline years 2010-12 and projections years 2014-25

The project uses electricity demand profiles from three calendar years 2010, 2011 and 2012. Using the demand profiles from these three calendar years reduces the chances of modelling an unrepresentative weather year. Additionally, these weather years provide half-hourly correspondence between electricity demand for each node on the NEM and wind power generated for the five levels of wind power penetration for each node on the NEM. The wind power generated is calculated from half-hourly wind climatology results for the years 2010 to 2012 (Wild et al. 2015).

The demand profiles in the three baseline-years are incremented to form projections for the years 2014 to 2025, making three projections. We simulated the five levels of wind penetration for each projection base year, making fifteen projections in all to allow sensitivity analysis.

Examining the three baseline years 2010 to 2012 considers the effect of differing annual weather systems on the dynamics of the NEM and the carbon dioxide emissions. In contrast, the projections years 2014 to 2025 consider the effect of growth in electricity demand on the dynamics of the NEM and the carbon dioxide emissions.

3 Results

This section presents the results, which should be read while viewing the diagrams in the project report *'Australian National Electricity Market model version 1.10'* (Wild et al. 2015, figs. 1-6). These diagrams relate the node numbers to the topology of the transmission network. Additionally, Wild et al. (2015, tbl. 5) relates the windfarms to their nodes on the NEM.

3.1 Inter State comparison of wind power, weather and growth effects

Table 2 presents the annual carbon dioxide emissions by State in millions of tCO_2. We examined system wide patterns using the lowest and highest wind penetration scenarios, A and E, and the first and last projection years, 2014 and 2025 for each of the baseline weather years 2010 to 2012. Three effects can explain the change in carbon dioxide emissions.

- Wind penetration effect shown between scenario A and E
- Weather effect shown between the baseline years 2010 to 2012
- Growth in demand effect shown between the projection years 2014 to 2025

The following three sections discuss these effects using data from Table 2. The ANEM model (Wild et al. 2015) calculates daily emissions for each generator in the NEM. Table 2 shows the sum of annual generation emissions by State.

Table 2: The annual carbon dioxide emissions for wind penetration scenarios A and E, the projection year 2014 and 2025 and baseline years 2010 to 2012 (millions of tCO_2)

Wind penetration effect	Weather effect	Growth in electricity demand effect						
Wind scenario	Baseline Year	Projection Year	NSW	QLD	SA	TAS	VIC	NEM
a	2010	2014	122.7	103.6	15.2	0.9	138.2	380.7
a	2010	2025	131.6	113.7	16.2	1.1	138.3	400.9
a	2011	2014	114.7	102.5	14.8	0.9	138.1	370.9
a	2011	2025	123.8	113.2	15.7	1.1	138.3	392.1
a	2012	2014	125.8	105.2	16.8	1.0	138.9	387.7
a	2012	2025	133.8	115.0	18.1	1.2	139.7	407.8
e	2010	2014	89.7	94.0	12.1	0.8	134.2	330.7
e	2010	2025	98.7	105.3	11.4	0.8	134.8	351.0
e	2011	2014	80.9	93.0	11.9	0.8	133.2	319.8
e	2011	2025	89.0	104.6	11.2	0.8	134.4	340.1
e	2012	2014	91.4	95.5	12.2	0.8	135.2	335.1
e	2012	2025	101.3	107.6	11.6	0.8	136.6	357.9

3.1.1 Wind penetration effect shown between Scenarios A and E

Figure 1 and Table 3 show the average annual emissions by State for the wind power penetration Scenarios A and E. Scenario A is no wind generation. In contrast, Scenario E contains all existing and planned wind generation that would meet the 2020 LRET. Figure 1 and Table 3 are the annual emission by State averaged across the baseline weather years 2010 to 2012 and the projection growth years 2014 and 2025. Victoria's (VIC) high emissions intensive brown coal generation fleet maintains its position as the NEM's highest emitter, with wind power inducing less than a 3% decrease in VIC's emissions. This small decrease is consistent with wind power replacing higher cost gas in VIC, with brown coal unaffected because of its low cost. The gas fleet is a lot smaller than the largely unaffected brown coal fleet. Section 4 discusses VIC's emissions unresponsiveness to wind power in more detail.

The States most responsive to wind power-induced reductions in emissions by percentage are New South Wales (NSW), South Australia (SA) and Tasmania (TAS). All three States have relatively large wind power deployments compared to their demand for electricity. In contrast, Queensland (QLD) has a much smaller percentage reduction. TAS's large hydro fleet maintains its position as the NEM's lowest emitter in absolute terms.

Table 4 shows that NSW has the largest cumulative wind power in Scenario E in the NEM. The merit order effect of wind on the NEM would displace NSW's more expensive black coal generators before VIC's cheaper brown coal generators. The wind penetration effect is by far the largest of the three effects for annual carbon dioxide emissions. The wind penetration effect is also the largest of the three effects for transmission line congestion (Bell et al. 2015b) and Wholesale Spot Prices (Bell et al. 2015a).

Figure 1: Comparing the average annual carbon dioxide emission between wind power scenarios A and E

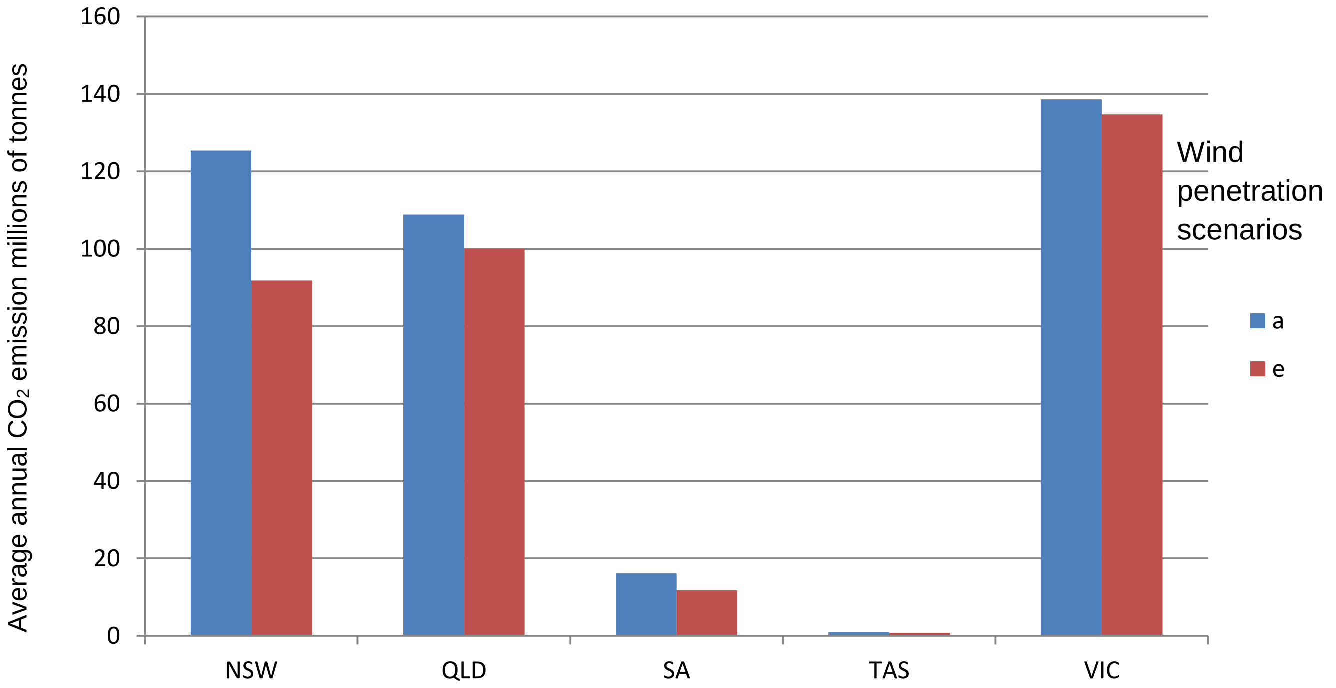

Table 3: Average annual CO_2 emissions for each State for the wind power scenarios A and E

States	a	e	% decrease
NSW	125.4	91.8	26.8
QLD	108.9	100.0	8.1
SA	16.1	11.7	27.3
TAS	1.0	0.8	22.6
VIC	138.6	134.7	2.8
Average	390.0	339.1	13.1

(Millions of tonnes of carbon dioxide)

Table 4: NEM Windfarms added each scenario by State

State/Scenario	No of WTG	Capacity (MW)	Average Capacity Factor	Annual Production (GWh)
NSW	**1,670**	**4,517**	**0.38**	**15,001**
b	350	666	0.36	2,090
c	329	915	0.39	3,137
d	580	1,722	0.39	5,964
e	411	1,215	0.37	3,810
QLD	**328**	**936**	**0.41**	**3,497**
b	20	12	0.36	38
c	25	75	0.40	263
d	208	624	0.44	2,407
e	75	225	0.40	789
SA	**1,152**	**3,052**	**0.38**	**10,885**
b	649	1,473	0.36	4,883
c	193	579	0.41	2,149
d	134	402	0.43	1,522
e	176	598	0.44	2,331
TAS	**323**	**923**	**0.42**	**3,324**
b	118	308	0.42	1,134
d	45	135	0.42	492
e	160	480	0.40	1,698
VIC	**1,471**	**3,784**	**0.39**	**13,201**
b	592	1,223	0.38	4,072
c	415	1,245	0.40	4,401
d	464	1,316	0.40	4,728
Total	**4,944**	**13,212**	**0.39**	**45,907**

(Source: Wild et al. 2015, tbl. 5)

3.1.2 Weather effect shown between the baseline years 2010 to 2012

Figure 2 and Table 5 show the average annual emissions by State for the baseline years 2010 to 2012. We attribute most of the variation in demand in the years 2010 to 2012 to variation in weather between these years. Figure 2 is the average across the wind scenarios A and E and the projection growth years 2014 and 2025. NSW's emissions are the most affected by changes in weather and wind speed. As discussed, Table 5 also shows the weather effect on emissions by percentage standard deviation. This provides a more suitable measure for comparison between States. The weather effect on emissions combines weather induced changes in demand and weather induced changes in wind power. The rank order from most susceptible to least susceptible to the weather effect is NSW, SA, TAS, QLD and VIC. The merit order effect of wind power on the NEM would displace NSW's more expensive black coal generators before VIC's cheaper brown coal generators. The weather effect is the smallest effect of the three for carbon dioxide emissions.

Figure 2: Average emissions for each State for the baseline years 2010 to 2012

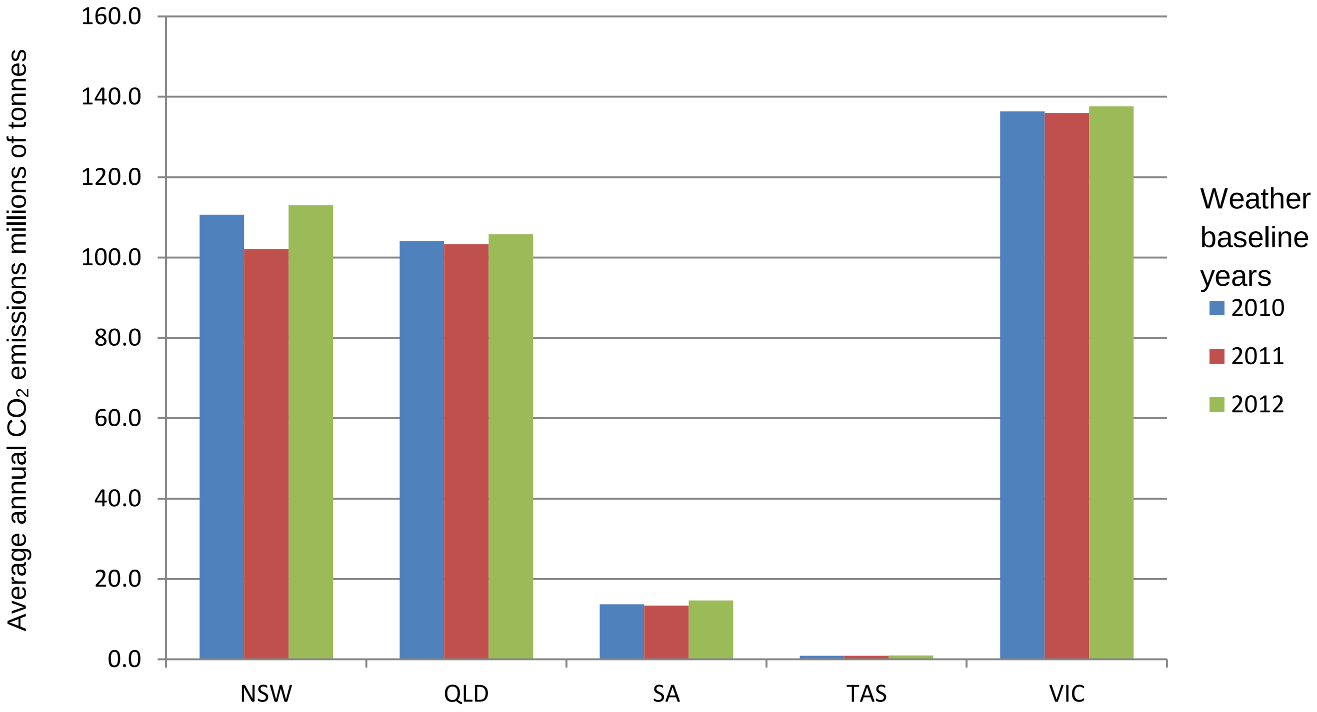

Table 5: Average annual CO_2 emission for each State for the baseline years 2010 to 2012

States	2010	2011	2012	Std. Dev.	% Std. Dev.
NSW	110.7	102.1	113.1	4.7	4.3
QLD	104.2	103.3	105.8	1.0	1.0
SA	13.7	13.4	14.7	0.5	3.9
TAS	0.9	0.9	1.0	0.0	2.6
VIC	136.4	136.0	137.6	0.7	0.5
NEM	365.8	355.7	372.1	6.8	1.9

(Millions of tonnes of carbon dioxide)

3.1.3 Growth in electricity demand effect shown between projection years 2014-25

Figure 3 and Table 6 show the average annual carbon dioxide emission for the projection years 2014 and 2025. We model the demand for electricity to grow from 2014 to 2025. Hence, a growth effect can account for the change in average carbon dioxide emission. Figure 3 is the average across the wind scenarios A and E and baseline years 2010 to 2012. We would expect the growth in demand to put upward pressure on carbon dioxide emission, which is evident in all the States of the NEM. VIC's brown coal generation is some of cheapest in the NEM, so is already being fully dispatched in 2014 there is little spare capacity to accommodate the increase in demand in 2025. TAS, QLD and NSW experience the largest increases in carbon dioxide emission as a proportion. This reflects the more bullish projection assumptions for QLD and, to a less extent, NSW's demand compared with the other states. This would result in relatively greater dispatch of the cheap black coal plant in both states accompanying this demand growth over the projection interval 2014-2025. The growth effect is the second largest of the three effects for carbon dioxide emissions.

Figure 3: Average emissions for each State for the projection years 2014-2025

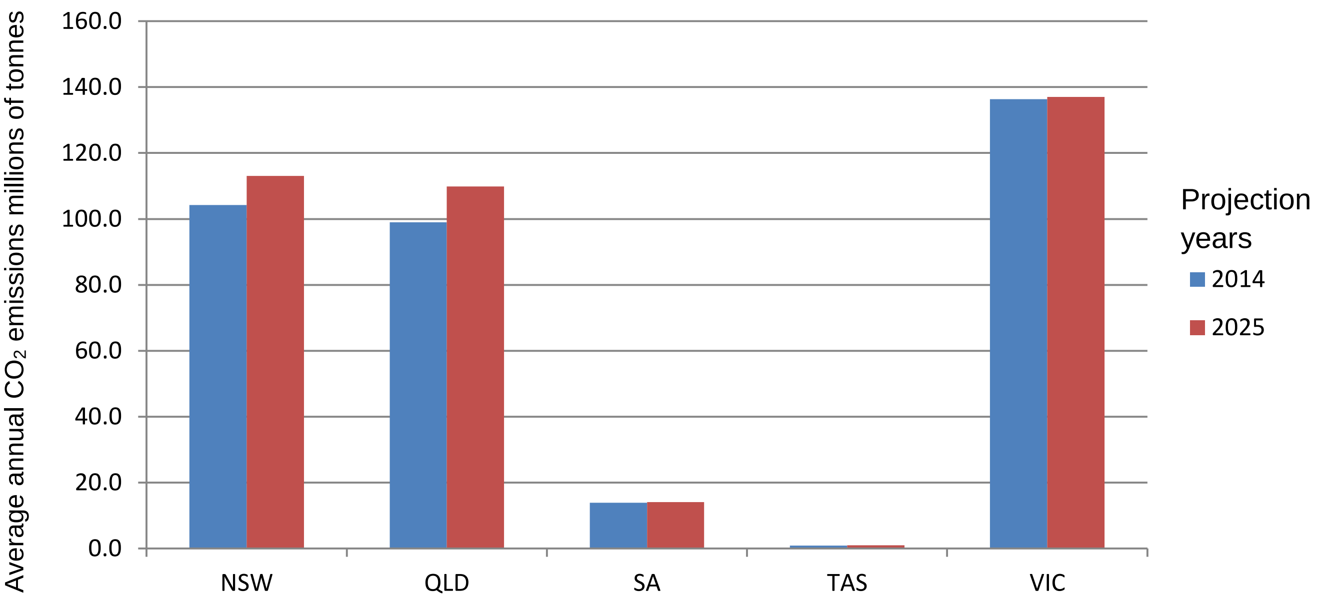

Table 6: Average annual CO_2 emissions for each State for the projection years 2014-2025

States	2014	2025	% increase
NSW	104.2	113.0	8.5
QLD	99.0	109.9	11.0
SA	13.8	14.0	1.4
TAS	0.9	1.0	11.5
VIC	136.3	137.0	0.5
NEM	354.2	375.0	5.9

(Millions of tonnes of carbon dioxide)

3.2 Comparing the three effects on emissions in individual States

This section compares the effect of wind power, weather and growth in electricity demand on emissions in each State and the NEM in total.

3.2.1 Comparing the three effects on the NEM

Figure 4 and Table 7 shows the effect of wind power, weather and demand growth on carbon dioxide emissions in the NEM. Table 8 shows the percentage decrease in carbon dioxide emissions from Scenario A. The increase in wind power from Scenario A to E shows a steady decrease in emissions for all weather and growth Scenarios that are the years 2010-2012 and 2014-2025 respectively.

Figure 4: Comparing wind power, weather and growth effects on the NEM's annual CO_2 emissions

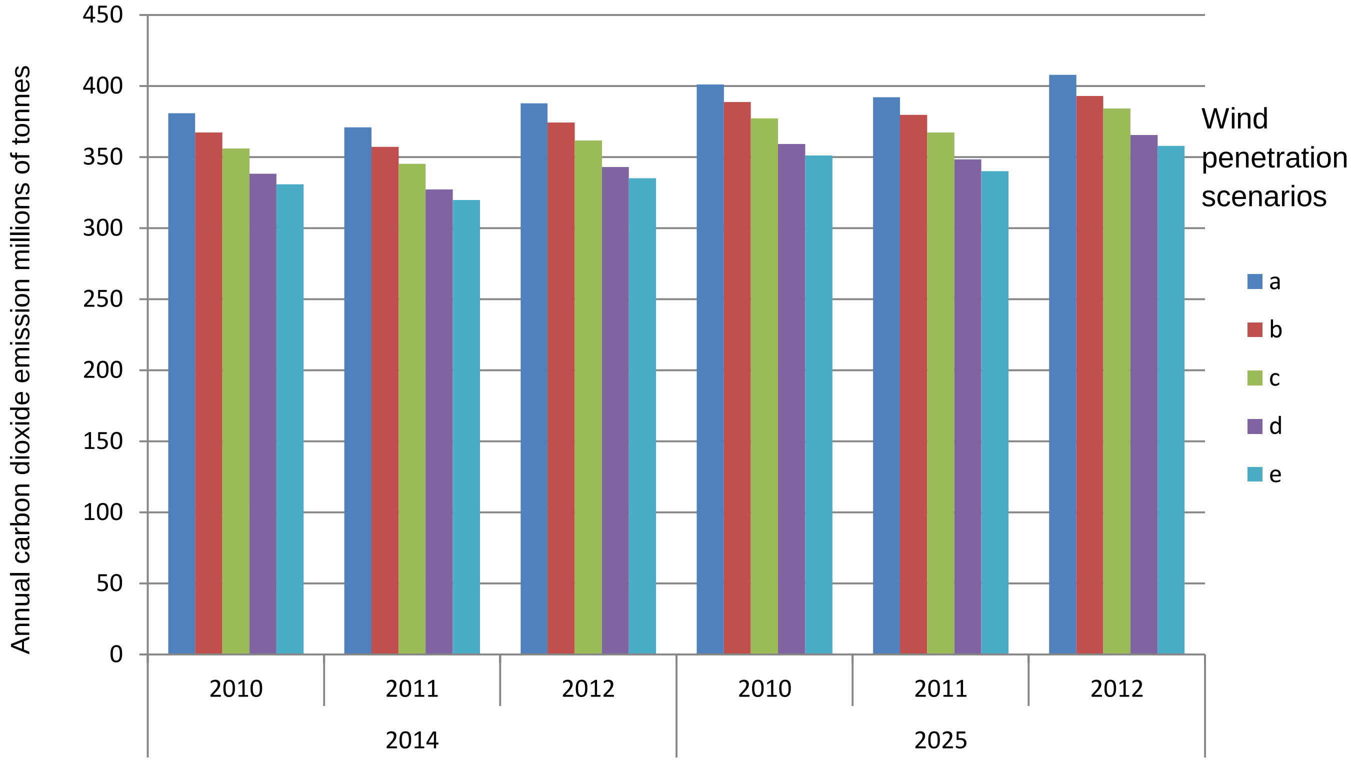

Table 7: Comparing wind power, weather and growth effects on the NEM's annual CO_2 emissions

NEM	a	b	c	d	e	Average
Average	**390.0**	**376.6**	**365.3**	**346.9**	**339.1**	**363.6**
2014	**379.7**	**366.1**	**354.3**	**336.1**	**328.5**	**353.0**
2010	380.7	367.2	356.1	338.3	330.7	354.6
2011	370.9	357.0	345.1	327.1	319.8	344.0
2012	387.7	374.2	361.6	343.0	335.1	360.3
2025	**400.3**	**387.1**	**376.2**	**357.7**	**349.6**	**374.2**
2010	400.9	388.6	377.2	359.1	351.0	375.4
2011	392.1	379.7	367.3	348.4	340.1	365.5
2012	407.8	393.0	384.2	365.4	357.9	381.7

(Millions of tonnes of carbon dioxide)

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Table 8: Comparing wind power, weather and growth effects on the NEM's % decrease in annual CO_2 emissions

NEM	a	b	c	d	e
% decrease	**0.0**	**3.4**	**6.4**	**11.1**	**13.1**
2014	**0.0**	**3.6**	**6.7**	**11.5**	**13.5**
2010	0.0	3.5	6.5	11.1	13.1
2011	0.0	3.7	6.9	11.8	13.8
2012	0.0	3.5	6.7	11.5	13.6
2025	**0.0**	**3.3**	**6.0**	**10.7**	**12.7**
2010	0.0	3.1	5.9	10.4	12.5
2011	0.0	3.2	6.3	11.1	13.3
2012	0.0	3.6	5.8	10.4	12.2

(Percentage decrease in tonnes of carbon dioxide from Scenario A)

3.2.2 Comparing the three effects in NSW

Figure 5 and Table 9 shows the effect of wind power, weather and demand growth on carbon dioxide emissions in NSW. Table 10 shows the percentage decrease in carbon dioxide emissions from Scenario A. The increase in wind power from Scenario A to E shows a steady decrease in emissions for all weather and growth Scenarios that are years 2010-2012 and 2014-2025 respectively. The wind power induced emissions reduction rate in NSW is about twice that of the NEM.

Figure 5: Comparing wind power, weather and growth effects on the NSW's annual CO_2 emissions

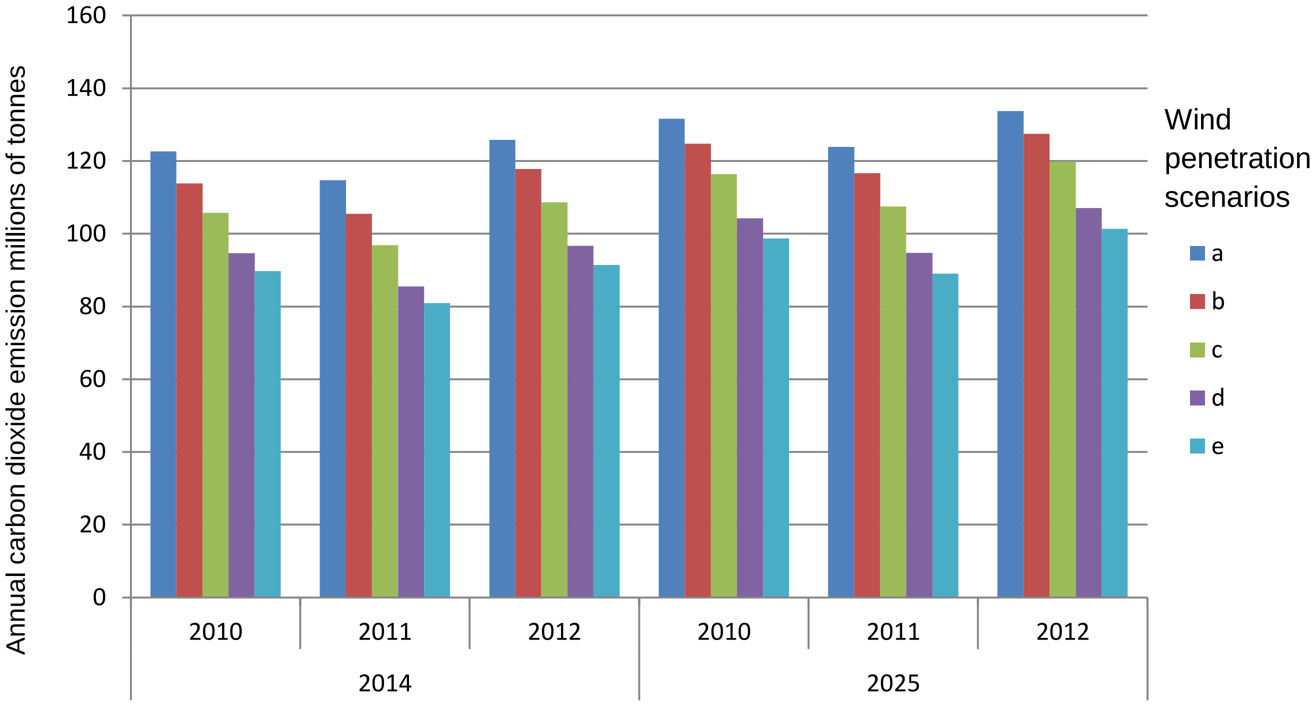

Table 9: Comparing wind power, weather and growth effects on the NSW's annual CO_2 emissions

NSW	a	b	c	d	e	Average
Average	**125.4**	**117.7**	**109.1**	**97.2**	**91.8**	**108.2**
2014	**121.1**	**112.4**	**103.7**	**92.3**	**87.3**	**103.4**
2010	122.7	113.9	105.7	94.7	89.7	105.3
2011	114.7	105.4	96.8	85.5	80.9	96.7
2012	125.8	117.8	108.7	96.7	91.4	108.1
2025	**129.7**	**123.0**	**114.6**	**102.0**	**96.3**	**113.1**
2010	131.6	124.7	116.4	104.3	98.7	115.1
2011	123.8	116.7	107.5	94.7	89.0	106.4
2012	133.8	127.5	119.8	107.1	101.3	117.9

(Millions of tonnes of carbon dioxide)

Table 10: Comparing wind power, weather and growth effects on the NSW's % annual CO_2 emissions

NSW	a	b	c	d	e
% decrease	**0.0**	**6.2**	**13.0**	**22.6**	**26.8**
2014	**0.0**	**7.2**	**14.3**	**23.8**	**27.9**
2010	0.0	7.2	13.8	22.8	26.9
2011	0.0	8.1	15.6	25.4	29.5
2012	0.0	6.4	13.6	23.2	27.3
2025	**0.0**	**5.2**	**11.7**	**21.4**	**25.8**
2010	0.0	5.2	11.6	20.8	25.0
2011	0.0	5.8	13.2	23.5	28.1
2012	0.0	4.7	10.4	20.0	24.2

(Percentage decrease in tonnes of carbon dioxide from Scenario A)

3.2.3 Comparing the three effects in QLD

Figure 6 and Table 11 shows the effect of wind power, weather and demand growth on carbon dioxide emissions in QLD. Table 12 shows the percentage decrease in carbon dioxide emissions from Scenario A. The increase in wind power from Scenario A to E shows a steady decrease in emissions for all weather and growth Scenarios that are years 2010-2012 and 2014-2025 respectively. The wind power induced emissions decrease rate in QLD is about half that of the NEM. QLD has a relatively low proportion of wind power in its generation fleet compared with other States, as a proportion of total generation capacity and demand.

Figure 6: Comparing wind power, weather and growth effects on the QLD's annual CO_2 emissions

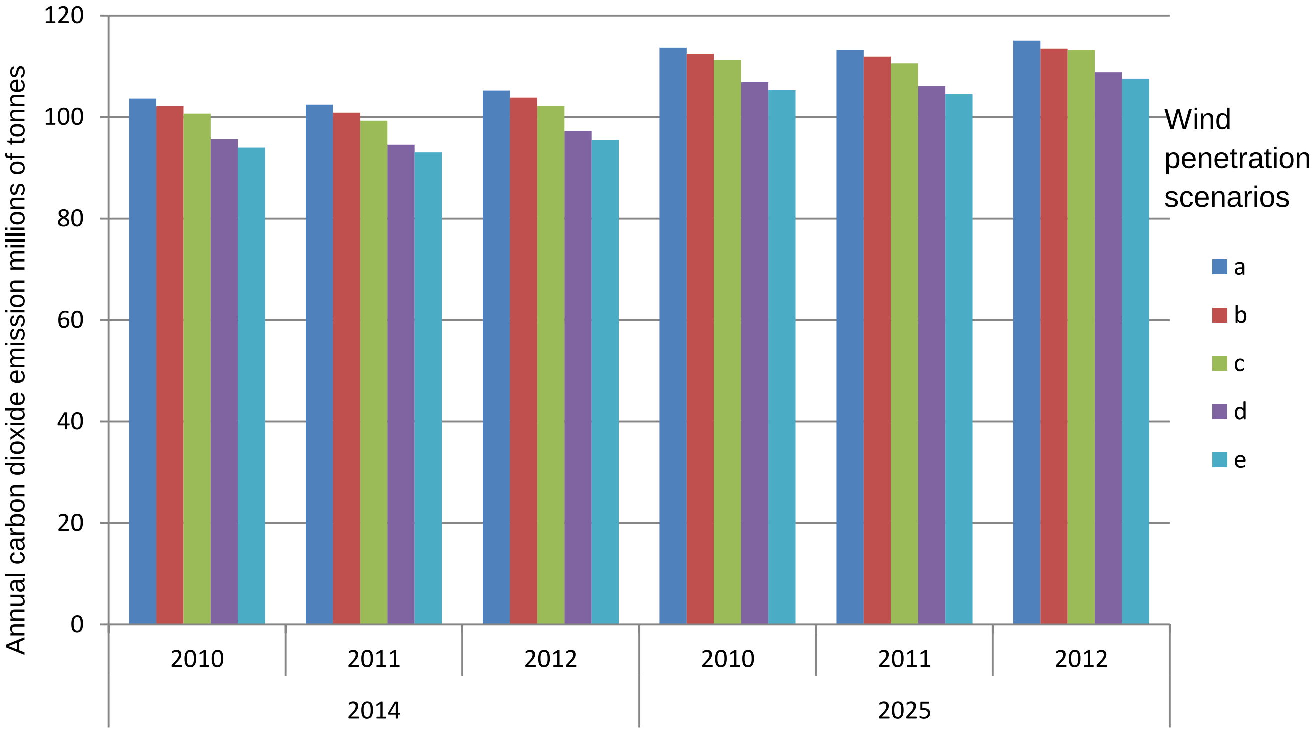

Table 11: Comparing wind power, weather and growth effects on the QLD's annual CO_2 emissions

QLD	a	b	c	d	e	Average
Average	**108.9**	**107.5**	**106.2**	**101.6**	**100.0**	**104.8**
2014	**103.8**	**102.3**	**100.7**	**95.8**	**94.2**	**99.4**
2010	103.6	102.2	100.7	95.6	94.0	99.2
2011	102.5	100.9	99.3	94.6	93.0	98.1
2012	105.2	103.8	102.2	97.3	95.5	100.8
2025	**114.0**	**112.6**	**111.7**	**107.3**	**105.8**	**110.3**
2010	113.7	112.5	111.3	106.9	105.3	109.9
2011	113.2	111.9	110.6	106.1	104.6	109.3
2012	115.0	113.5	113.2	108.8	107.6	111.6

(Millions of tonnes of carbon dioxide)

Table 12: Comparing wind power, weather and growth effects on the QLD's % annual CO_2 emissions

QLD	a	b	c	d	e
% decrease	**0.0**	**1.3**	**2.5**	**6.8**	**8.2**
2014	**0.0**	**1.4**	**3.0**	**7.7**	**9.2**
2010	0.0	1.4	2.9	7.7	9.3
2011	0.0	1.5	3.1	7.7	9.2
2012	0.0	1.3	2.9	7.6	9.2
2025	**0.0**	**1.2**	**2.0**	**5.9**	**7.2**
2010	0.0	1.0	2.1	6.0	7.4
2011	0.0	1.1	2.3	6.3	7.6
2012	0.0	1.4	1.6	5.4	6.5

(Percentage decrease in tonnes of carbon dioxide from Scenario A)

3.2.4 Comparing the three effects in SA

Figure 7 and Table 13 shows the effect of wind power, weather and demand growth on carbon dioxide emissions in SA. Table 14 shows the percentage decrease in carbon dioxide emissions from Scenario A. The increase in wind power from Scenario A to E shows a steady decrease in emissions for all weather and growth Scenarios that are years 2010-2012 and 2014-2025 respectively. The wind power induced emissions decrease rate in SA is about twice that of the NEM. Most of SA's reduction in emissions comes in Scenario B. This coincides with SA's largest wind power deployment in Scenario B shown in Table 4. In comparison, when compared with the size of the incremental capacity expansions in wind power occurring in this State under Scenarios C, D and E. The power from the smaller wind power deployments in Scenarios C, D and E is more likely to be exported reducing emission elsewhere in the NEM rather than within SA.

Figure 7: Comparing wind power, weather and growth effects on the SA's annual CO_2 emissions

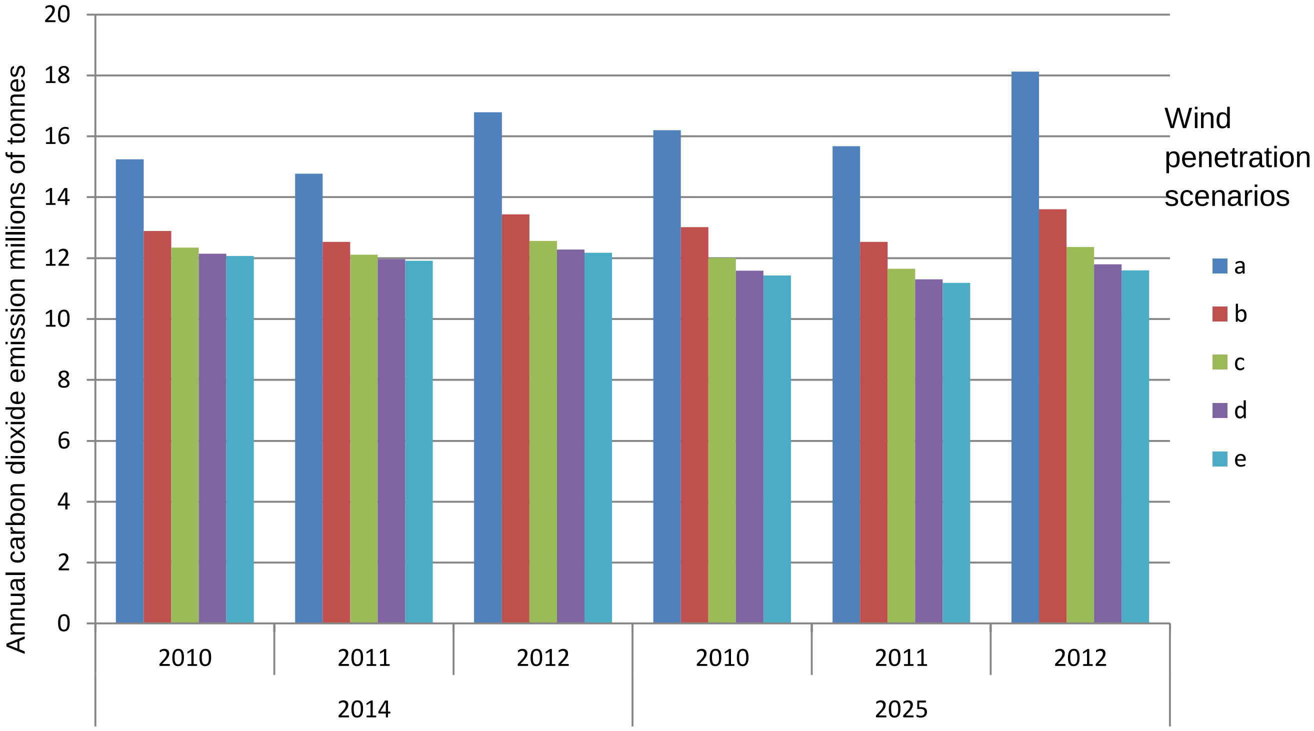

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Table 13: Comparing wind power, weather and growth effects on the SA's annual CO_2 emissions

SA	a	b	c	d	e	Average
Average	**16.1**	**13.0**	**12.2**	**11.8**	**11.7**	**13.0**
2014	**15.6**	**13.0**	**12.3**	**12.1**	**12.1**	**13.0**
2010	15.2	12.9	12.3	12.1	12.1	12.9
2011	14.8	12.5	12.1	12.0	11.9	12.7
2012	16.8	13.4	12.6	12.3	12.2	13.4
2025	**16.7**	**13.1**	**12.0**	**11.6**	**11.4**	**12.9**
2010	16.2	13.0	12.0	11.6	11.4	12.8
2011	15.7	12.5	11.6	11.3	11.2	12.5
2012	18.1	13.6	12.4	11.8	11.6	13.5

(Millions of tonnes of carbon dioxide)

Table 14: Comparing wind power, weather and growth effects on the SA's % annual CO_2 emissions

SA	a	b	c	d	e
% decrease	**0.0**	**19.2**	**24.3**	**26.3**	**27.0**
2014	**0.0**	**16.9**	**20.7**	**22.1**	**22.6**
2010	0.0	15.4	19.0	20.3	20.8
2011	0.0	15.2	18.0	19.0	19.4
2012	0.0	20.0	25.2	26.8	27.5
2025	**0.0**	**21.6**	**27.8**	**30.4**	**31.4**
2010	0.0	19.7	25.9	28.5	29.4
2011	0.0	20.1	25.7	27.9	28.7
2012	0.0	24.9	31.8	34.9	36.0

(Percentage decrease in tonnes of carbon dioxide from Scenario A)

3.2.5 Comparing the three effects in TAS

Figure 8 and Table 15 shows the effect of wind power, weather and demand growth on carbon dioxide emissions in TAS. Table 16 shows the percentage decrease in carbon dioxide emissions from Scenario A. The increase in wind power from Scenario A to E shows a large decrease in emission in Scenario B and much smaller decreases in subsequent Scenarios for all weather growth Scenarios that are years 2010-2012 and 2014-2025 respectively. The wind power induced emissions decrease rate in TAS is about twice that of the NEM. Most of TAS's reduction in emissions comes in Scenario B. This coincides with TAS's second largest wind power deployment in Scenario B shown in Table 4. Note that this effect must be attributable to the displacement of gas-fired generation. There is no wind power deployment in Scenario C in TAS but neighbouring VIC has major deployment in Scenario C. Imported wind power from VIC would displace fossil fuel generation and their emissions in TAS.Figure 8 shows a large increase in emissions from 2014 to 2025 in Scenario A to meet the growth in electricity demand. This shows a requirement for some expansion in fossil fuel based generation in excess of any additional output that can be sourced from TAS's hydro resources, in the absence of wind power.Table 16's comparatively large disparity in percentage decrease in emissions between 2014 and 2025 reflect the larger emissions base in Scenario A for 2025.

Figure 8: Comparing wind power, weather and growth effects on the TAS's annual CO_2 emissions

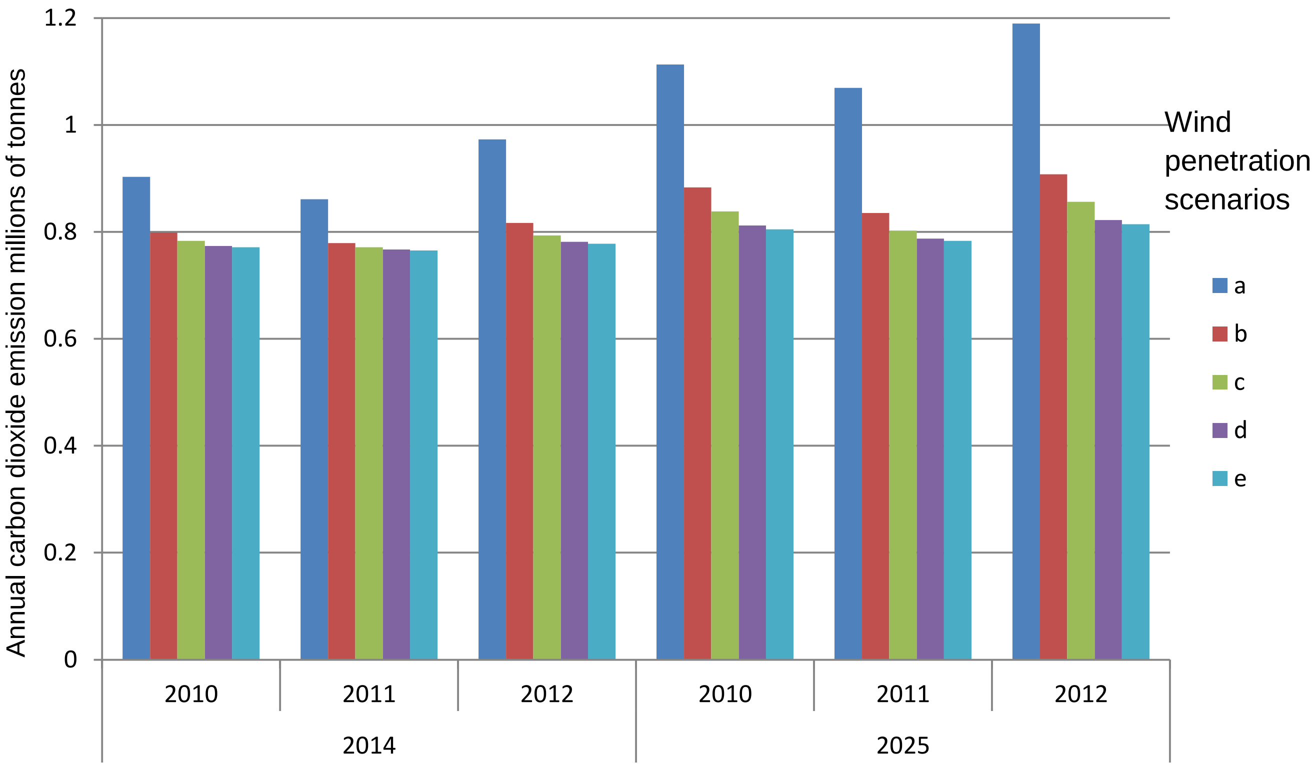


Table 15: Comparing wind power, weather and growth effects on the TAS's annual CO_2 emissions

TAS	a	b	c	d	e	Average
Average	**1.0**	**0.8**	**0.8**	**0.8**	**0.8**	**0.8**
2014	**0.9**	**0.8**	**0.8**	**0.8**	**0.8**	**0.8**
2010	0.9	0.8	0.8	0.8	0.8	0.8
2011	0.9	0.8	0.8	0.8	0.8	0.8
2012	1.0	0.8	0.8	0.8	0.8	0.8
2025	**1.1**	**0.9**	**0.8**	**0.8**	**0.8**	**0.9**
2010	1.1	0.9	0.8	0.8	0.8	0.9
2011	1.1	0.8	0.8	0.8	0.8	0.9
2012	1.2	0.9	0.9	0.8	0.8	0.9

(Millions of tonnes of carbon dioxide)

Table 16: Comparing wind power, weather and growth effects on the TAS's % annual CO_2 emissions

TAS	a	b	c	d	e
% decrease	**0.0**	**17.2**	**20.0**	**21.5**	**22.0**
2014	**0.0**	**12.4**	**14.1**	**15.0**	**15.2**
2010	0.0	11.5	13.3	14.3	14.6
2011	0.0	9.5	10.5	10.9	11.1
2012	0.0	16.1	18.5	19.7	20.0
2025	**0.0**	**22.1**	**25.9**	**28.1**	**28.7**
2010	0.0	20.6	24.7	27.0	27.7
2011	0.0	21.9	25.0	26.4	26.8
2012	0.0	23.7	28.0	30.9	31.6

(Percentage decrease in tonnes of carbon dioxide from Scenario A)

3.2.6 Comparing the three effects in VIC

Figure 9 and Table 17 shows the effect of wind power, weather and demand growth on carbon dioxide emissions in VIC. Table 18 shows the percentage decrease in carbon dioxide emissions from Scenario A. The wind power induced emissions decrease rate in VIC is the smallest in the NEM of about only 3 percent. This is a matter for attention given VIC is the largest emitter in the NEM. Section 4 discusses this further.

The increase in wind power shows a steady decrease in emissions for all weather and growth scenarios that are years 2010-2012 and 2014-2025 respectively. Table 4 shows VIC has no additional wind power deployment in Scenario E. However, the adjoining States of TAS and SA have a large deployment of wind power in Scenario E whose output could be exported to VIC especially give the limited demand bases prevailing in both of these two States.

Figure 9: Comparing wind power, weather and growth effects on the VIC's annual CO_2 emissions

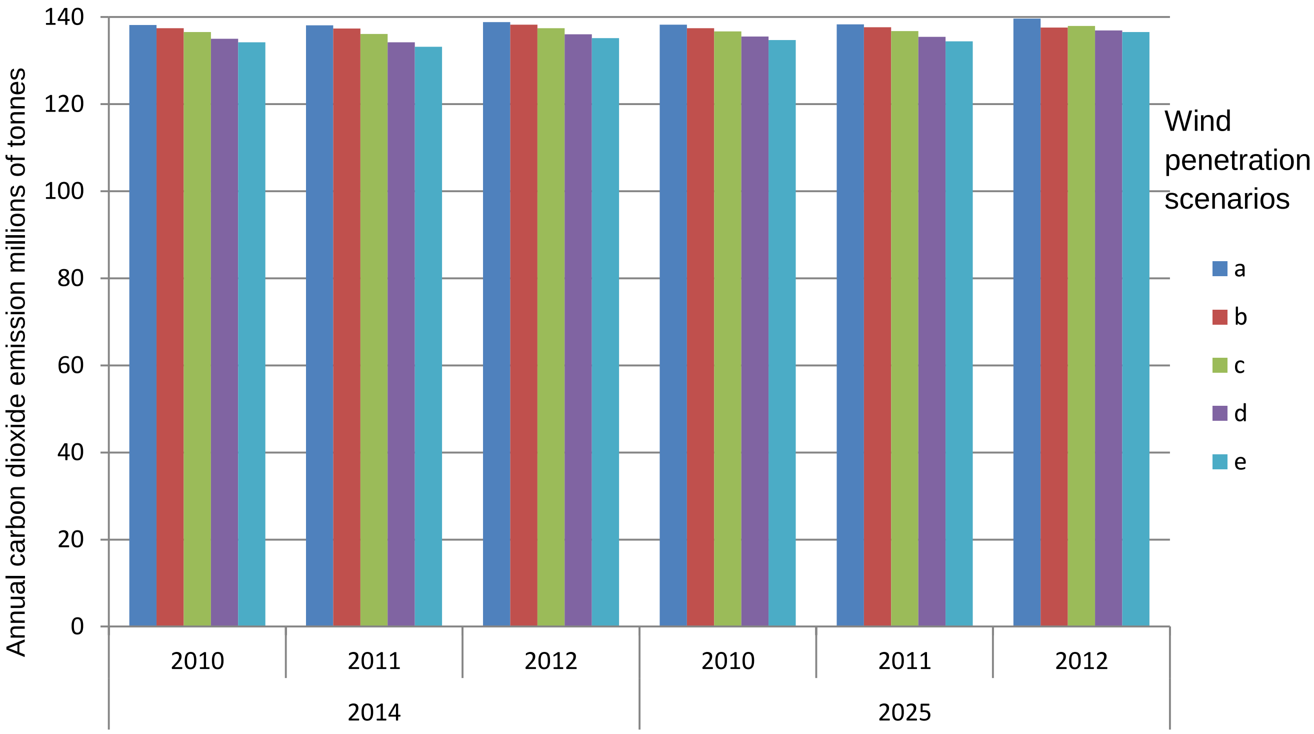


Table 17: Comparing wind power, weather and growth effects on the VIC's annual CO_2 emissions

VIC	a	b	c	d	e	Average
Average	**138.6**	**137.6**	**136.9**	**135.6**	**134.7**	**136.7**
2014	**138.4**	**137.7**	**136.7**	**135.1**	**134.2**	**136.4**
2010	138.2	137.4	136.5	135.0	134.2	136.3
2011	138.1	137.4	136.1	134.3	133.2	135.8
2012	138.9	138.3	137.4	136.1	135.2	137.2
2025	**138.8**	**137.6**	**137.2**	**136.0**	**135.3**	**137.0**
2010	138.3	137.5	136.7	135.6	134.8	136.6
2011	138.3	137.7	136.8	135.5	134.4	136.6
2012	139.7	137.6	137.9	136.9	136.6	137.7

(Millions of tonnes of carbon dioxide)

Table 18: Comparing wind power, weather and growth effects on the VIC's % annual CO_2 emissions

VIC	a	b	c	d	e
% decrease	**0.0**	**0.7**	**1.2**	**2.2**	**2.8**
2014	**0.0**	**0.5**	**1.2**	**2.4**	**3.0**
2010	0.0	0.6	1.2	2.3	2.9
2011	0.0	0.5	1.4	2.8	3.5
2012	0.0	0.4	1.0	2.0	2.6
2025	**0.0**	**0.9**	**1.2**	**2.0**	**2.5**
2010	0.0	0.6	1.1	2.0	2.6
2011	0.0	0.5	1.1	2.1	2.8
2012	0.0	1.5	1.2	2.0	2.2

(Percentage decrease in tonnes of carbon dioxide from Scenario A)

4 Discussion

We have conducted a sensitivity analysis of the effect of increasing the number of wind turbine generators (WTG) on the annual carbon dioxide emissions in the Australian National Electricity Market from Scenario A that is no WTG or 0% to Scenario E that is sufficient WTG to meet the 2020 Large Renewable Energy Target. The sensitivity analysis also considered the effect of weather and electricity demand growth on carbon dioxide emissions. We used simulations from the Australian National Electricity Market (ANEM) Model (Wild et al. 2015) to perform the sensitivity analysis. This reports builds on insights gained in the project's transmission congestion report (Bell et al. 2015b) and the project's wholesale spot price report (Bell et al. 2015c) that also use the ANEM model and the five wind penetration Scenarios A to E.

4.1 VIC and the Carbon Pollution Reduction Scheme

In an Inter State comparison, we investigated the effect of three factors on the annual carbon dioxide emissions. These factors include (1) a growth in electricity demand using the projection years 2014 and 2025, (2) weather using the baseline years 2010 to 2012 and (3) wind power using the five wind power penetration Scenarios A to E. We found that wind power has the largest effect on carbon emissions followed by growth in demand and finally the weather effect, see Figure 1, Figure 2 and Figure 3. In agreement, the wholesale spot price report (Bell et al. 2015c) finds the effects in the same order. However, the transmission congestion report (Bell et al. 2015b) finds that wind power still has the largest effect but the weather effect is larger than the growth effect.

Figure 1 shows that VIC has the largest carbon dioxide emissions and Table 3 shows VIC's emissions respond least to increases in wind power. Wind power is effective in reducing emissions in NSW, SA and TAS. Wind power is also effective in QLD given its smaller deployment of wind power. VIC's large brown coal generation fleet produce relatively cheaper per unit of electricity than the gas or black coal generation fleets in NSW, QLD SA and TAS. Hence, wind power via the merit order effect is likely to induce two effects on fossil fuel generation: (1) replace output from gas-fired generation in VIC and TAS; and (2) cuts in gas and possibly coal generation in NSW, QLD and SA. Putting aside issues regarding the uneven emission cuts between States, the brown coal generators produce more carbon dioxide per unit of electricity. This situation is suboptimal for carbon emissions reductions.

The merit order effect induces the replacement of more expensive forms of generation including gas and coal with cheaper wind power. However, it is unable to promote fuel switching from emission intensive coal-fired generation to lower emissions intensive gas generation. There is a policy requirement to alter the relative marginal costs between coal and gas generation for switching to occur. A carbon pricing mechanism can accomplish this and the ill-fated repealed Carbon Pollution Reduction Scheme (CPRS) provided such a mechanism.

Introducing a carbon price via the CPRS is theoretically sound in promoting least cost carbon-emission abatement but its implementation and semantics fermented it demise. The coal industry including the coal generators, have the most to lose by the carbon price and the coal industry is able to fund major publicity campaigns against the CPRS, providing enough funding to unseat a Government.

> The coal industry as a political lobby group has fought a long battle with the government over the introduction of the Carbon Pollution Reduction Scheme

> (CPRS) and Mineral Resource Rent Tax (MRRT). For instance Orr and Costar (2012) discuss the Australian Electoral Commission's slow disclosure of political lobbying and donations *"More successful were the big miners… The Mining Council of Australia reported $4 million and the Association of Mining Export Companies $2.2 million. But this was just the tail-end of the anti-mining tax campaign, the bulk of which (over $22 million more in advertising) had been spent in the previous financial year and helped bring down Rudd's prime ministership."* This slow disclosure is a flaw in the electoral process that undermines the democratic process and is a source of maladaptation to climate change. Orr and Costar (2012) call for a real time disclosure of political lobbying and donations via a publically accessible website among other measures to remedy the situation. These measures would address this source of maladaptation [to climate change].
>
> (Foster et al. 2013, sec. 9.3)

A major weakness in the carbon price was semantic. If the legislation were renamed "pollution penalties", the coal industry would find the publicity campaign hard to wage and the Government much easier to sell "pollution penalties" rather than a "carbon tax" to the electorate. Similarly, the ill-fated "Mineral Resource Rent Tax" would be easier to sell to the electorate as "Australian's Mineral Wealth Share" and provide some semantic immunity from the mining lobby.

A further weakness was the change from a fixed carbon price to an emissions trading scheme. The fixed carbon price provided the Government with a more stable source of income to more easily budget whereas the emissions trading scheme puts Government revenue at the vagaries of the market. The carbon price revenue replaced some income tax revenue but income tax revenue is subject to the vagaries business cycle. However, the business cycle is less volatile than the Emissions Trading Schemes, for example the European Emissions Trading Scheme.

The withdrawal of the CPRS and Mineral Resource Rent Tax has left the sitting Australian Federal Government with a large self-inflicted budget deficit. Introducing "pollution penalties" would both help resolve the Federal Government's deficit and improve the effectiveness of wind power to reduce carbon dioxide emissions. Wild, Bell and Foster (2014) investigate carbon prices required to start a switch from brown coal to black coal or gas using the ANEM model. We recommend expanding this investigation to incorporate wind power.

The CPRS was engineered to have an economy wide effect. In comparison, the Australian Large Renewable Energy Target (LRET) is much smaller in scope, by design being specific to the electricity industry. Section 4.3 discusses the LRET.

4.2 SA and transmission congestion induced spillage

Compromising SA wind power's ability to induce emissions reductions are four factors.

- SA's small demand compared to the wind power deployment;
- congestion on the interconnectors restricting export capacity;
- electricity demand and wind power supply timing mismatches; and
- negative wholesale spot price and spillage.

Table 4 shows that SA is the State with the largest wind power deployment in Scenario B but SA is a State with relatively small electricity demand. Additionally, Table 19 shows that there is a high correlation of demand between states and a high correlation of wind speed between States but little correlation between demand and wind speed between States. Bell et al. (2015b, 2015c) discuss the interconnector congestion between SA and VIC that compound these problems.

Table 19: Correlation of wind speed and demand

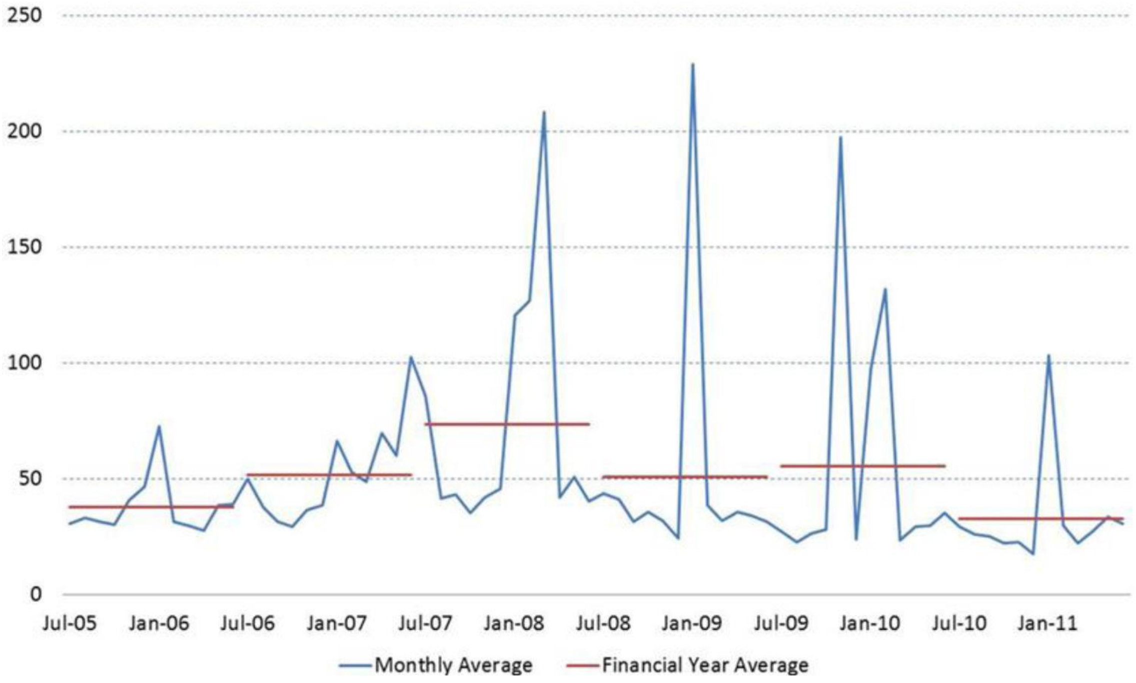
		Demand					Wind speed			
		NSW	**QLD**	**SA**	**TAS**	**VIC**	**NSW**	**SA**	**TAS**	**VIC**
Demand	**NSW**	1								
	QLD	0.83	1							
	SA	0.81	0.67	1						
	TAS	0.72	0.54	0.58	1					
	VIC	0.89	0.75	0.85	0.78	1				
Wind Speed	**NSW**	0.08	0.11	0.05	0.1	0.07	1			
	SA	-0.16	-0.08	-0.07	-0.15	-0.16	0.34	1		
	TAS	-0.06	0.04	-0.06	-0.04	-0.04	0.31	0.24	1	
	VIC	-0.08	-0.05	-0.06	0	-0.05	0.44	0.64	0.47	1

(Source: Bannister & Wallace 2011, p. 15)

A consequence of mismatches between electricity demand and wind power supply and interconnector congestion are volatile wholesale spot prices. Wholesale spot prices are sensitive to the addition of such a large penetration of wind power whose marginal cost is nearly zero. This adversely affects the profitability of existing plant and affects the investment decisions for new plant. SA has experienced both increased volatility and reduced average wholesale spot prices. The opportunity to reduce emissions is lost whenever negative prices occur. The negative prices indicate that there is an excess supply of electricity over demand and a fossil fuel generator pays to continue operating at its minimum operational level. The large baseload capacity in SA relative to demand and the limited ability to export surplus electricity to VIC combine to exacerbate the effect of the large penetration of wind power in SA on the wholesale spot price. This becomes more apparent when windy conditions can occur during periods of low demand and baseload capacity is unable to adequately: ramp-down or shutdown to accommodate wind power.

> The Australian Energy Market Commission (AEMC) chairman (Pierce 2011) confirms this reduction in the average spot price for electricity in SA, see Figure 10. However, the AEMC chairperson also discusses the increase in volatility in spot price in Table 19 where there have been increases in half-hours with negative spot prices and increases in half-hours with spot prices above $5,000 and $300 per MWh. The increase in negative spot prices continues but the increase in high positive spot prices saw a downturn in 2010. Therefore, the increasing penetration of wind power provides economic benefit to electricity users.
>
> (Bell, Wild & Foster 2014, sec. 2.3.3)

Figure 10: Average wholesale spot price in SA per MWh



(Source: Pierce 2011, p. 7)

Table 20: SA's wholesale spot prices

Year	Number of half-hour prices in SA			
	Above $5,000/MWh	Above $300/MWh	Below $0/MWh	Below -$300/MWh
2006	1	62	1	0
2007	3	78	10	2
2008	52	78	51	3
2009	50	97	93	8
2010	24	58	139	18

(Source: Pierce 2011, p. 8)

Solutions that reduce both wholesale spot price volatility and emissions include:

- Increase the thermal capacity of the interconnectors from SA to VIC to enable export of surplus power in SA into VIC. The wholesale spot price report (Bell et al. 2015c) discusses this option.
- Introduce unregulated interconnectors with storage as congestion and intermittency management solutions. The wholesale spot price report (Bell et al. 2015c) also discusses this option.

The recent decision to close the Northern Power Station and Torrens Island A eliminates all coal generation in SA and a significant portion of gas thermal capacity. The remaining gas thermal generator is Torrens Island B that is a baseload plant and slow to start-up or shutdown. Torrens Island B is the last remaining plant in SA that can offer governor response services to correct frequency deviations before they become serious. In contrast, solar and wind is unable to supply governor response as an initial response mechanism to correct frequency deviations. However, batteries can now offer very fast frequency response services.

We (Bell et al. 2015f) performed a correlation of wind speed and electricity demand including QLD and found the results in Table 19 slightly overestimated the wind speed correlation between each state and overestimated electricity demand correlation between each state but under estimated the wind speed-electricity demand correlation between each state. Overall these results undervalue the contribution of wind power to the NEM system stability and underestimate the requirement for interconnection augmentation for the NEM to avail itself of the benefits of higher penetrations of wind power. The inclusion of QLD in our study also improved the ability of wind power to contribute to system stability and meet changes in demand.

We investigate the augmentation of the NEM's electricity grid in two further reports (Bell et al. 2015d, 2015e). These reports perform a sensitivity analysis on the effect of NEMLink on congestion and wholesale spot prices under the 5 wind penetration scenarios. NEMLink is a major augmentation of the Australian National Electricity Market's transmission grid outlined in the National Transmission Network Development Plan (AEMO 2010a, 2010b, 2011a, 2011b). The problems identified in SA largely disappear under a NEMLink argumentation.

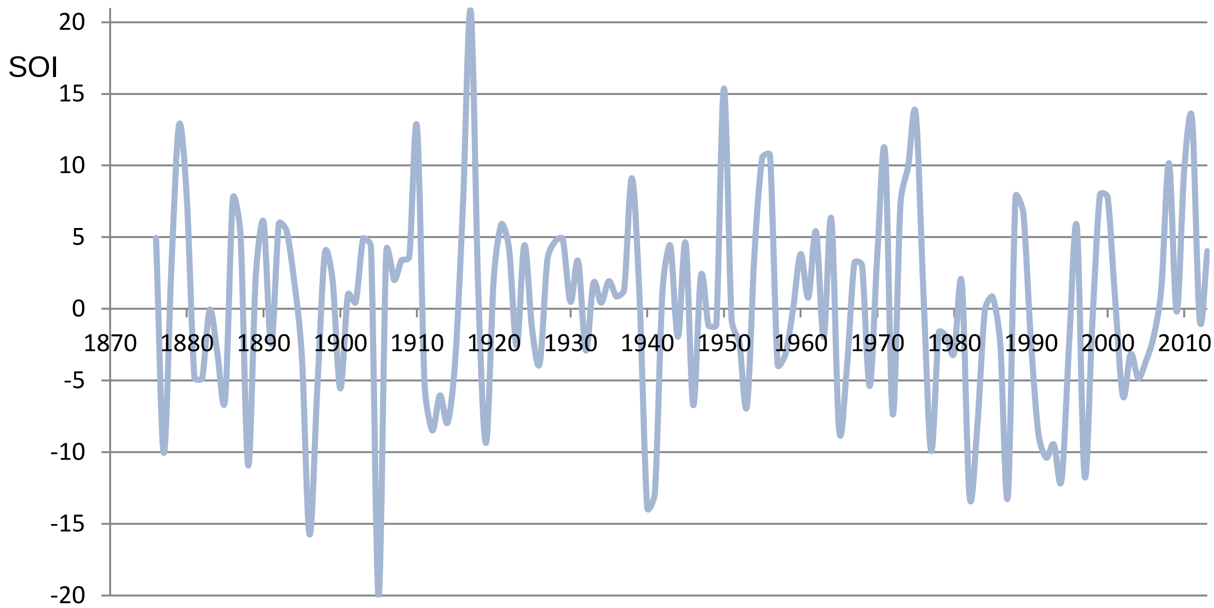
4.3 Uncertainty in electricity demand and in the Renewable Energy Target

In the ANEM model (Wild et al. 2015) for this project, we assume low growth in electricity demand. The growth in emissions in Figure 3 and Table 6 reflects this growth in electricity demand. However, there are permanent structural changes occurring in the NEM to cause downward pressure on electricity demand met through the National Electricity Market (Bell, Wild & Foster 2014, sec. 2.2). These include the decline of manufacturing, smart meters, energy efficiency, price awareness, and electricity demand met behind the meter via solar PV and storage. A consequence of this decline in demand is the recent change to the Large Renewable Energy Target (LRET) to reduce the energy requirements to maintain a proportional 20% target. This change in LRET and the low wholesale spot prices have undermined investment in wind power and the ability to reduce emissions further.

This reduction of the LRET may be premature based on a temporary demand reduction induced by the El Niño Southern Oscillation (ENSO). Figure 11 shows the mean annual southern oscillation index (SOI) for 1875-2013 where a positive SOI indicates a La Niña (BoM 2014b) bias and the negative SOI indicates an El Niño (BoM 2014a) bias. The weather during a La Niña phases is usually cooler and wetter than an El Niño. Hence, electricity demand during La Niña phases is usually less than during El Niño phases. The recent changes to the LRET were made following a period with a La Niña bias. In comparison, the Renewable Energy (Electricity) Act 2000 came into force after a long period with a strong *El Niño* bias.

Is there a requirement to put in place automatic mechanisms to ensure the LRET adjusts for both the long-term trends discussed above and fluctuations in the ENSO? Something like a 10-year moving average of electricity demand would avoid the wind power investment uncertainty induced by the political process to adjust the LRET. The 10-year moving average would also remove the political uncertainty. However, the current LRET legislation is 20% by 2020, so the imminent end date itself is a source of investment uncertainty. A key question remains however - how do we solve this source of uncertainty?

Figure 11: Mean annual SOI 1875-2013



(Source: BoM 2014c)

Australia's 20% renewable electricity target by 2020 is extremely modest when compared to renewable electricity targets for New Zealand 90% by 2025 and California 50% by 2030. The People Republic of China (PRC) and the European Union including its 28 member countries have adopted an all-encompassing renewable energy target unlike Australia's more narrow renewable electricity target. The European Union's target is 20% by 2020 and PRC's 20% by 2030 (Clean Energy Council 2015). Given Australia is the world's largest per capita emitter of GHG and one of world's wealthiest countries per capita, Australia will eventually have to adopt a more ambitious renewable energy target more commensurate with its international responsibility.

Developing a long term 100% LRET would provide a clear direction for investment. This larger target would require considerations for congestion management, as discussed in the projects' wholesale spot price and transmission congestion reports (Bell et al. 2015b, 2015c). Additionally, the long term trends in electricity demand require considering and the temporary changes induced by the ENSO as discussed above.

4.4 El Niño Southern Oscillation and the project's weather years 2010-12

Figure 11 shows this project's weather years 2010 to 2012 are during a La Niña phase. Hence, the years 2010 to 2012 have relatively low electricity demand and emissions.

5 Conclusion

We find the annual carbon dioxide emissions for all States in the NEM decrease when wind power increases from Scenario A that is '0% or no wind power' to Scenario E that meets Australia's 2020 Large Renewable Energy Target (LRET). The LRET and wind power are successful in reducing carbon dioxide emissions. However, diminishing the full potential of wind power to reduce emissions is the lack of pollution penalties, congestion in the interconnectors, uncertainty in electricity demand and LRET, and the imminent end date of the LRET.

VIC is the largest emitter in the NEM and its emissions are least sensitive to wind power. VIC's large brown coal generation fleet produces each unit of electricity more cheaply than the other fossil fuel generators. Hence, wind power induces the more expensive fossil fuel generators to cut generation first. However, the brown coal generators produce more carbon dioxide per unit of electricity. The Carbon Pollution Reduction Scheme addressed this issue but the sitting Government repealed the scheme. Reintroducing the CPRS as a "pollution penalty" would provide a more semantically resilient policy to the coal industry's lobbying and publicity campaigns. Reintroducing a rebranded CPRS would help improve wind power's ability to curtail emissions and help resolve the sitting Federal Government's self-inflicted budget deficit.

SA has the largest deployment of wind power in Scenario B that includes wind power under construction and operational plant. However, a number of factors prevent SA's wind power reaching its full potential to induce reductions in emissions. SA has relative small electricity demand and relatively large baseload fleet. This makes it necessary for SA to export a large portion of its wind power to prevent price volatility, negative prices and spillage. However, SA's baseload fleet is potentially diminishing with the retirement of Playford B, Northern and Torrens Island A power stations. Nevertheless, the interconnectors to VIC are small and often congested. Bell et al. (2015b, 2015c) discuss solutions including increasing the capacity on the existing interconnectors, unregulated interconnectors with storage as congestion and intermittency management solutions, pumped hydro storage in TAS and NEMLink. Bell et al. (2015b, 2015c) also discuss legislative changes required to enable these solutions.

The LRET successful in launching Australia on a path to address climate change and rallying industry to the challenge requires some adjustment to ensure continued success. The investment uncertainty surrounding the LRET stems from two sources the 2020 end date and the political process to change the rules at any time. The recent declines in electricity demand were unforeseen when the RET legislation was drafted. This prompted policy intervention to reduce the LRET in quantity of energy to maintain a 20% proportion. Introducing a rule into the LRET legislation to accommodate these changes would reduce the need for political intervention and reduce investment uncertainty, such as, making the LRET a proportion of the 10-year moving average of electricity demand. This rule could accommodate both the temporary changes in demand induced the El Niño Southern Oscillation and the slower more permanent changes such as the decline in the industrial sector. Lastly, introducing a 100% LRET would help overcome long-term investment uncertainty. For instance, New Zealand already has a 90% target by 2025.

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