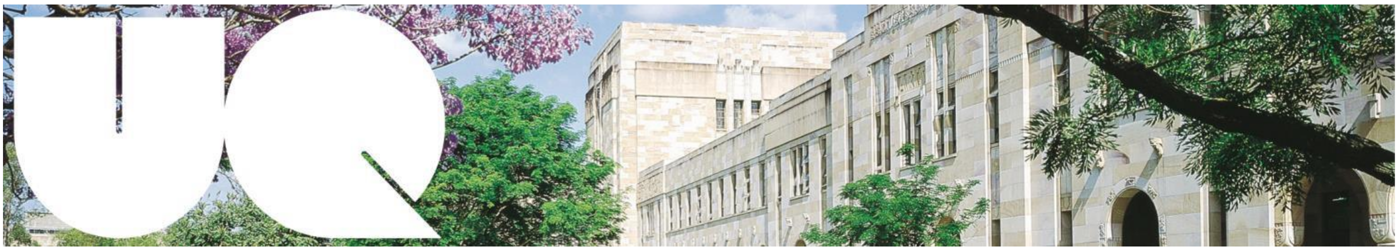

The effect of increasing the number of wind turbine generators on wholesale spot prices in the Australian National Electricity Market from 2014 to 2025

EEMG Working Paper 4-2015 - Version 24

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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 wholesale spot prices 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)* provides 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.

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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, Foster, J, and Hewson, M (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, Foster, J, and Hewson, M (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, Foster, J, and Hewson, M (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 wholesale spot prices in the Australian National Electricity Market's (NEM) existing transmission grid from 2014 to 2025. This reports answers urgent questions concerning the capability of the existing transmission grid to cope with significant increases in wind power. 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 wholesale spot prices. 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 wholesale spot prices 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 divergence in the prices between states and similar prices for nodes within states. This pattern reflects the findings in our transmission congestion report (Bell et al. 2015a). Only 14 of the 68 transmission lines in the ANEM Model (Wild et al. 2015) are congested but these 14 congested transmission lines include six of the NEM's interstate interconnectors and eight of the intrastate transmission lines although only three of the intrastate transmission lines exhibited any significant degree of congestion. This supports Garnaut's (2011, p. 38) assessment on gold plating intrastate transmission and under investing in interstate transmission.

We find increasing wind power penetration decreases wholesale spot prices but retail prices fail to reflect the decrease in wholesale spot prices. Victoria is the only state in NEM with a deregulated retail sector and the retail sector has increased profits rather than through the savings to retail customer. The other states are regulated and unable pass through the savings. There is a requirement for simply better regulation or increased competition by breaking up the large generator-retails companies into separate retail and generator companies.

Wind power has the potential to further reduce wholesale prices across the whole of the NEM but the congestion in the interconnectors limits this potential. There is a requirement for a high capacity transmission backbone that can link the NEM's peripheral states via Victoria and NSW (Bell et al. 2015d). This requirement will become more pressing as Australia moves beyond its current 20% LRET. However both the regulatory and institutional arrangements require some adjustment before such a project becomes feasible and for the NEM to avail itself of the full benefit of wind power to reduce both wholesale spot prices and carbon emissions.

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

Contents

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Tables

Abbreviations

ABS	Australian Bureau of Statistics
AEMC	Australian Electricity Market Commission
AEMO	Australian Energy Market Operator
AGL	Australian Gas Limited
ANEM	Australian National Electricity Market Model (from EEMG)
CER	Clean Energy Regulator
DC OPF	Direct Current Optimal Power Flow
EEMG	Energy Economics and Management Group (at UQ)
kV	Kilovolt
LNG	Liquid Natural Gas
LRET	Large-scale Renewable Energy Target
MW	Megawatt
MWh	Megawatt hour
NEM	National Electricity Market
NSP	Network Service Provider
NSW	New South Wales
PPA	Power Purchase Agreement
QLD	Queensland
SA	South Australia
TAS	Tasmania
TNSP	Transmission Network Service Providers
UQ	University of Queensland
VIC	Victoria
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 wholesale spot prices 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 wholesale spot prices. 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 power 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 price islanding effects that reflect potential transmission constraints through VIC and NSW as well as between other States.

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 of 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 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 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 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 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 wholesale spot prices. In contrast, the projections years 2014 to 2025 consider the effect of growth in electricity demand on the dynamics of the NEM and the wholesale spot prices.

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.

The project's transmission congestion report (Bell et al. 2015a, tbl. 2) finds congestion on only 14 of the 68 transmission lines in the ANEM Model (Wild et al. 2015). Notably, these 14 congested transmission lines include all the NEM's six interstate interconnectors and eight intrastate transmission lines but only three of the intrastate transmission lines exhibited any significant congestion. The other five of the intrastate transmission lines exhibited extremely low levels of congestion.

The congestion on all the interstate interconnectors justifies an Inter State comparison of the average wholesale spot prices. Section 1 compares average wholesale spot prices between the States of the NEM to identify system wide effects and Section 2 examines prices on individual nodes in detail to evaluate the observations made in Section 1 in higher resolution. Section 2 focuses on 'Representative State Nodes' for each State because there is little Intrastate congestion to induce price difference between nodes within a State. Additionally, the 'Unrepresentative State Nodes' are discussed.

3.1 interstate comparison to identify system wide effects

Table 2 presents the average wholesale spot prices for the States. 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 wholesale spot prices.

- 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 half hourly spot prices for each node in the NEM. The State prices in Table 2 are the average of the State's nodal average wholesale spot prices.

The ANEM model's average wholesale spot prices in Table 3 for Queensland (QLD) are higher than that for the Australian Energy Market Operator (AEMO 2015a). Six factors explain this disparity.

- QLD has a heavier reliance on gas generation than New South Wales (NSW) and the ANEM model assumes high gas prices for all gas-fired generators based on current and future spot market prices associated with benchmarked internationally traded gas prices. In reality, many gas-fired generator companies have existing contracts for gas supply negotiated when the gas supply in the NEM was for domestic consumption only. This domestic only market resulted in much lower gas prices. Currently, international Liquid Natural Gas (LNG) prices determine spot gas prices in the NEM because domestic gas is liquefied for exported as LNG. New gas supply contracts will reflect the higher gas spot prices determined in the international LNG market once these low gas price contracts expire. These expiries will bring closer correspondence between the prices of the AEMO (2015a) and the ANEM model.

- QLD has the lowest wind penetration of all the States, so is least able to benefit from wind power's low marginal cost of electricity in Scenario E.
- The electricity demand projections for 2014-2025 for QLD tend to be more bullish than for other States. This reflects expected increased demand associated with mining and mineral processing industries, including LNG exports.
- The ANEM model assumes the short run marginal cost of generation increases at an inflation rate of 2.5% p.a. over the period 2014-2025. The high cost of gas generation maintains Queensland's position with the highest average wholesale electricity spot price.
- The ANEM model uses a Direct Current Optimal Power Flow (DC OPF) model of the NEM and assumes generators use marginal costing to produce supply offers. In reality, generators in the NEM use strategic bidding and produce supply offers above marginal costs. This strategic behaviour typically produces higher wholesale spot prices than the ANEM model calculates.
- The ANEM model assumes that baseload gas generation such as Natural Gas Combined Cycle (NGCC) plant continue to operate in this role, albeit at higher gas prices. Baseload plant has non-zero minimum stable operating levels. If baseload plant dispatches at their minimum stable operating levels, nodal prices approximate an average of the marginal costs of coal and NGCC plant. This average price is below the marginal cost of the marginal NGCC plant. However, if the plant dispatch above their minimum stable operating level, they will set the nodal price at a higher level much closer to their marginal cost.

However, the possibility of importing cheaper electricity from NSW may ameliorate QLD dependence on gas generation. The modelling results illustrate how higher gas prices increase wholesale electricity prices and how wind generation works to insulate wholesale electricity prices from the impact of rising gas prices via the merit order effect.

Table 2: The average wholesale spot prices for wind penetration scenarios A and E, the projection year 2014 and 2025 and baseline years 2010 to 2012

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	23.21	60.05	44.45	47.39	41.65	41.81
a	2010	2025	38.56	167.89	102.02	75.23	97.56	91.30
a	2011	2014	20.05	49.79	40.34	45.03	36.91	36.95
a	2011	2025	29.48	161.19	80.97	72.19	75.55	80.40
a	2012	2014	23.83	64.81	54.54	50.99	51.21	46.59
a	2012	2025	39.66	165.45	132.05	79.31	134.57	101.69
e	2010	2014	14.15	45.05	9.48	27.75	13.42	22.82
e	2010	2025	21.31	107.04	18.86	43.70	27.47	44.80
e	2011	2014	11.94	32.71	7.13	26.18	10.86	18.53
e	2011	2025	17.83	98.53	14.06	40.31	20.76	39.60
e	2012	2014	14.32	44.20	10.27	25.92	14.81	22.62
e	2012	2025	21.25	117.98	20.39	41.25	31.47	47.40

3.1.1 Wind penetration effect shown between Scenarios A and E

Figure 1 and Table 3 show the average price of each State for the wind 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 average across the baseline weather years 2010 to 2012 and the projection growth years 2014 and 2025. The largest decrease in average price is just over $62/MWh for South Australia (SA) and the smallest decrease is just over $12/MWh for NSW. The other States fall between these two extremes. QLD has the smallest percentage decrease in average prices at 33% and SA the largest percentage decrease. These percentage point price decreases reflect the relative number of windfarms within each State and adjoining States. The high congestion on the interconnectors that link State transmission grids, maintains the large variation in average spot prices between States (Bell et al. 2015a). The wind penetration effect is by far the largest of the three effects for average wholesale spot price. This demonstrates existence of the merit order effect associated with the role-out of wind power in the NEM. This wind penetration effect is also the largest of the three effects for transmission line congestion (Bell et al. 2015a).

Figure 1: Average prices for each State for the wind power scenarios A and E

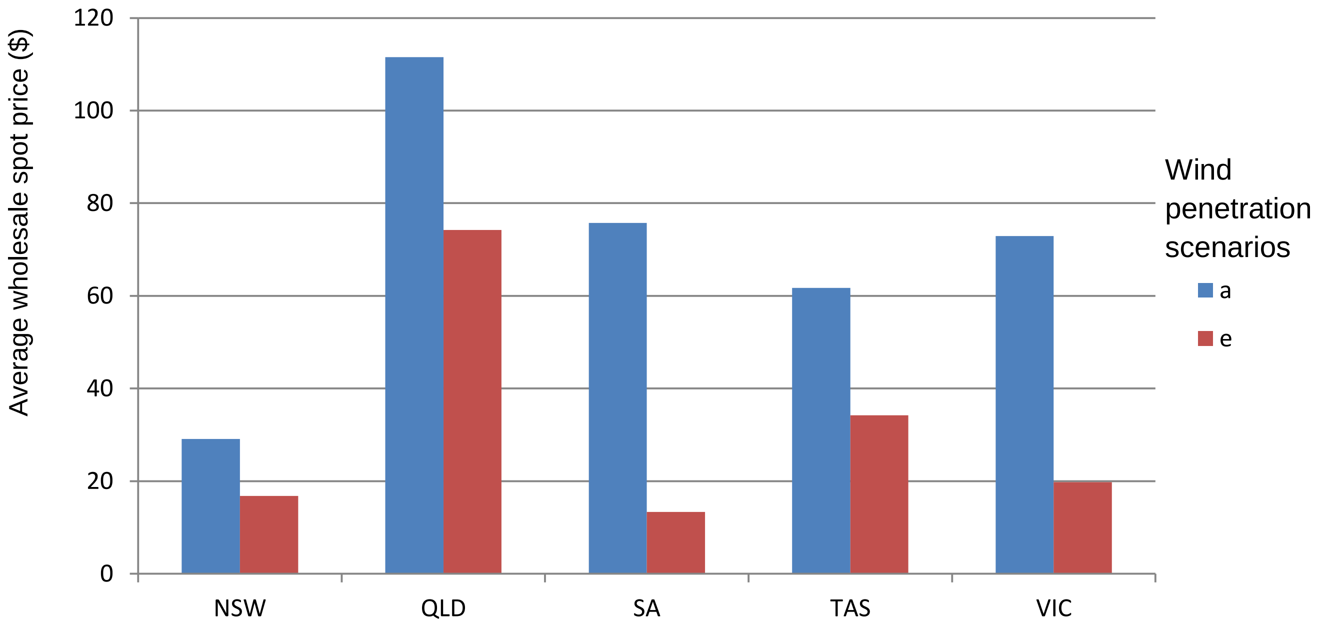


Table 3: Average prices for each State for the wind power scenarios A and E

States	a	e	Average
NSW	29.13	16.80	22.97
QLD	111.53	74.25	92.89
SA	75.73	13.36	44.55
TAS	61.69	34.19	47.94
VIC	72.91	19.80	46.35

3.1.2 Weather effect shown between the baseline years 2010 to 2012

Figure 2 and Table 4 show the average wholesale price 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. Tasmania (TAS) has the smallest change in average wholesale spot price induced by the weather effect and Victoria (VIC) the largest. The weather effect is the smallest effect of the three for wholesale spot prices.

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

Table 4: Average price for each State for the baseline years 2010 to 2012

States	2010	2011	2012	Average
NSW	24.31	19.83	24.76	22.97
QLD	95.01	85.55	98.11	92.89
SA	43.70	35.62	54.31	44.55
TAS	48.52	45.93	49.37	47.94
VIC	45.03	36.02	58.02	46.35
NEM	**50.18**	**43.87**	**54.58**	**49.54**

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

Figure 3 and Table 5 show the average wholesale spot price 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 wholesale spot price. 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 wholesale spot price, which is evident in all the States of the NEM. QLD experiences the largest increase in wholesale spot price both nominally and as a proportion. This reflects the more bullish projection assumptions for QLD's demand compared with the other states. Additionally, in contrast, the relatively higher penetration of wind generation in the other States helps moderate the effect of the growth in electricity demand to increased wholesale spot prices. As discussed, QLD's higher reliance on gas generation exacerbates its growth in average wholesale spot prices. The growth effect is the second largest of the three effects for wholesale spot prices.

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

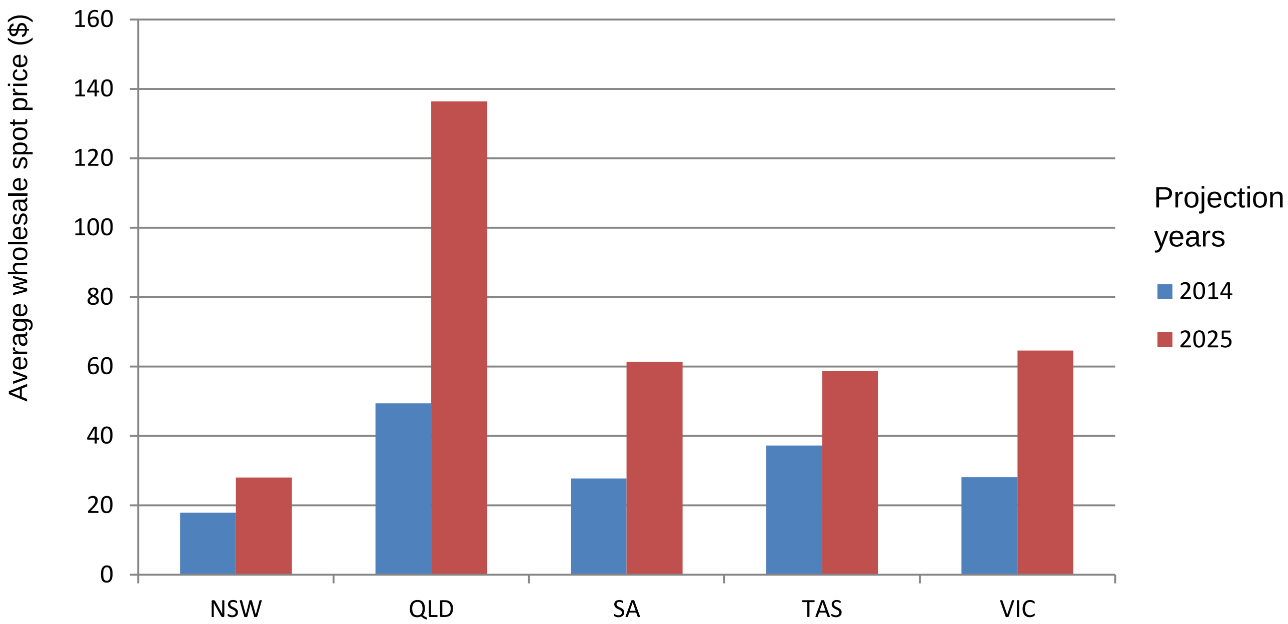


Table 5: Average price for each State for the projection years 2014-2025

States	2014	2025	Average
NSW	17.92	28.02	22.97
QLD	49.43	136.35	92.89
SA	27.70	61.39	44.55
TAS	37.21	58.67	47.94
VIC	28.14	64.57	46.35
NEM	**31.56**	**67.53**	**49.54**

3.1.4 Comparing the effect of the five wind scenarios on State Prices

Figure 4 on the next page shows the average wholesale spot price for the wind penetration scenarios A to E. These scenarios are progressive increases in wind power penetration. Figure 4 presents the five wind scenarios. In contrast, Figure 1 only shows Scenarios A and E. The average wholesale spot prices shown in both Figure 1 and Figure 4 are the average across the baseline weather years 2010 to 2012 and the projection growth years 2014 and 2025. The effect of increasing wind power from Scenario A to E on the average wholesale spot prices is to decrease prices for all States. This demonstrates the merit order effect of wind power. However, the rate of prices decrease varies greatly between States.

Figure 5 also on the next page shows the additional annual energy from wind power for each wind penetration scenario for each State. Figure 5 is based on the '*Windfarm Annual Production*' figures in Wild et al. (2015, tbl. 5). Note Scenario A "no wind power" has zero wind power output but is included to ensure the legend colour coding of the Wind Power Scenarios is the same on both Figure 4 and Figure 5 to allow easier comparison. Comparing Figure 5 with Figure 4 helps to explain the drivers for the changes in the average wholesale spot prices for each State but the picture is incomplete without considering the congestion on the interstate interconnectors.

Comparing Figure 5 with Figure 4 for the introduction of wind that is from Scenario A to B, we find price decreases correspond with the relative size of the introduction of windfarm energy production to State energy demand that is SA, VIC, TAS, NSW and QLD. We use the relative size of windfarm energy production to State energy demand because a windfarm would a have proportional effect on prices. For instance, the same sized windfarm in NSW and TAS would have a lesser effect on prices in NSW because NSW's demand is about six times larger than TAS. This simplifying assumption is valid because the congestion on the interconnectors maintains price differentials between States.

Comparing Figure 5 with Figure 4 for increasing wind power from Scenario A to E, we find diminishing returns in the reduction of prices from investing in more wind power. VIC, NSW and SA more clearly exhibit this diminishing returns effect. Building more capacity into the interconnectors could overcome this diminishing returns effect provided the wind power between States is uncorrelated. Table 6 shows that there is little wind power correlation between States, so increasing interconnector capacity will overcome diminishing returns on price reduction for increasing wind power. However, Table 6 also shows that there is even less correlation between wind power and electricity demand. This suggests the requirement for both energy storage and increasing the capacity of the interconnectors to maximise the reductions in prices from wind power. The optimal mix of increasing interconnector capacity and energy storage is a question left for further research discussed in Sections 4.2 and 4.5. There are strong profits motive for existing fossil fuel generators to oppose such augmentation discussed in Section 4.2.

Figure 4: Comparing the effect of the five wind scenarios on prices in each States

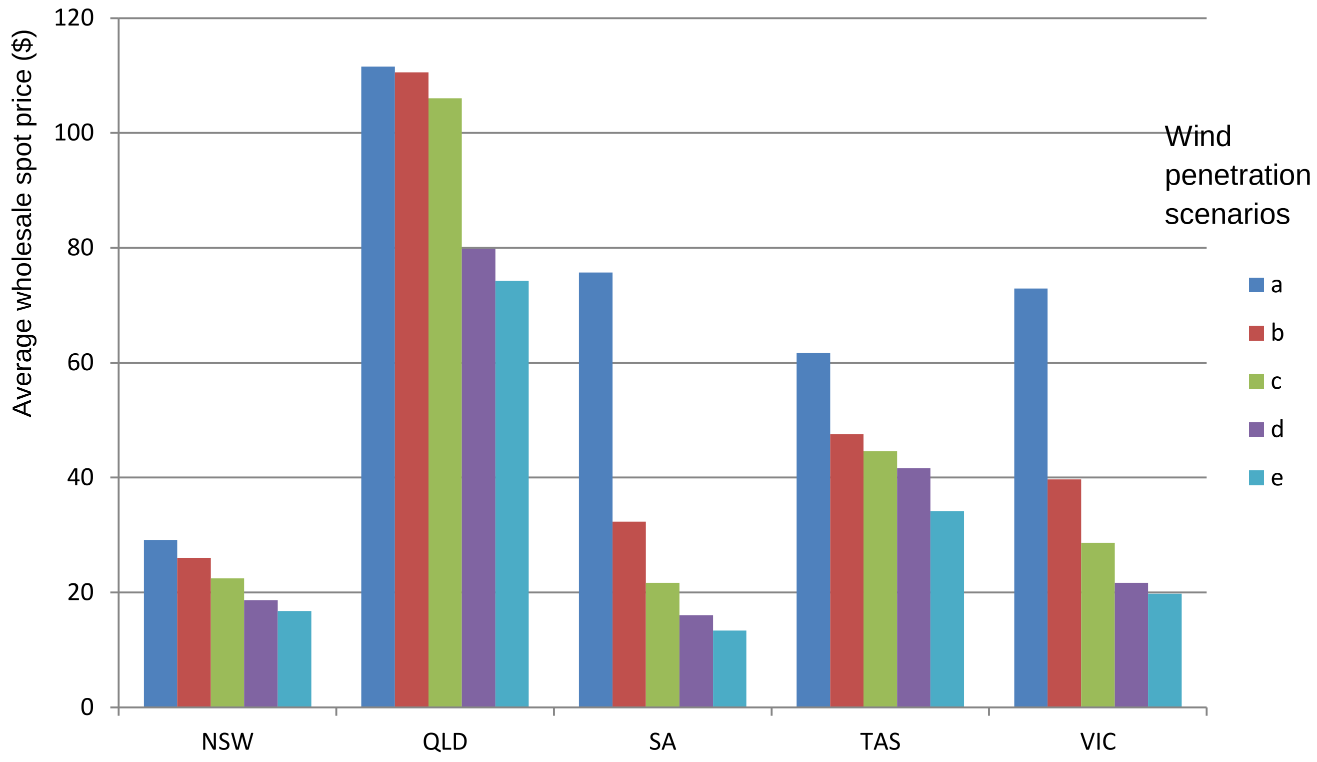


Figure 5: Comparing the additional annual wind power for each wind penetration scenario for each State

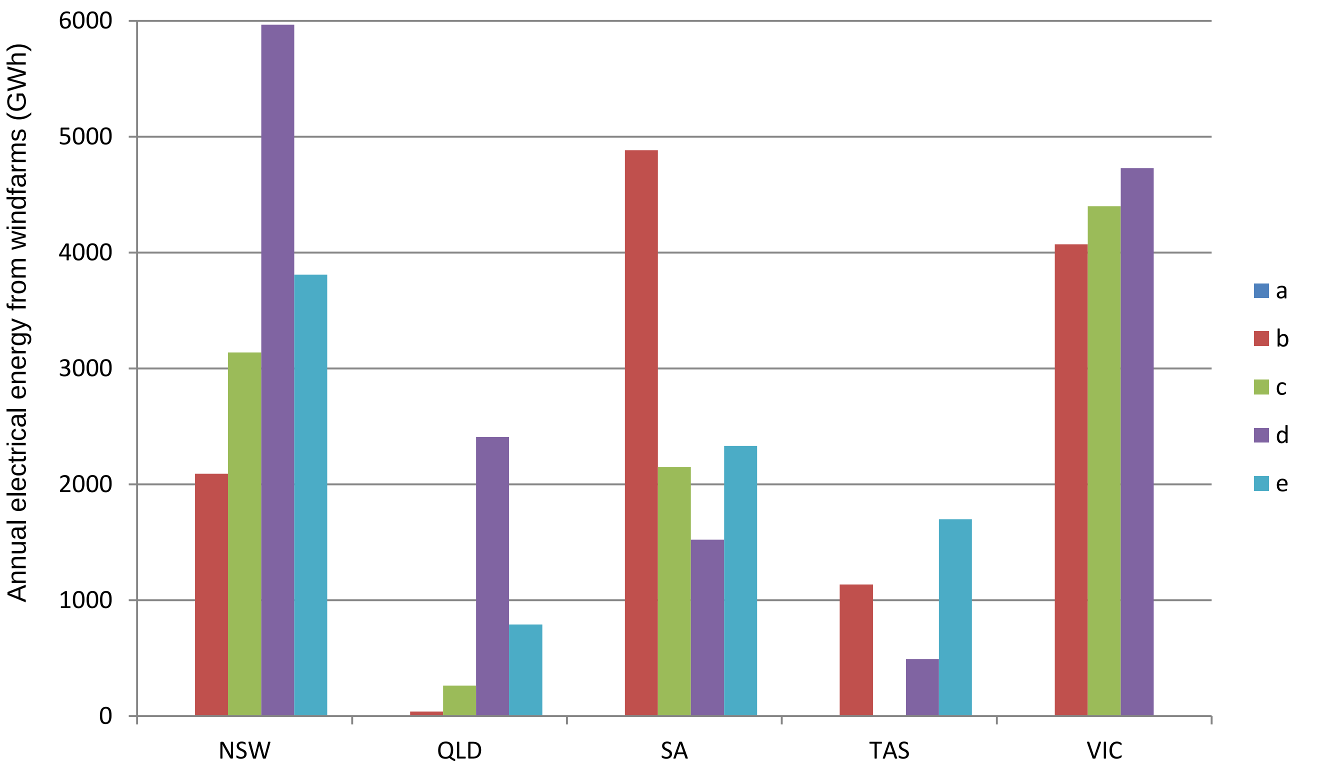


Table 6: Correlation of wind speed and demand

		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)

QLD is absent from the wind speed analysis in Table 6. QLD had little planned wind power at the time of Table 6's construction, which could account for QLD's omission. Nevertheless, QLD is on the periphery of the NEM, which would act to reduce its wind speed correlation with the other States, as would its tropical climate. This observation is further reinforced by the fact that the best wind resources in QLD are thought to be located in Far North QLD, which is thousands of kilometres from the nearest neighbouring southern state of NSW. Additionally, QLD is the only State in the NEM that ignores day light saving. This would reduce its demand correlation with other States. Both these factors would help reinforce wind power's roles in reducing wholesale spot prices in QLD and the NEM when increasing the capacity of the interconnectors.

We (Bell et al. 2015d) performed a correlation of wind speed and electricity demand including QLD and found the results in Table 6 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 demand.

We investigate the augmentation of the NEM's electricity grid in two further reports (Bell et al. 2015b, 2015c). 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.

3.2 Detailed investigation of individual nodes

In the previous section, the wind penetration effect was by far the largest, followed by the growth in electricity demand and the smallest being the weather effect. Hence, the following presentation focuses on the largest effect but analysing individual nodes allows consideration of the two lesser effects. Viewing the node diagrams in Wild et al. (2015, Figs. 1-6) while reading this section would aid comprehension for readers who are unfamiliar with the NEM's topology. Reviewing the average wholesale prices for the 52 nodes in the ANEM model is unnecessary because groups of nodes linked by uncongested transmission lines tend to follow the same price movements in magnitude and pattern. Therefore, identifying these groups of nodes within each State's network both provides an alternative view of transmission congestion and 'Representative State Node' analysis reduces needless repetition.

Section 1 evaluates wholesale spot prices at each node within each State to identify a 'Representative State Node' for each States and to identify 'Unrepresentative State Nodes' whose wholesale spot prices are at odds with the majority of other nodes in the State. Sections 2 analyses the 'Representative State Nodes'. Section 3 analyses the 'Unrepresentative State Nodes' to elicit what dynamics cause their price behaviour to be at odds with the 'Representative State Nodes'.

3.2.1 Identifying representative and unrepresentative State Nodes

Figure 6 shows NSW average wholesale spot prices by node by projections years 2014 and 2025 and by weather baseline years 2010, 2011 and 2012. The average wholesale spot prices fall neatly into two groups Node 12 (Lismore) and all the other nodes in NSW represented by Node 13 (Armidale). Node 12 (Lismore) and Node 13 (Armidale) connect NSW to QLD via DirectLink and QNI, respectively.

Figure 7 shows the QLD average wholesale spot prices by node by projections years 2014 and 2025 and by weather baseline years 2010, 2011 and 2012. The average wholesale spot prices fall neatly into four groups Node 7, Node 8, Node 11 and all the other nodes in QLD. Node 8 (South West QLD) and Node 11 (Gold Coast) connect QLD to NSW via QNI and DirectLink, respectively. Node 7 only slightly deviates from the 'Representative State Node' unlike Node 8 and 11 whose deviations are more considerable.

Figure 6: NSW average wholesale spot prices by node by projections years 2014 and 2025 and by weather baseline years 2010, 2011 and 2012

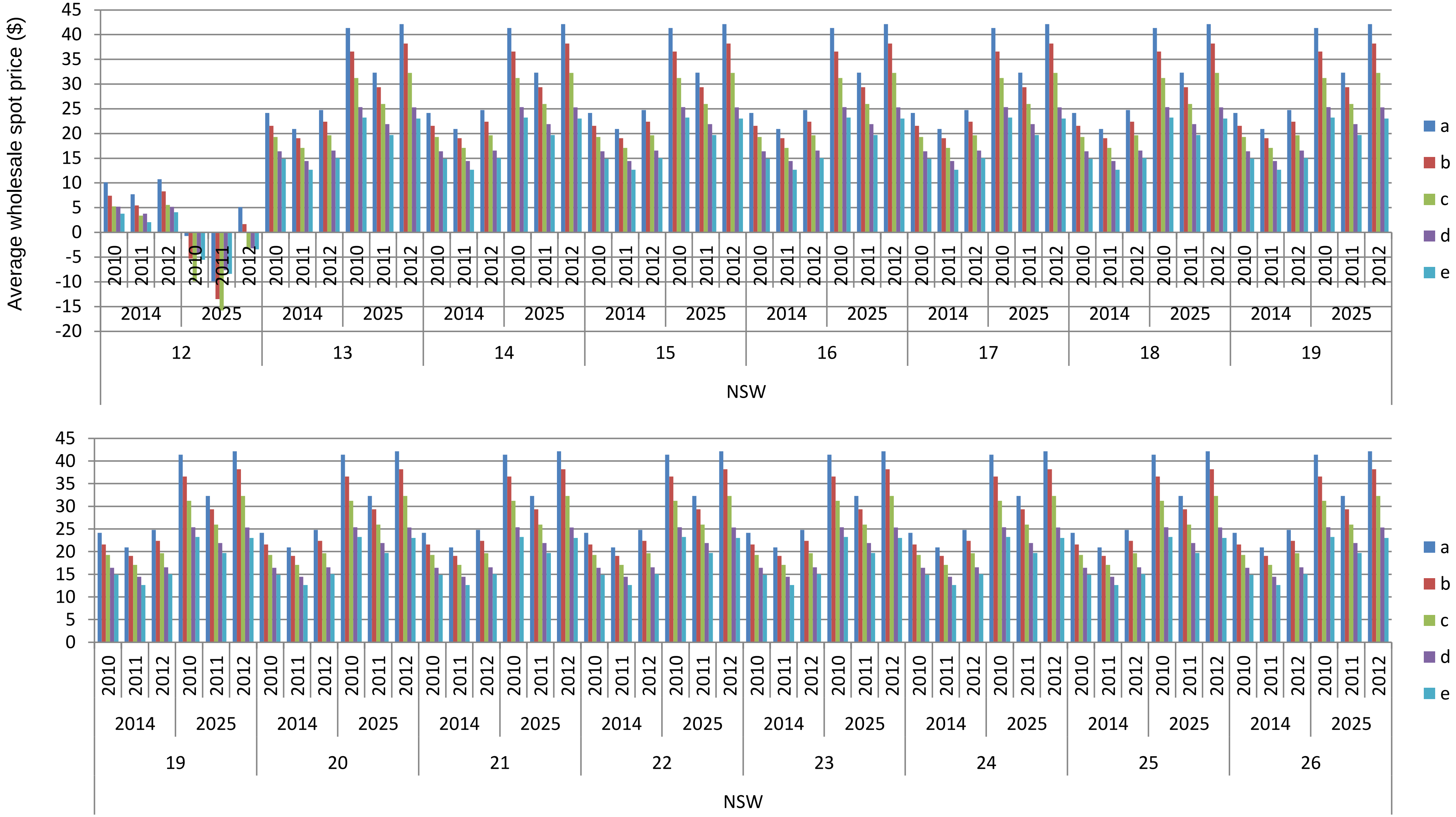


Figure 7: QLD average wholesale spot prices by node by projections years 2014 and 2025 and by weather baseline years 2010, 2011 and 2012

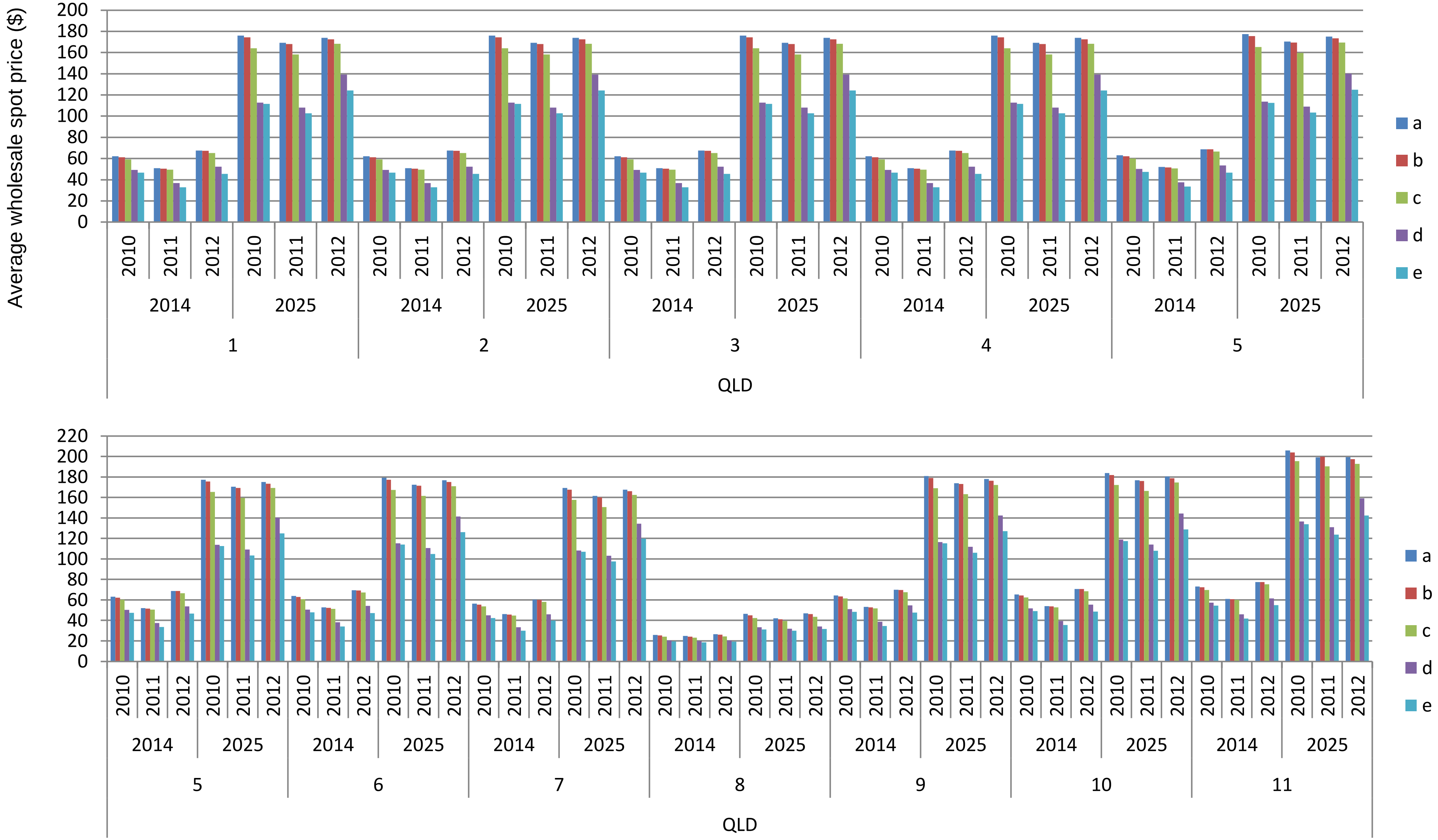


Figure 8 shows the SA average wholesale spot prices by node by projections years 2014 and 2025 and by weather baseline years 2010, 2011 and 2012. Any node in the State of SA represents the average wholesale spot price of the entire State, excluding Node 35, which shows slightly higher prices under certain conditions. The Heywood interconnector links Node 35 to VIC.

Figure 8: SA average wholesale spot prices by node by projections years 2014 and 2025 and by weather baseline years 2010, 2011 and 2012

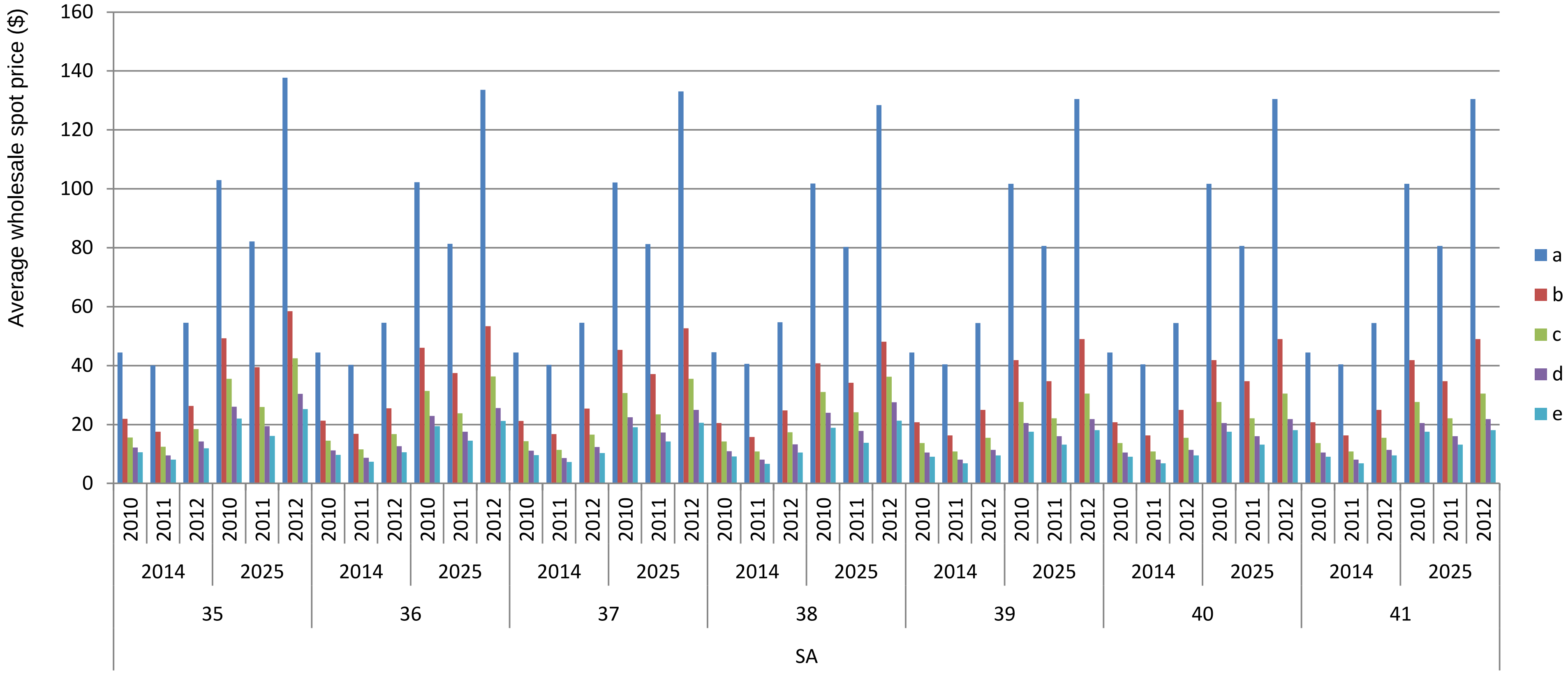
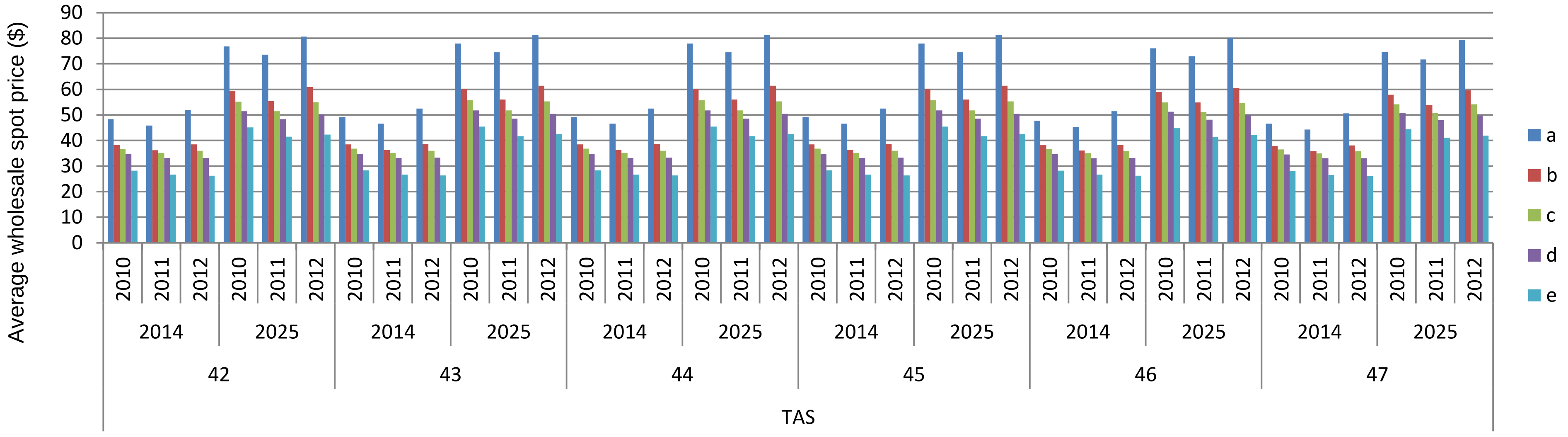


Figure 9 shows the TAS average wholesale spot prices by node by projections years 2014 and 2025 and by weather baseline years 2010, 2011 and 2012. Any node in the State of TAS represents the average wholesale spot price of the entire State. Node 50 exhibits a slightly lower deviation from the 'Representative State Node'.

Figure 9: TAS average wholesale spot prices by node by projections years 2014 and 2025 and by weather baseline years 2010, 2011 and 2012



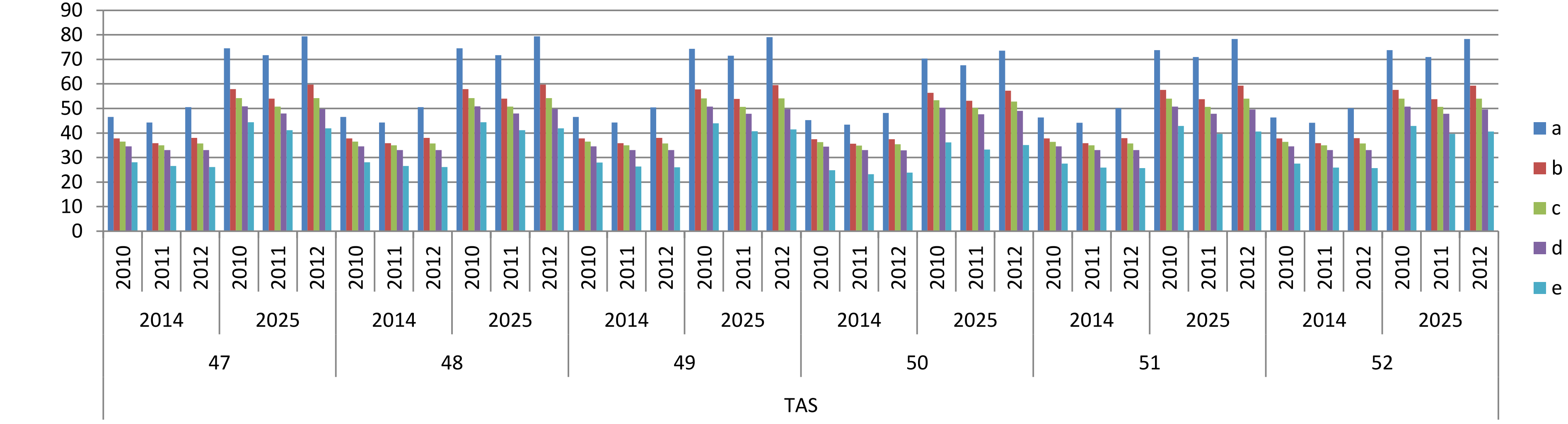
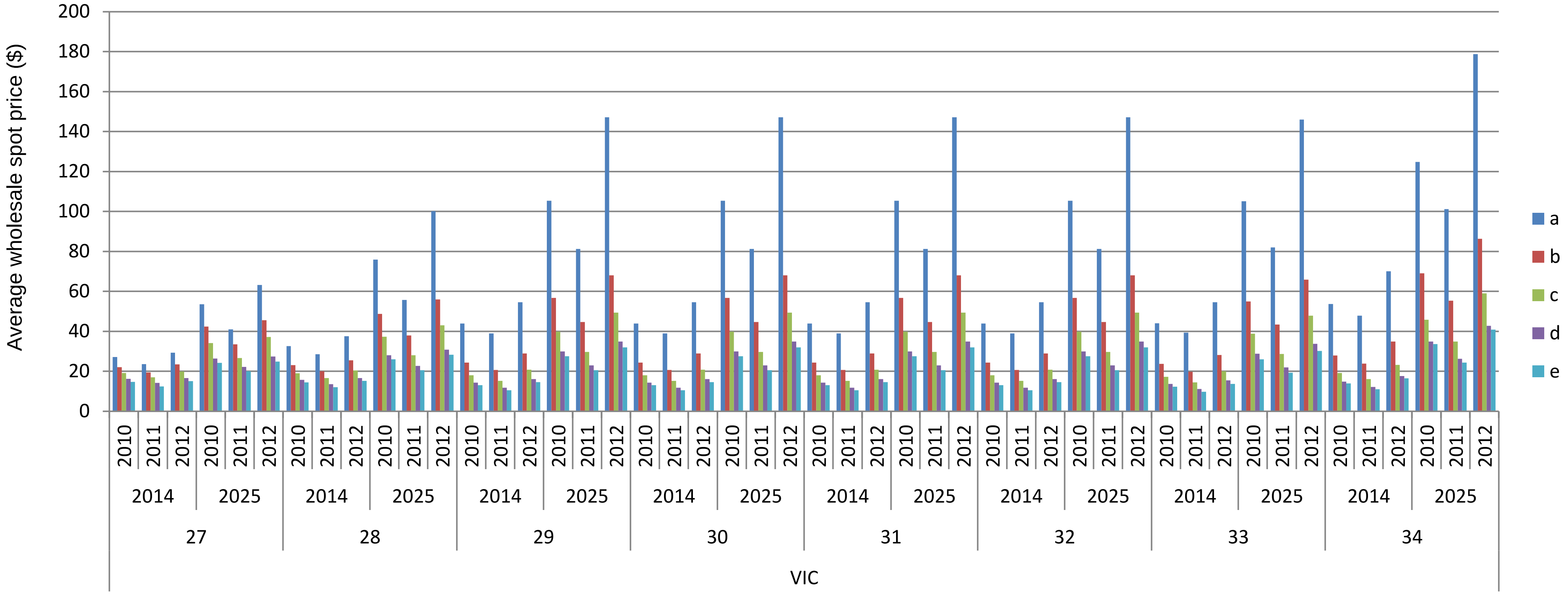


Figure 10 shows the VIC average wholesale spot prices by node by projections years 2014 and 2025 and by weather baseline years 2010, 2011 and 2012. The average wholesale spot price fall into four groups; Node 27, Node 28, Node 34 and the remaining Nodes 29 to 33. Nodes 27, 28 and 34 form the VIC end of the interconnection to NSW. Node 34 also connects VIC to SA via the MurrayLink Interconnector.

Figure 10: VIC average wholesale spot prices by node by projections years 2014 and 2025 and by weather baseline years 2010, 2011 and 2012



3.2.2 Representative State Nodes

This section analyses the representative nodes of each State. The 'Representative State Nodes' are those nodes that represent the same average wholesale spot price as most of the nodes in the State. The ability to use representative nodes comes from a price islanding effect where the transmission network within each State have relatively little congestion but the interconnectors between States are relatively congested. Section 3.2.3 analyses the 'Unrepresentative State Nodes'. Figure 11 compares the average wholesale spot price between each of the representative nodes. Table 7 lists the NEM's windfarms by State and Scenario. The rank order by Annual Production for all Scenarios is NSW, VIC, SA, QLD and TAS. Comparing Figure 11 and Table 7 helps to explain the decrease in average wholesale spot prices. The remainder of the section discusses the representative nodes in more detail and the windfarm nodal location within each State to identify any potential contribution factors for the unrepresentative nodes.

Figure 11: The representative nodes for each State in the NEM

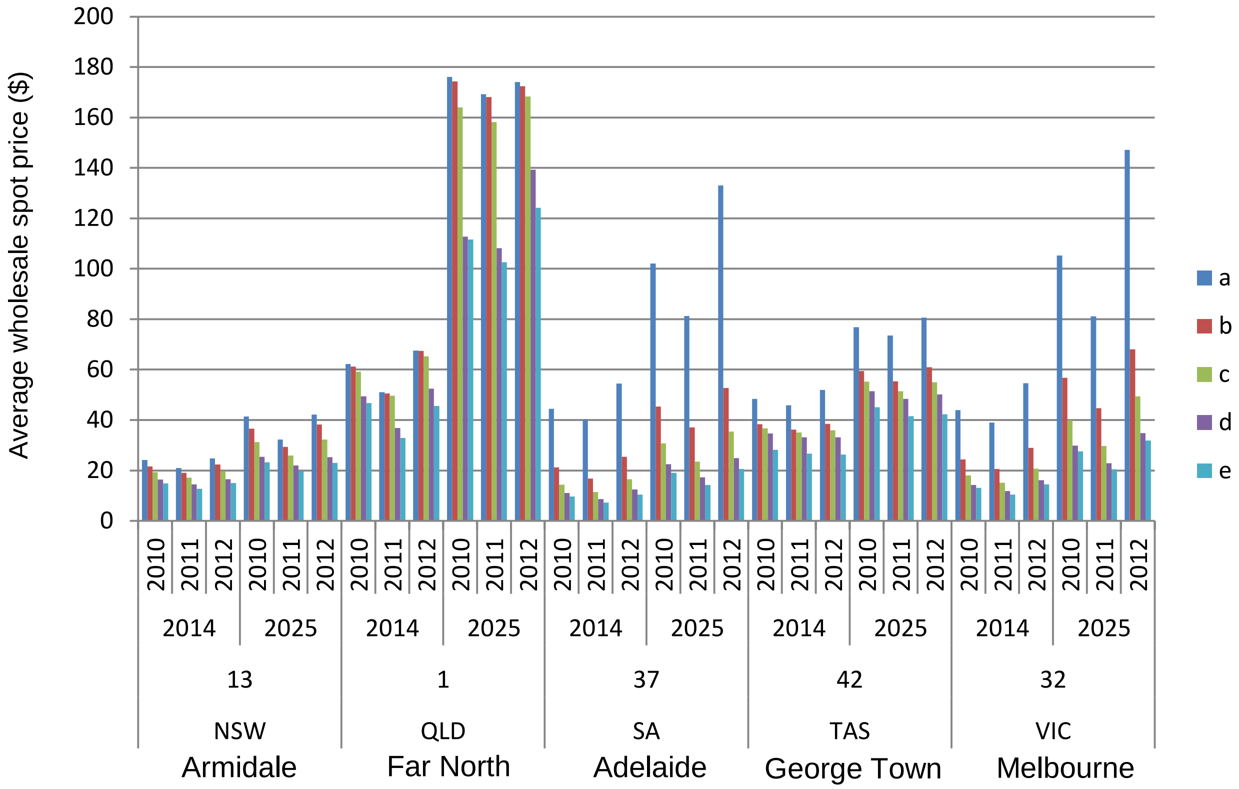


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Table 7: NEM Windfarms by State and Scenario

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)

3.2.2.1 QLD's representative Node: Far North (Node 1)

Figure 12 shows average wholesale spot price for QLD's representative node, Node 1 (Far North). Section 3.2.3 discusses QLD's unrepresentative nodes that are Nodes 8 and 11. Comparing Figure 12 and Table 8 shows a high correspondence between reduction in average wholesale spot price and Annual Production (GW) from wind generation. The high degree of nodal price equalisation within QLD reflects the fact that there is little if any congestion on intra-state transmission branches. Apart from Node 8 (South West QLD), this lack of congestion produces a common marginal generation unit within QLD and the observed price equalisation across QLD's Nodes. Table 8 shows that only the Far North (Node 1) and Tarong (Node 7) have windfarms in QLD. Node 1 in the Far North is unlikely to affect the unrepresentative QLD Nodes (Nodes 8 and 11) but a transmission line links Node 8 (South West) and Node 7 (Tarong), so the windfarms on Node 7 could affect the prices on Node 8. In concurrence, Figure 7 shows Node 7's price's deviate only slightly from those of the 'Representative State Node.'

Figure 12: QLD's representative Node: Far North (Node 1) excludes Nodes 8 and 11

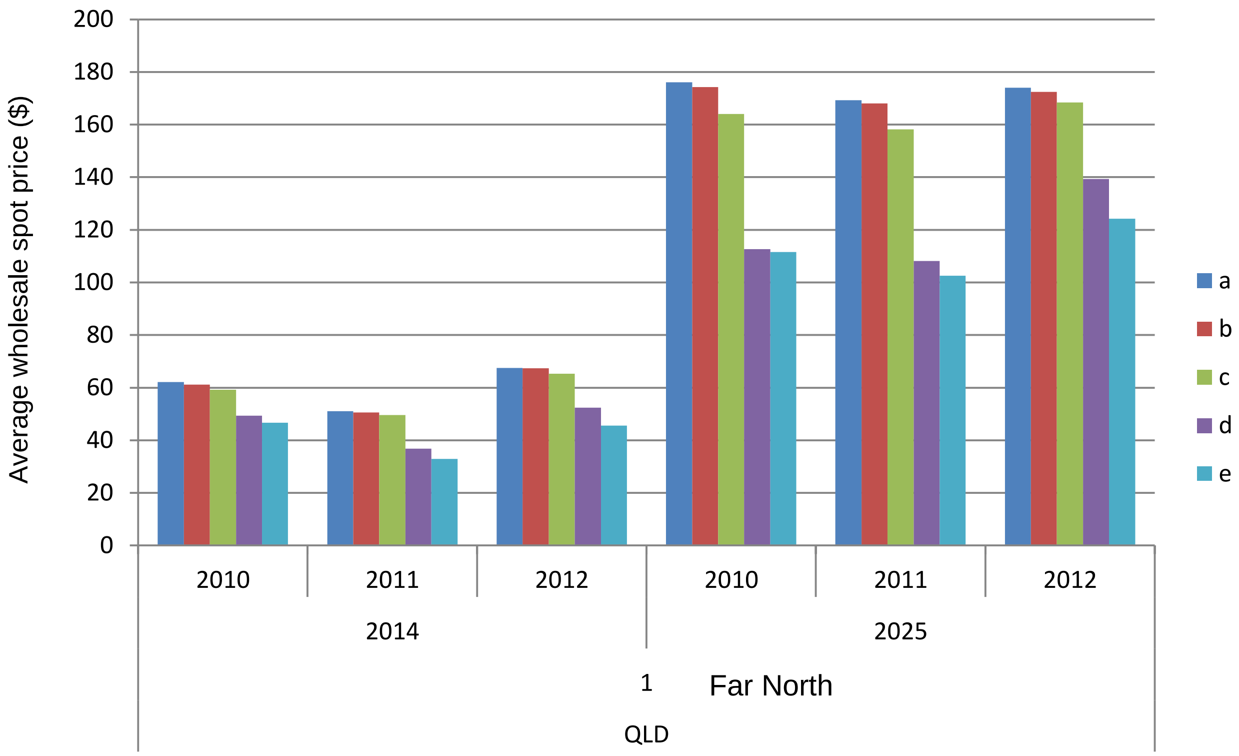


Table 8: QLD Windfarms by Node and Scenario

Scenario/Node	No of WTG	Capacity (MW)	Average Capacity Factor	Annual Production (GWh)
b	**20**	**12**	**0.36**	**38**
1	20	12	0.36	38
c	**25**	**75**	**0.40**	**263**
1	25	75	0.40	263
d	**208**	**624**	**0.44**	**2,407**
1	92	276	0.43	1,073
7	116	348	0.44	1,334
e	**75**	**225**	**0.40**	**789**
7	75	225	0.40	789
Total	**328**	**936**	**0.41**	**3,497**

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

3.2.2.2 NSW's representative Node: Armidale (Node 13) excludes Node 12

Figure 13 shows average wholesale spot price for NSW's representative node, Armidale (Node 13). Section 3.2.3 discusses NSW's unrepresentative node that is Node 12. Comparing Figure 13 and Table 9 shows a high correspondence between reduction in average wholesale spot price and Annual Production (GW) from wind generation. In general, the overall trend towards lower wholesale spot prices in NSW when compared to the other States is a combination of less bullish demand projections over 2014 to 2025, a supply of cheap black coal generation and increasing wind power crowding out more expensive gas and hydro generation. Note that the wind penetration scenarios in NSW have a more even temporal penetration of wind power than QLD.

Figure 13: Armidale (Node 13) representing all NSW Nodes except Node 12

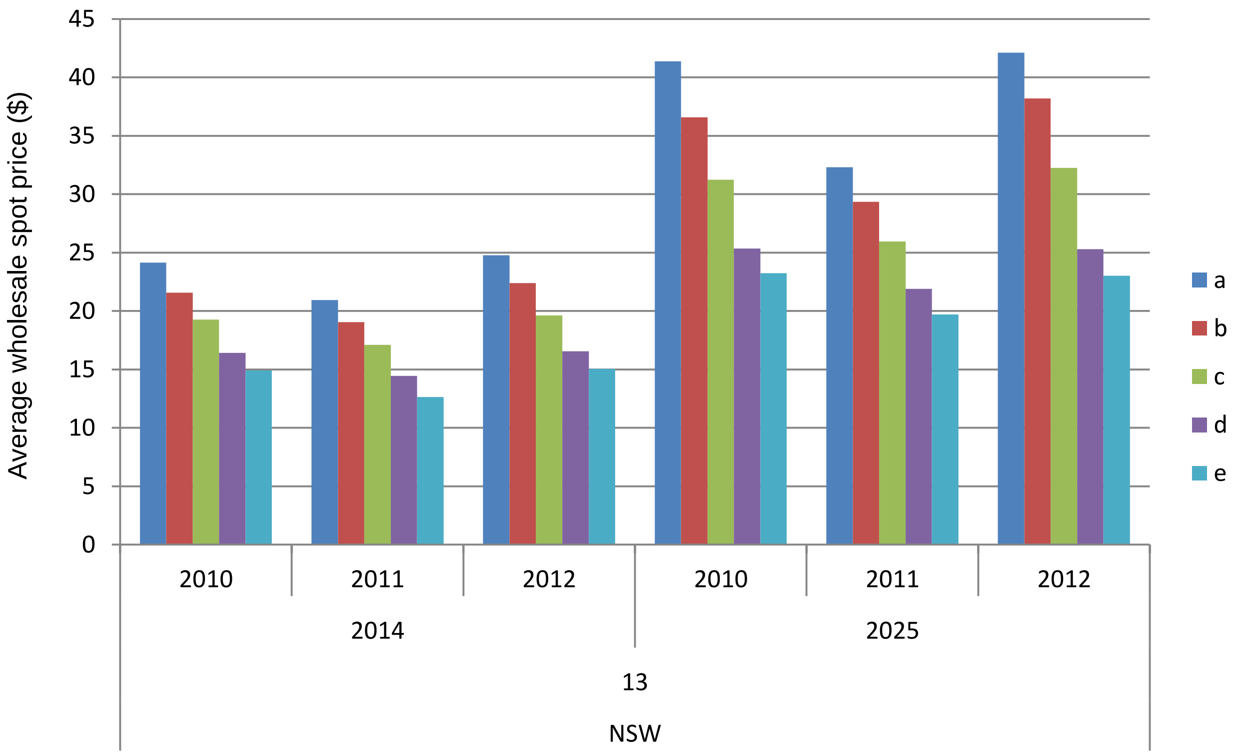


Table 9 shows that seven of the fifteen nodes in NSW have windfarms. This makes the windfarms more spatially dispersed than QLD. The only unrepresentative Node in NSW is Node 12 (Lismore), which lacks any windfarms, but the adjoining Node 13 (Armidale) has the largest cumulative annual production in NSW. Node 13 also adjoins the Unrepresentative QLD Node 8 via QNI.

Noteworthy, the NSW Node 26 (Tumut) possess a relatively large amount of wind power, see Table 9, and links NSW to all three 'Unrepresentative VIC Nodes' 27, 28 and 34. The large Silverton Windfarm adjoins Node 26.

Table 9: NSW Windfarms by Node and Scenario

Scenario/Node	No of WTG	Capacity (MW)	Average Capacity Factor	Annual Production (GWh)
b	**350**	**666**	**0.36**	**2,090**
20	15	10	0.34	30
23	132	277	0.36	890
25	203	379	0.37	1,170
c	**329**	**915**	**0.39**	**3,137**
13	25	75	0.39	256
21	33	99	0.40	346
23	46	138	0.36	438
25	141	351	0.37	1,145
26	84	252	0.43	951
d	**580**	**1,722**	**0.39**	**5,964**
13	293	879	0.39	3,009
20	106	318	0.40	1,105
21	38	114	0.35	350
23	35	105	0.36	334
24	18	36	0.39	124
26	90	270	0.44	1,043
e	**411**	**1,215**	**0.37**	**3,810**
21	288	864	0.36	2,687
24	123	351	0.38	1,123
Total	**1670**	**4,517**	**0.38**	**15,001**

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

3.2.2.3 SA's representative node: Greater Adelaide (Node 37)

Figure 14 shows average wholesale spot price for the 'Representative SA Node' 37 (Greater Adelaide). Excepting, Node 35 exhibits slightly higher prices under certain conditions. Comparing Figure 14 and Table 10 shows a high correspondence between reduction in average wholesale spot price and Annual Production (GW) from wind power. In the States of the NEM, SA has the largest installation of wind power by Annual Production in Scenario B and consequently a large reduction in price from Scenario A to B. SA has cumulative windfarms on five of its seven nodes by Scenario E but over half of the wind power is concentrated at Node 39 (Mid North). The 'Unrepresentative SA' Node 35 has four wind farms installed in Scenario B and connects SA to VIC via the Heywood interconnector that has the least congestion of all the interconnectors (Bell et al. 2015a). Both factors would account for node 35's slight deviation in prices from those of the 'Representative SA Node 37'.

Figure 14: Greater Adelaide (Node 37) representing all nodes in SA

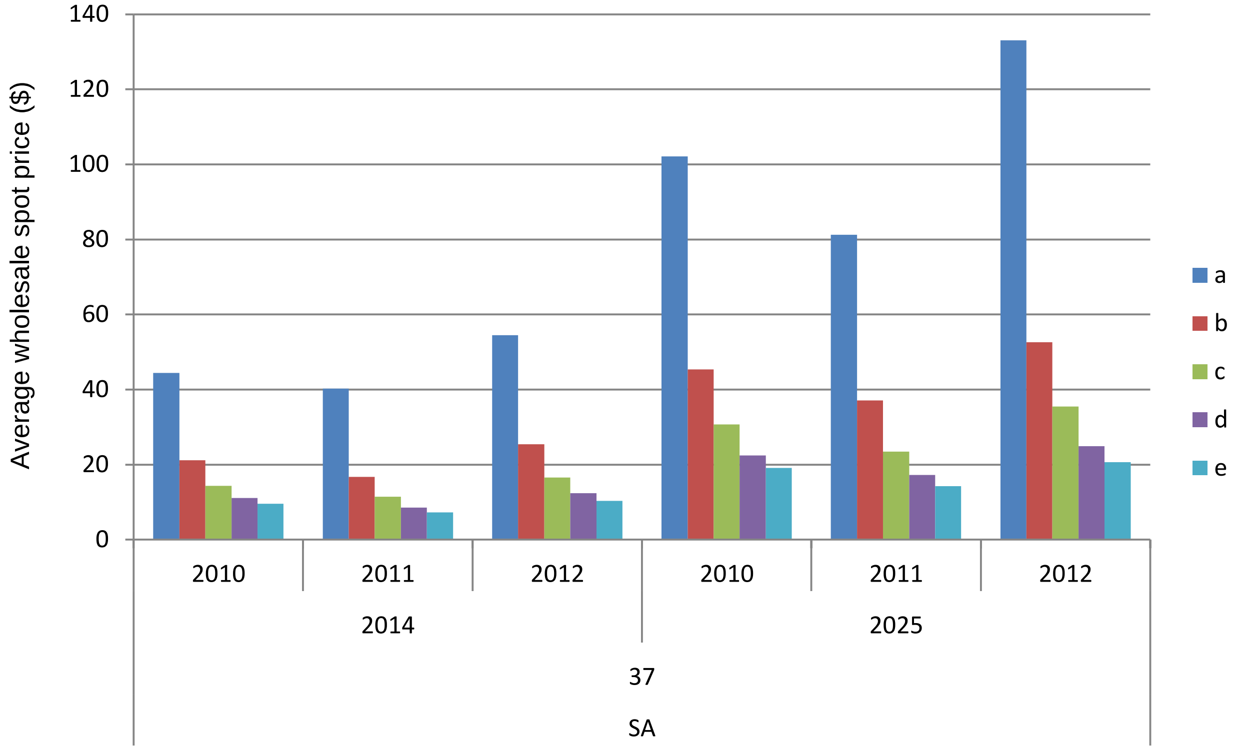


Table 10: SA Windfarms by Node and Scenario

Scenario/Node	No of WTG	Capacity (MW)	Average Capacity Factor	Annual Production (GWh)
b	**649**	**1,473**	**0.36**	**4,883**
35	135	325	0.32	921
37	23	35	0.30	91
39	423	978	0.40	3,487
41	68	136	0.32	384
c	**193**	**579**	**0.41**	**2,149**
39	193	579	0.41	2,149
d	**134**	**402**	**0.43**	**1,522**
39	75	225	0.43	842
40	59	177	0.44	681
e	**176**	**598**	**0.44**	**2,331**
37	176	598	0.44	2,331
Total	**1152**	**3,052**	**0.38**	**10,885**

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

3.2.2.4 VIC's representative node: Melbourne (Node 32) excludes 27, 28 and 34

Figure 15 shows average wholesale spot price for the 'Representative VIC Node 32' Melbourne. Section 3.2.3 discusses the Unrepresentative VIC Nodes 27, 28 and 34. Comparing Figure 15 and Table 11 shows decreasing returns between reduction in average wholesale spot price and Annual Production (GW) from wind generation. VIC has an even installation of wind power throughout Scenarios B, C and D of about 4,000 GW by Annual Production but there are diminishing returns on average spot price reduction.

The Unrepresentative VIC Node 34 possesses about half of VIC's cumulative wind power Annual Production for all Scenarios. Node 34 is also at the junction of two low MW capacity interconnectors VIC-NSW (Line 37 - Tumut-Regional VIC) and VIC-SA (MurrayLink) that have high levels of congestion (Bell et al. 2015a). Section 3.2.3.2 discusses further the Unrepresentative VIC Node 34's high concentration of windfarms and interconnectedness.

Figure 15: Melbourne (Node 32) representing all VIC nodes except 27, 28 and 34

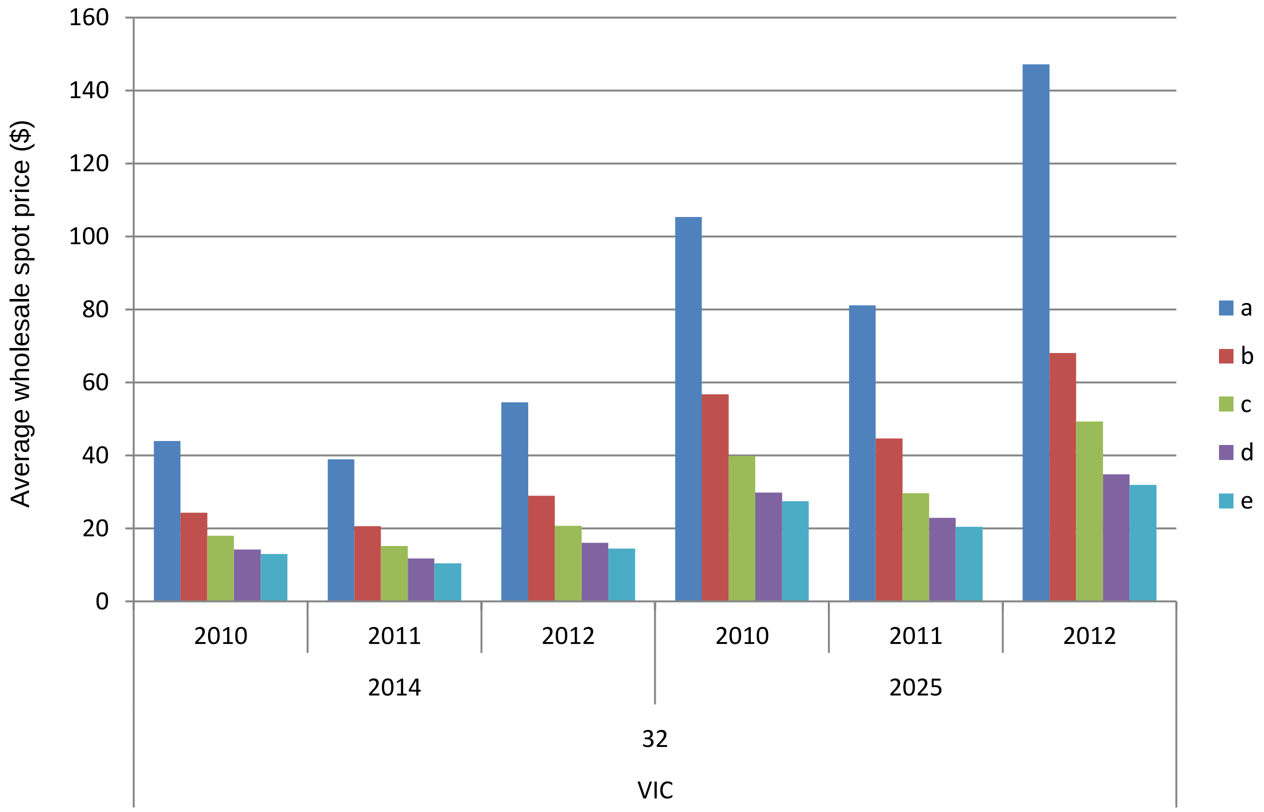


Table 11: VIC Windfarms by Node and Scenario

Scenario/Node	No of WTG	Capacity (MW)	Average Capacity Factor	Annual Production (GWh)
b	**592**	**1,223**	**0.38**	**4,072**
30	70	140	0.38	476
33	280	685	0.38	2,264
34	242	399	0.37	1,332
c	**415**	**1,245**	**0.40**	**4,401**
33	98	294	0.41	1,053
34	317	951	0.39	3,348
d	**464**	**1,316**	**0.40**	**4,728**
32	9	27	0.40	94
33	240	644	0.41	2,367
34	215	645	0.40	2,268
Total	**1471**	**3,784**	**0.39**	**13,201**

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

3.2.2.5 TAS's representative Node: George Town (Node 42)

Figure 16 shows average wholesale spot price for the 'Representative TAS Node 42' George Town. Node 50 (Tarraleah) exhibits slightly lower prices in Scenario E. This reflects the additional dispatch of the Cattle Hill Windfarm in Scenario E.

Comparing Figure 16 and Table 10 show a high correspondence between reduction in average wholesale spot price and Annual Production (GW) from wind generation. The exception is Scenario C that witnesses a reduction in average prices without any additional deployment of wind power in TAS in Scenario C. However, Table 9, Table 10 and Table 11 show that NSW, VIC and SA have sizable deployments of wind power in Scenario C and there is an increase in congestion in BassLink in Scenario C, possibly indicating the importation of power into TAS from VIC. Section 3.2.5 in the project's transmission report (Bell et al. 2015a) discusses this further.

The lower average price in Node 50 (Tarraleah) in Scenario E is a combination of more than doubling TAS wind power in Scenario E (Table 10) at Node 50 and the congestion on Line 64 (Tarraleah-Waddamana) discussed in Section 3.2.5 of the project's transmission report (Bell et al. 2015a).

Figure 16: George Town (Node 42) representing all TAS Nodes

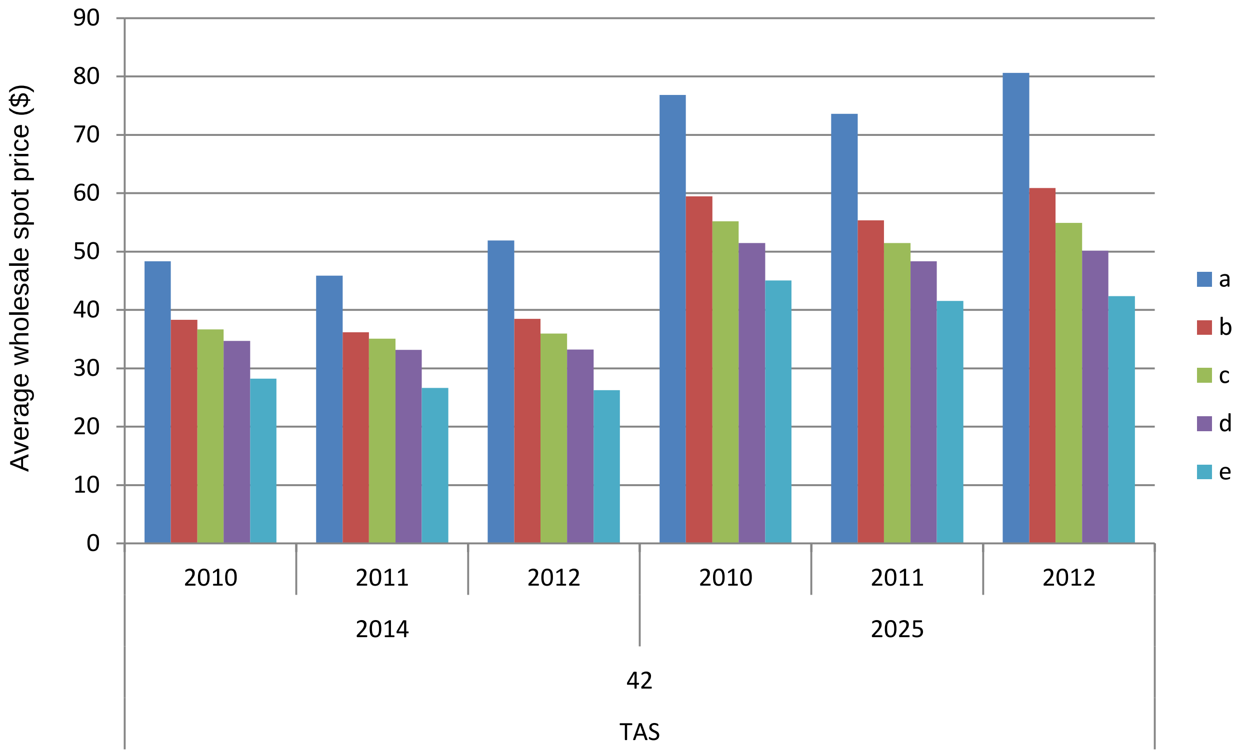


Table 12: TAS Windfarms by Node and Scenario

Scenario/Node	No of WTG	Capacity (MW)	Average Capacity Factor	Annual Production (GWh)
b	**118**	**308**	**0.42**	**1,134**
44	62	140	0.41	501
46	56	168	0.43	633
d	**45**	**135**	**0.42**	**492**
42	12	36	0.43	137
45	33	99	0.41	355
e	**160**	**480**	**0.40**	**1,698**
50	160	480	0.40	1,698
Total	**323**	**923**	**0.42**	**3,324**

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

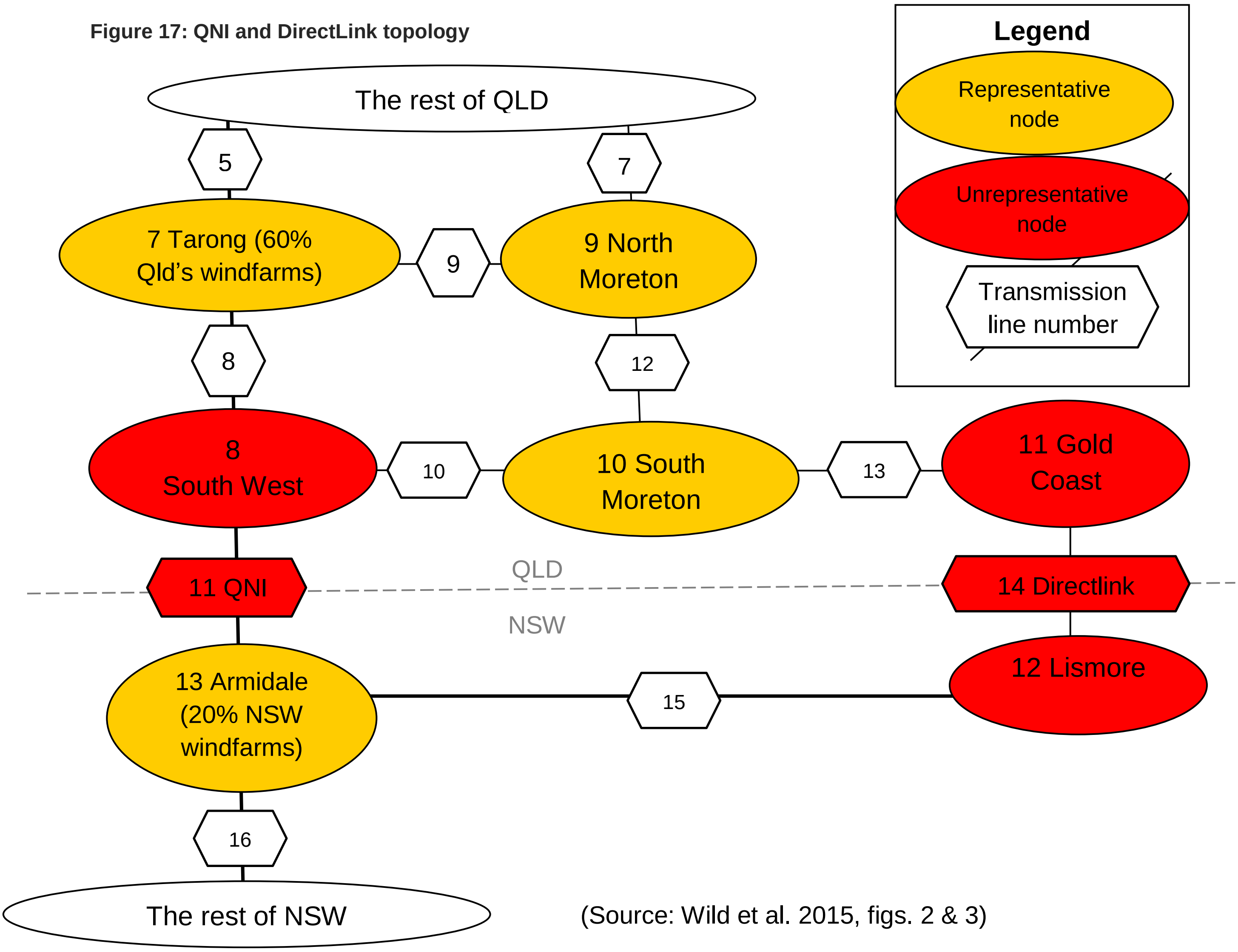
3.2.3 Unrepresentative State Nodes

This section analyses the unrepresentative nodes of each State. Those nodes whose average wholesale spot price deviates from the average wholesale spot price exhibited by most of the other nodes in the State. Most of the unrepresentative nodes exist around the interconnectors. Therefore, we analyse these unrepresentative nodes in groups around their interconnectors. Section 1 discusses the QNI and DirectLink group of unrepresentative nodes. Section 2 discusses the interconnectors NSW-VIC and Murray Link group of unrepresentative nodes.

3.2.3.1 QNI and DirectLink Interconnector terminal Nodes 8, 11, 12 and 13

Explaining the Unrepresentative State Nodes 8, 11 and 12 in Figure 17 requires considering (1) the topology about the QNI and DirectLink interconnectors, (2) the deployment of windfarms in adjacent nodes and (3) the congestion on QNI and DirectLink.

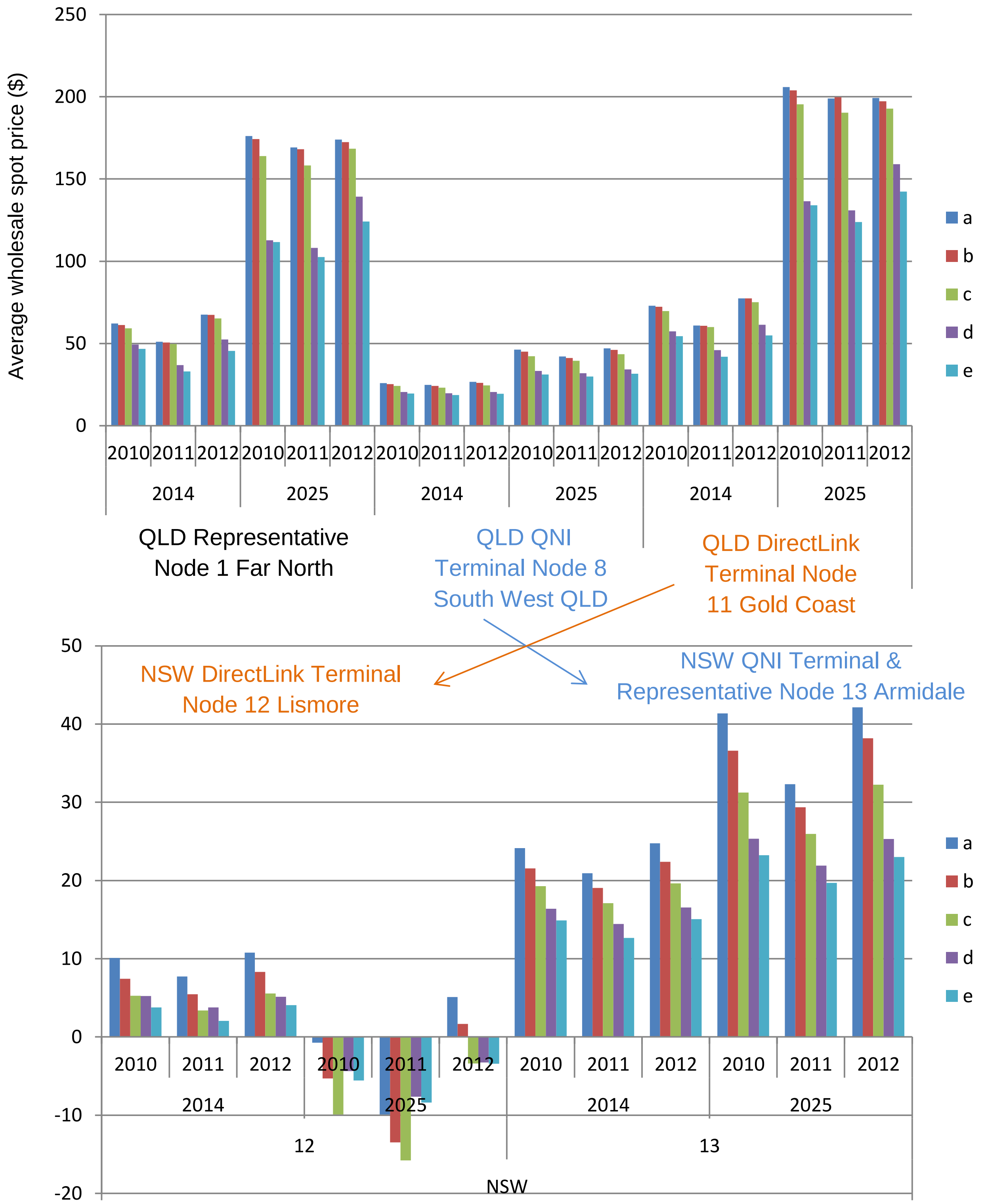
Figure 17: QNI and DirectLink topology



(Source: Wild et al. 2015, figs. 2 & 3)

Figure 17 shows the two interconnectors, QNI and Directlink, connecting QLD and NSW. Notably, there is mesh structure connecting the rest of QLD to the interconnectors. In contrast, a single transmission line connects the rest of NSW. Bell et al. (2015a, sec. 3.2.1) discuss the complementary congestion on QNI and DirectLink. The congestion on QNI decreases with increasing wind power in both Node 13 (Armidale) and Node 7 (Tarong). QNI would have to transfer less power into both QLD and NSW because Nodes 7 and 13 can more readily meet demand within their respective States. Lower congestion on QNI would also imply a greater tendency towards price equalisation between Nodes 8 and 13. This equalisation is shown in Figure 18 that compares the average wholesale spot prices for the terminal nodes on QNI and Directlink.

Figure 18: QNI and DirectLink Interconnector terminal Nodes 8, 11, 12 and 13



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In contrast to the decrease in congestion QNI with increases in wind power, the congestion on DirectLink increases with increasing wind power. This reflects increased power flows from wind generation at Armidale flowing into QLD via the Lismore node and Directlink. This increase power flow quickly congests DirectLink's small MW thermal limit. The congestion maintains a price divergence between the Gold Coast and the Lismore node shown in Figure 18.

Figure 18 shows the average wholesale price of the Representative QLD Node 1 to benchmark the Unrepresentative QLD Nodes 8 and 11. The Unrepresentative QLD Node 8's prices are much lower and Node 11's are higher relative to the Representative QLD Node 1. The prices of the Unrepresentative QLD Node 8 more closely follow the prices of the Representative NSW Node 13's prices. They are both terminal nodes for QNI.

Figure 18 also shows the average wholesale price of the Representative NSW Node 13 to benchmark the Unrepresentative NSW Node 12. Node 12 has some of the lowest prices in the NEM, starting in Scenario A pre-existing any wind power. The increase in wind power has further reduced the prices. The growth in demand for projection years 2014 to 2025 has also increased congestion on DirectLink (Bell et al. 2015a, Sec. 3.2.1) further reducing Node 12's prices and increasing Node 11' s prices.

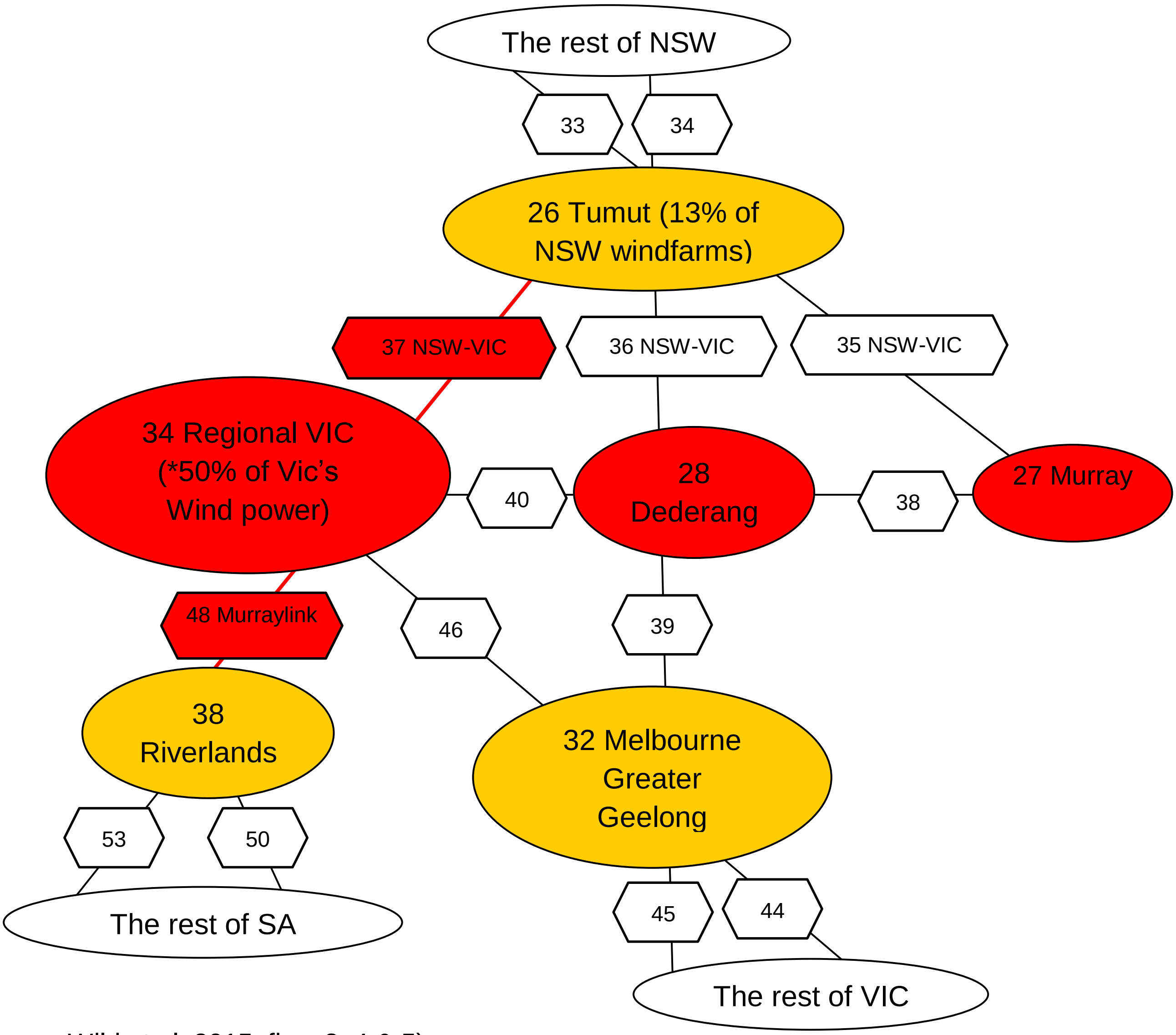
QNI's congestion is projected to decrease and DirectLink's congestion is projected to increase. Increasing the capacity on DirectLink would increase the prices on Node 12 and decrease the prices on Node 11. In effect, the prices at these Unrepresentative State Nodes would move closer to their respective Representative State Nodes.

Section 4.2 discusses further the QNI-DirectLink is grouping.

3.2.3.2 MurrayLink and NSW-VIC Interconnector terminal Nodes 27, 28 and 34

Figure 19 shows the MurrayLink and NSW-VIC interconnectors and their terminal nodes. Coloured red are both the Unrepresentative VIC Nodes 27, 28, 34 and congested interconnector Lines 37 and 48 (Bell et al. 2015a, Secs. 3.2.2 & 3.2.4).

Figure 19: MurrayLink and NSW-VIC Interconnector terminal nodes



(Source: Wild et al. 2015, figs. 3, 4 & 5)

- Figure 19 asterisks Node 34 (Regional VIC) with 50% of Vic's wind power. In a more complete explanation, Node 34 by Scenario D has about 50% of VIC Annual Energy Production from wind power and number of WTG. See Table 11.

Figure 20 shows the average wholesale spot prices for the Unrepresentative VIC Nodes 27, 28 and 34. The Representative VIC Node 32 is included for benchmarking. Node 34 shows slightly higher or equal prices as the Representative Node 32. Both Node 27 and 28 exhibit prices above and below the Representative VIC Node 32. The low congestion on the NSW-VIC interconnectors Lines 35 and 36 means prices in the VIC Nodes 27 and 28 will more closely match those prices in the NSW Node 26 (Tumut).

Figure 20: Benchmarking Unrepresentative VIC Nodes 27, 28 and 34 with Representative Node 32

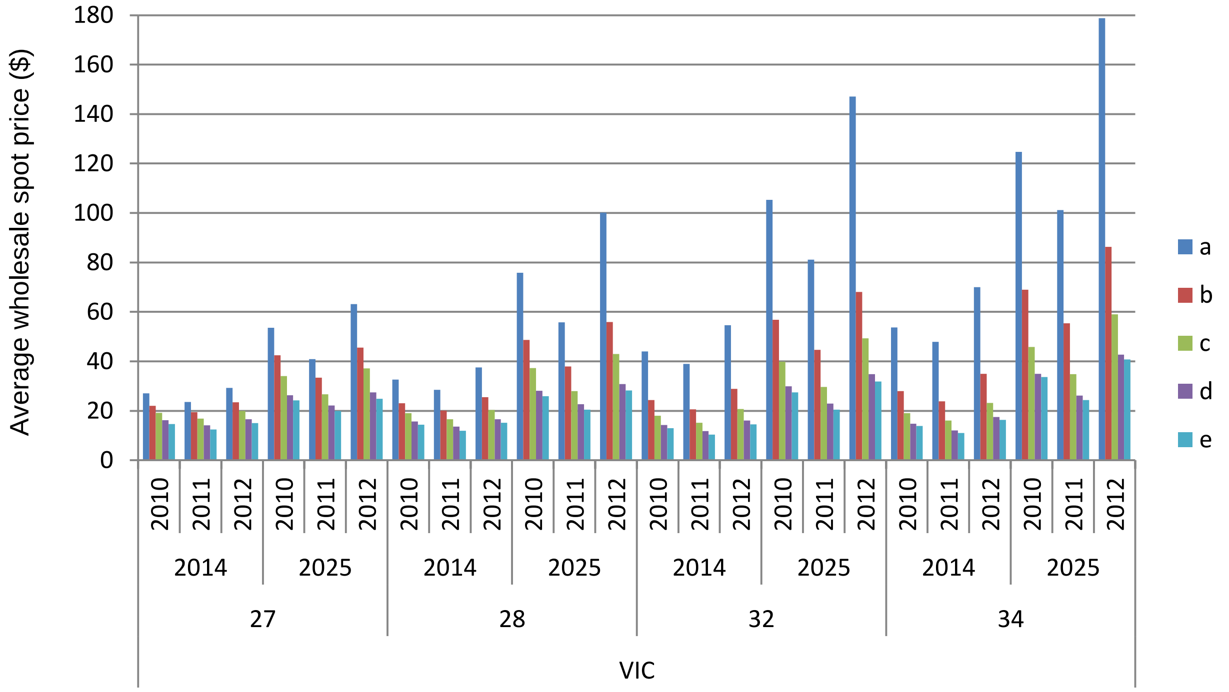
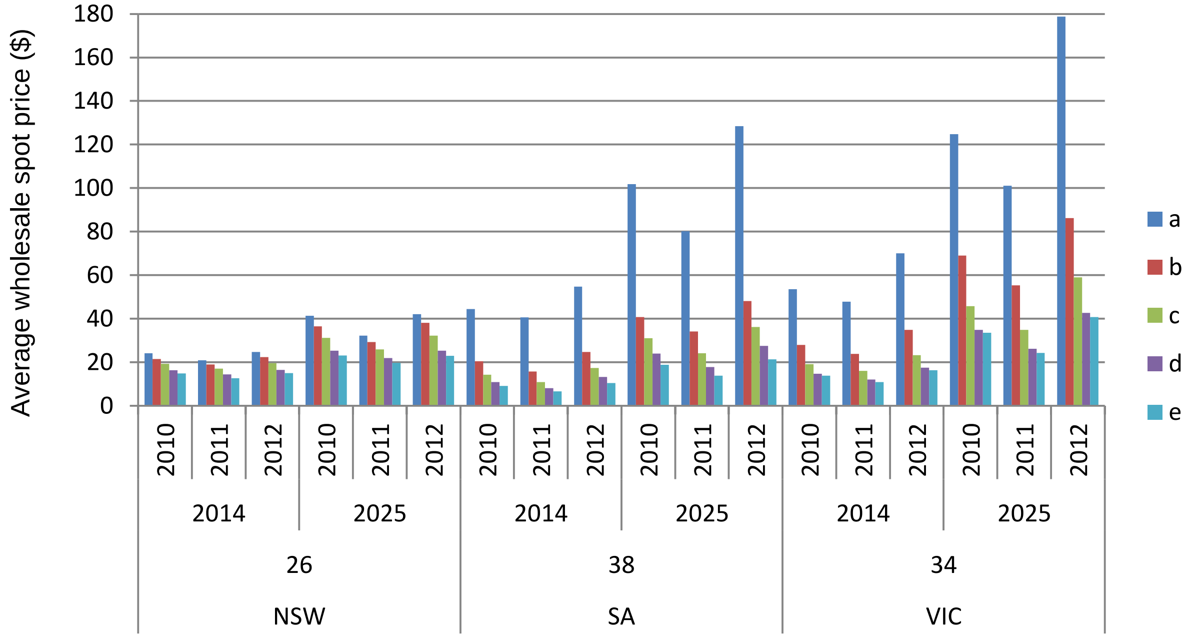


Figure 21 shows the three Nodes: 26, 38 and 34 that are the terminal nodes for MurrayLink and NSW-VIC (Line 37) interconnectors. These nodes are located in NSW, SA and VIC, respectively. Figure 21 shows the average wholesale spot prices for these nodes. There is sufficient difference in their average wholesale spot prices for electricity exports from SA and NSW to VIC. This export potential is based purely on average prices without considering the additional imports and exports stemming from the lack of correlation in wind power between the States.

Figure 21: MurrayLink and NSW-VIC interconnector nodal price comparison



The transmission network about node 34 (Regional VIC) is fragile, which makes assessment difficult. For instance on MurrayLink, from SA to VIC there is a 132 kV network and NSW to SA there is a single circuit 220 kV network. On the Regional VIC network, there is a combination of single and double circuit 220 kV networks that connect from Regional VIC to both the Dederang and Melbourne nodes. Thus the whole network can be characterised as low voltage, low thermal capacity network that, as a result, is prone to congestion. This situation can be contrast with the higher voltage 500 kV and 500/330 kV network backbones found in VIC and NSW. Section 4.2 discusses further the MurrayLink-NSW-VIC interconnector grouping.

4 Discussion

We have conducted a sensitivity analysis of the effect of increasing the number of wind turbine generators (WTG) on average wholesale spot prices 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 41TWh Large Renewable Energy Target. The sensitivity analysis also considered the effect of weather and electricity demand growth on average wholesale spot prices. 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. 2015a) that also uses the ANEM model and the five wind penetration Scenarios A to E.

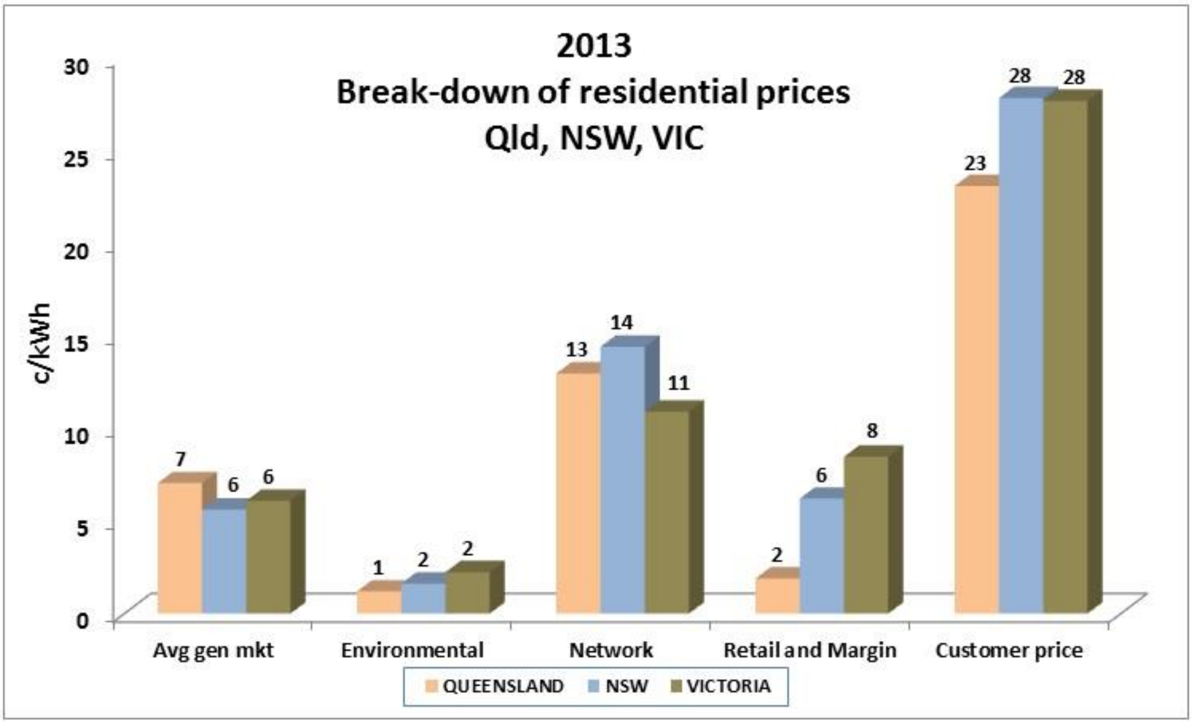
4.1 Interstate comparison to identify system wide effects

In an interstate comparison, we investigated the effect of three factors on the average wholesale spot prices. 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 prices followed by growth in demand and finally the weather effect, see Figure 1, Figure 2 and Figure 3. In comparison, the congestion report (Bell et al. 2015a) finds that wind power still has the largest effect but the weather effect is larger than the growth effect.

Wind Power has both environmental and economic benefits that are reducing both emissions and wholesale spot prices. The average wholesale spot prices of all States decrease with an increase in wind power from Scenario A to E. See Figure 4. Wind power reduces average wholesale spot prices despite any induced transmission line congestion. Two questions arise from this observation. (1) Why are we not experiencing a decrease in retail electricity prices given the downward pressure on wholesale spot prices induced by wind power? (2) How do we reduce the transmission congestion to enhance wind power's geographic reach and ability to reduce wholesale spot prices and carbon emissions further? Sections 4.2 and 4.3 address the second question.

The first question addresses why retailers are not passing on the savings induced by wind power. VIC has a deregulated and privatised retail sector and the other States have regulated retail price. Benchmarking VIC's retail prices against other State retail prices helps evaluated the efficacy of privatisation and deregulation. The management of some electricity retail companies promote VIC as a successful trial of deregulation and privatisation. However, in an independent study Molyneaux and Foster (2014) find the retail margin in VIC is higher than in NSW and QLD, see Figure 22, but the retail prices in NSW and VIC are about equal because the cost of distribution and transmission in VIC is much lower than in NSW. VIC should have the lowest cost network per capita in the NEM because VIC is the State with the highest population density in the NEM and a higher density population makes distribution and transmission relatively less costly, see Table 13. Therefore, using VIC to evaluate the efficacy of deregulation and privatisation is misleading unless VIC's naturally low network costs are considered. In this case, the retailers are absorbing the wind power induced decreases in wholesale spot prices with increases in profit margins.

Figure 22: A 2013 breakdown of residential prices in Qld, NSW and VIC



(Source: Molyneaux & Foster 2014)

Table 13: Population density by State in the NEM: a relative indicator of network costs

State	Population 2014 Sept.	Estimated Area (km2)	Density of Population People per square kilometre
NSW	7,544,500	800,642	9.4
QLD	4,740,900	1,730,648	2.7
SA	1,688,700	983,482	1.7
TAS	515,000	68,401	7.5
VIC	5,866,300	227,416	25.8

(Source: ABS 2015)

Nepal and Jamasb (2015) investigate privatisation and deregulation in the electricity industry finding reality falls short of the benefits promised and a more nuanced approach to development is required. They question the advocacy of following a one-size fits all plan in an idealised textbook theory of splitting the electricity industry into three segments: generation, network and retail, then privatising and deregulating. This process is supposed to engender competition and bring about price reductions. Ideally, competition to reduce prices occurs when there are numerous firms without the ability to exercise market power.

Foster et al. (2013, sec. 10) discuss how the NEM compares to the market ideal and the prognosis for the NEM for increasing market power among the large retailer-generator companies who can leverage on their exiting market power. Figure 23 shows the ownership patterns in the NEM by indicative share. In the retail sectors, three large private retailer-generation companies own over 70% of the entire retail market and nearly 90% of the private market. This equates to considerable market power.

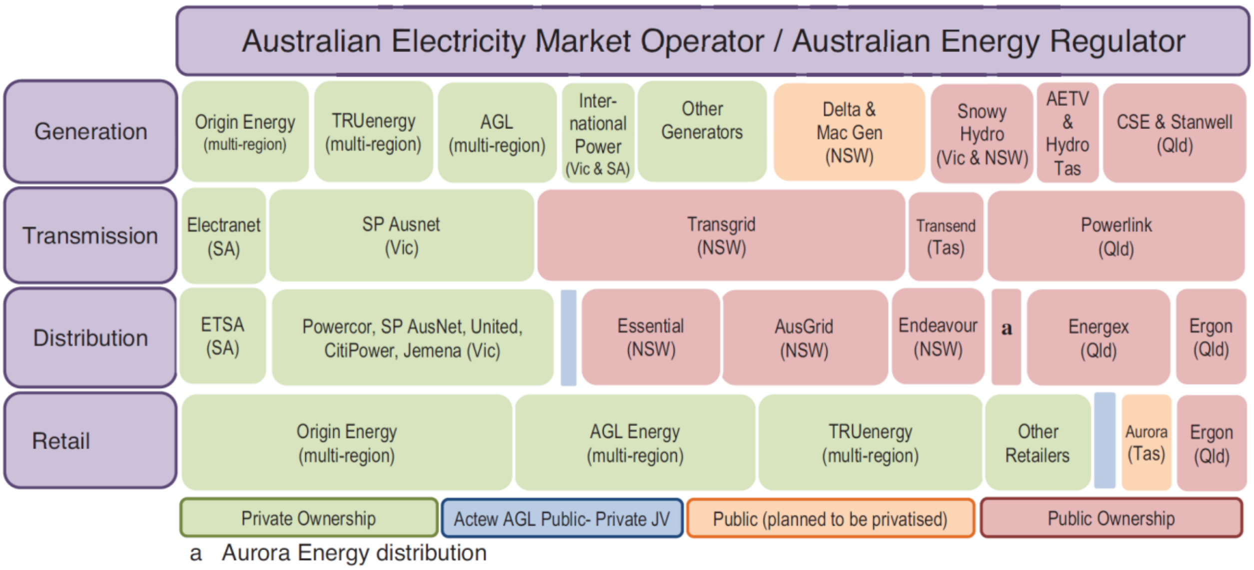
In the generation market, the same three retailer-generator companies own about 64% of the private market but since 2013 AGL bought Delta & Mac Gen from the NSW Government.

This takes the same three retailer-generators market share of the private sector to 68%. These three retailer-generators are well positioned to buy the remaining State owned generation assets. Without intervention, the situation will develop where the market power by the big three retail-generation companies will become similar to the market power exerted by Woolworths and Coles within the supermarket sector.

We could define the “market” as both generation and retail sectors. In which case, splitting the combined retail-generator companies into separate retail and generation companies would reduce market share and enhance competition. We leave the reader to calculate the market share of the big three retailer-generators in this expanded definition of a market.

In comparison, the whole transmission and distribution system is a natural monopoly where multiple companies owning the system only adds extra overheads and fails to provide any competition to reduce prices. Foster et al. (2013, sec. 10) discuss the multiple transmission and distribution problem in more detail.

Figure 23: Ownership patterns in the NEM by indicative market share



(Source: QCA 20013)

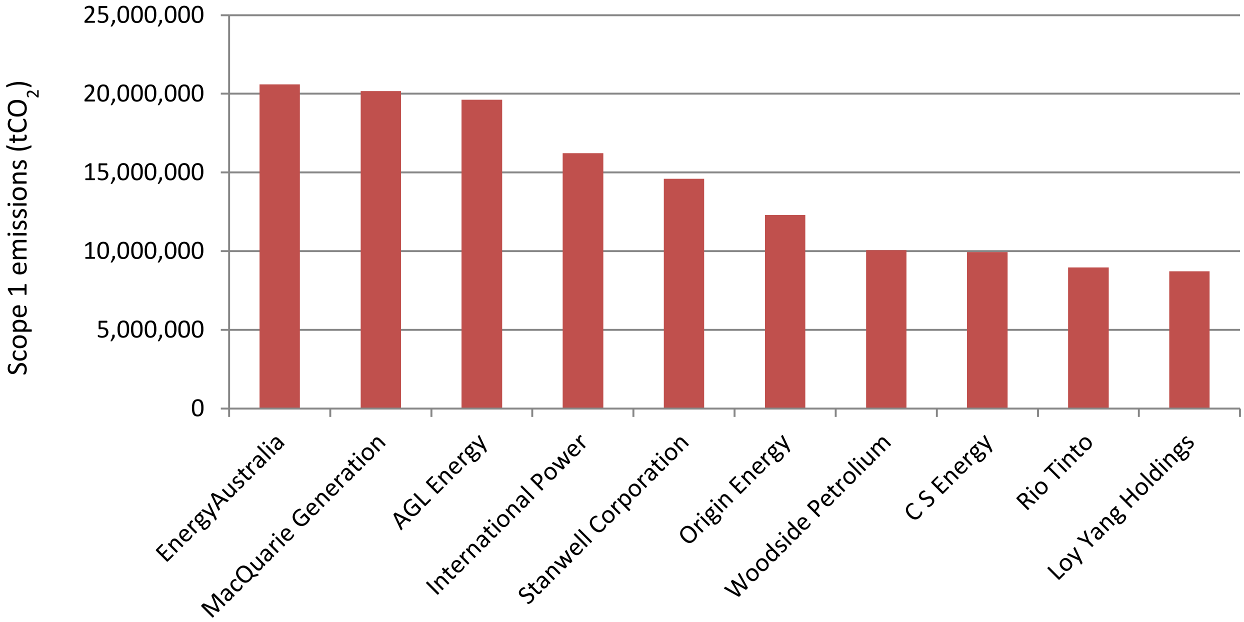
Figure 24 shows that the three retail-generator companies are also among Australia’s largest emitters of greenhouse gases because they are the largest owners of fossil fuel generators. This poses a conflict of interest issue for these retail-generators because wind power is reducing the wholesale spot market prices, so reducing the profits of their large fossil fuel fleets. AGL Energy became Australia’s largest emitter since buying MacQuarie Generation. In a further conflict of interest, any new wind project (or any other new renewable project) would usually require a Power Purchase Agreement (PPA) with one of the three retail-generator companies before the project could obtain financing from banks. Thus, the willingness of the three above companies to write PPA’s affects the development of renewable energy projects in the NEM.

Additionally, the fossil fuel divestment movement is gaining pace both internationally and within Australia. These three companies will be among those targeted for divestment. Divestment sends a message that burning fossil fuels is unethical, undermines the share value of fossil fuel companies and compromises their ability to finance any further development.

If Australia is to privatise and deregulate the retail electricity sector further to maintain downward pressure on retail prices, it makes sense to split the retail-generation companies beforehand for four reasons:

- to improve competition within both the retail and generation sectors,
- to prevent cross-subsidy between the sectors,
- to make the retail sector less vulnerable to fossil fuel divestment, and
- to reduce the market power of those fossil fuel companies with conflict of interest with wind power.

Figure 24: Australia's Top Greenhouse Gas emitters



(Source: CER 2015)

4.2 Detailed investigation of individual nodes

In Section 3.2.1, we identify nodes in each State whose average wholesale spot prices can represent most of the other nodes in the State, the 'Representative State Nodes'. We also identify those nodes whose average prices are at odds with most of the other nodes in the State, the 'Unrepresentative State Nodes'.

In Section 3.2.2, in an interstate comparison of 'Representative State Nodes' prices, we find an islanding effect between States where each State maintains its own price levels. This finding is consistent with high levels of congestion found on most of the interconnectors in our transmission congestion report (Bell et al. 2015a). We also find a high correlation between increases in wind power within each State and decreases in the average wholesale spot prices of the 'Representative State Node' within each State. These findings suggest little intrastate transmission line congestion. Our congestion report (Bell et al. 2015a) corroborates this inference.

In Section 3.2.3, we find all ‘Unrepresentative State Nodes’ are also terminal nodes for the interconnectors. These ‘Unrepresentative State Nodes’ form two groups (1) those around the QLD-NSW interconnectors QNI and DirectLink shown in Figure 17 and (2) those about the MurrayLink and NSW-VIC (Tumut-Regional VIC) interconnectors shown in Figure 19.

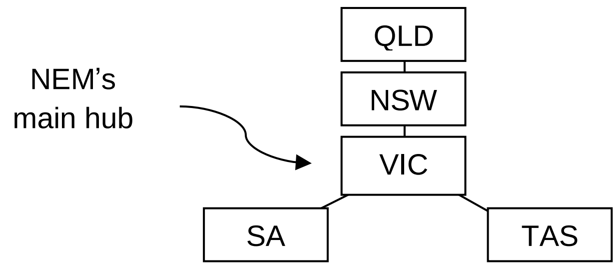
The QLD-NSW interconnectors, QNI and DirectLink, shown in Figure 17 have an interesting topology that causes the congestion on QNI and DirectLink to act in a complementary pattern. Increases in wind power from Scenario A to E increases the congestion on DirectLink but decreases congestion on QNI (Bell et al. 2015a, fig. 5). The topology that causes this associated behaviour is the single transmission that links Node 13 (Armidale) to the rest of NSW. In contrast, there is a mesh of Nodes and Lines connecting the rest of QLD to QNI and DirectLink with a minimum of two lines. Compounding this basic congestion pattern are the high concentrations of windfarms on Node 7 (Tarong, QLD) and Node 13 (Armidale, NSW).

Regarding average wholesale prices, Figure 18 shows that Node 12 (Lismore, NSW) experiences the lowest prices in the NEM and these prices turn negative during growth in electricity demand from 2014 to 2025. In comparison, QLD is likely to experience the largest growth in electricity demand and prices in the NEM. The congestion on QNI and DirectLink requires addressing for QLD to benefit from the more abundant wind power and lower wholesale spot price electricity in the other States of the NEM. There are the additional benefits that QLD being tropical and on the periphery of the NEM, its wind speed and demand are less correlated. Any congestion solution requires considering the unique topology discussed.

The ‘Unrepresentative VIC Nodes’ and the MurrayLink and NSW-VIC interconnectors shown in Figure 19 present a much simpler topology dynamic than QNI and DirectLink. However, VIC is the central hub in the NEM shown in Figure 25, so the ‘Unrepresentative VIC Nodes’ have strategic importance. In particular, the Unrepresentative VIC Node 34 (Regional VIC) links VIC to both NSW and SA via MurrayLink and Tumut-Regional VIC Interconnectors. This position makes the Unrepresentative VIC Node 34 the most strategic in the NEM. In addition, Node 34 has 50% of VIC’s windfarms. Both MurrayLink and NSW-VIC (Line 37) interconnectors show congestion (Bell et al. 2015a, secs. 3.2.2 & 3.2.4). MurrayLink shows increasing congestion with increasing wind power from Scenario A to E from a few percent to over sixty percent. In comparison, the congestion on NSW-VIC stays at about 50 percent

The VIC and NSW intrastate transmission backbone has 500 kV and 500/330 kV capacity. In comparison, the interconnectors linking Node 34 to SA and NSW as well as Regional VIC itself has either a single or double circuit 132 or 220 kV network structure. A simple solution is to increase the capacity on both interconnectors and intra-state linkages from Regional VIC to both the Dederang and Melbourne nodes.

Figure 25: VIC the NEM's main hub



AEMO (2010a, 2010b, 2011a, 2011b) propose a high capacity backbone to the NEM grid called NEMLink that augments the existing transmission lines to address interstate congestion. The ANEM model report (Wild et al. 2015, figs. 1-6) shows the transmission lines augmented in the NEMLink proposal in red. NEMLink includes and eliminates congestion on the following three interconnectors QNI, MurrayLink and Regional VIC-Tumut NSW. The AEMO (2010a, 2010b, 2011a, 2011b) Regulatory Investment Tests for Transmission (RIT-T) for NEMLink excluded BassLink from the proposed NEMLink augmentation. BassLink, being a HVDC submarine cable interconnector, is the most capital intensive of the all augmentations evaluated. However, the RIT-T for the NEMLink also excluded the benefits of high penetrations of renewable energy. We (Bell et al. 2015d) perform a wind speed and electricity demand correlation analysis for the NEM to determining wind turbine generators' ability to meet electricity demand without energy storage. We found a lack of correlation between the NEM's peripheral states wind speeds and lack of correlation between the peripheral states' electricity demand but a small correlation between the peripheral states wind speed and electrify demand. NEMLink would enable the NEM to more fully avail itself of the benefits wind power. This will become more valuable as the proportion of electricity from wind power increases towards the 2020 target and beyond. We investigate the effect of NEMLink on transmission congestion and wholesale spot prices under the five wind penetration scenarios in two subsequent reports (Bell et al. 2015b, 2015c).

4.3 Gold-plated State networks and interconnectors as hosepipes

The previous section discussed the uncongested intrastate transmission lines and the congested Inter State transmission lines inducing a price island effect for each State. This observation supports Garnaut's (2011, p. 2) claim regarding inadequate interconnectors and gold-plated State networks.

> "However, Nunn (2011) disagrees with Garnaut's (2011, p. 38) assessment on gold plating intrastate transmission and under investing in interstate transmission. Nunn (2011) claims that Garnaut (2011, p. 38) has a *"pipeline congestion"* view where interconnectors are bottlenecks, so the implied solution is increase the capacity of the interconnectors. Nunn (2011) demonstrates using binding constraint data on the transmission network that bottlenecks occur well before the pipeline limit. Therefore, any part of the network can affect flows on the interconnectors. Importantly, studying the frequency of the binding constraints shows that there lacks an obvious solution, as the binding constraints move around the network over time. In agreement, the Australian Energy Market Commission (AEMC 2008, p. viii) states that empirical research from the National

Electricity Market Management Company (NEMMCO) shows that congestion tends to be transitory and influenced significantly by network outages. So, if bottlenecks in interstate transmissions are to be resolved, deeper integration of the interconnectors within the intrastate networks is required, which requires a whole of NEM focus rather than state focus.

This difference in focus on state rather than whole of NEM appears to reconcile the gap between Garnaut's (2011, p. 38) view on the institutional dynamics affecting interstate and intrastate transmission investment differently and Nunn's (2011) demonstration using binding constraint data. As part of the ongoing process to remedy newly identified problems on the transmission network, the AEMC (2008, p. vii) recommends that AEMO (2011c) provides information on congestion to enable participants to better manage risk. In addition the AEMO (2011c) provides information on proposed transmission investments to reduce congestion. However, the interactive map shows a single proposed upgrade to interstate transmission and the remainder of the proposed transmission developments are for intrastate, which is consistent with Garnaut's (2011, p. 38) gold plating claim. Furthermore, an AEMC (2008, p. iv) recommendation could account for some of this focus on intrastate development being to *"clarify and strengthen the Rules governing the rights of generators who fund transmission augmentations as a means of managing congestion risk, so that in the future connecting parties make a contribution to those funded investments from which they will benefit".* This rule leaves the interconnector used by many generators in an overtly complex situation, so favouring intrastate investment over interstate."

(Foster et al. 2013, sec. 6.1)

4.4 Developing transmission to new wind resources

In addition to the aforementioned dynamics favouring intrastate transmission over Inter State transmission, there are two issues impeding the introduction of new transmission to suitable areas for windfarms and other renewable energy sources:

- Regulatory Investment Tests for Transmission (RIT-T); and
- The fragmentation of the transmission companies and conflict of interest.

"RIT-T requires that new investments meet peak demand. This essentially puts the consideration of new transmission to sites suitable for renewable energy outside of the current RIT-T procedures. The RIT-T procedure requires changing to incorporate economic viability tests for sites suitable for renewable energy. This change would align RIT-T with the broader government policies of addressing climate change. Foster et al. (2013, sec. 7) detail the transmission requirements to incorporate new sites suitable for renewable energy. Foster et al. (2013, sec. 7.7) further discusses RIT-T.

There is a conflict of interest in deploying the optimal size of transmission to new locations suitable for clusters of wind farms over who pays and who benefits. Foster et al. (2013, sec. 6.7) further discusses this conflict of interest. Additionally, there is the intergenerational aspect. Since future generations will benefit from these long-term investments in transmission to new renewable sites, there is justification for long-term loans to finance these projects. Bear in mind that the State Governments funded the transmission for the existing coal fleet. The recommendation in Foster et al. (2013, sec. 10.1) goes some way to addressing both the financing and conflict of interest issues."

(Foster et al. 2013, sec. 10.3)

4.5 *Unregulated interconnectors with storage as congestion and intermittency management solutions*

We discuss unregulated interconnectors with energy storage as a further solution to transmission congestion. AEMO (2015b) discusses how there are two types of interconnectors in the NEM: regulated and unregulated. There is only one unregulated interconnector in the NEM that is BassLink. The regulated interconnectors include all other interconnectors.

A regulated interconnector is an interconnector that has passed the AER-devised regulatory test. TNSPs that own these interconnectors receive a fixed annual revenue based on the value of the asset as set by the AER, regardless of actual usage. The revenue is collected as part of the network charges included in the accounts of electricity end-users.

An unregulated (or market) interconnector derives revenue by trading on the spot market. They do this by purchasing energy in a lower priced region and selling it to a higher priced region, or by selling the rights to revenue traded across the interconnector. Unregulated interconnectors are not required to undergo the regulatory test evaluation.

(AEMO 2015b)

The unregulated interconnector has the benefit of capturing the full benefit from introducing energy storage that is both transmission investment deferment and arbitrage profit from time shifting. The transmission-energy storage combination also addresses the intermittence of renewable energy. This combined approach to both congestion and intermittency management is worthy of investigation. In further research, we could extend the ANEM model to investigate the benefits of unregulated interconnectors with storage on all NEM's interconnectors.

If this unregulated combination proved successful for interconnectors, we could also investigate the approach for intrastate transmission. However, the wholesale spot pricing system in the NEM would require changing from pricing by State to pricing by node for transmission-energy storage entities to capture the full arbitrage value.

5 Conclusion

We find the average wholesale spot price for all nodes 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 Large Renewable Energy Target (LRET). However, there is a failure to pass through these wind power induced wholesale spot price decreases to the retail prices. We find in VIC, whose retail market is deregulated and privatised that the retail margin has simply increased under deregulation absorbing any wholesale spot price decrease induced by wind power (Section 4.1). There is a requirement to improve competition before further privatisation and deregulation for the benefits of wind power to flow through to retail customers. Increasing completion would also mitigate climate change by eliminating any cross subsidy from the retail sector to coal generators owned by retail-generator companies. The alternative to privatisation and deregulation is more enforceable and better regulation. We also find that wind power curtails wholesale spot price increases induced by demand growth and high gas prices.

We find there is a need to address congestion in the interconnectors to reduce the NEM's average wholesale spot prices induced by wind power further and improve the profitability of wind power. The average wholesale spot prices by node provide us with an alternative perspective on congestion discussed in our congestion report (Bell et al. 2015a). We find a single node's average wholesale spot prices can represent the majority of nodal' prices within each State and find price differentiation between States. These observations are consistent with Garnaut's (2011, p. 38) claim of gold-plating within State networks and underinvestment in interconnectors. We identify regulations that perpetuate this situation and require amendment. There is also a conflict of interest between coal generators within each State and expanding interconnector capacity to States with surplus wind power. We also find a requirement to investigate the adequacy of the Regulatory Investment Tests for Transmission to allow the introduction of wind power in locations remote from the grid discussed in Section 4.4.

We find the 'Unrepresentative State Nodes' are clustered about two groups of interconnectors. The 'Unrepresentative State Nodes' are those that fail to follow price movements of the majority of other nodes within the State. Their location is consistent with interconnector congestion and the topology of these groups. The two groups are QNI-DirectLink and MurrayLink-NSW-VIC interconnections. The QNI-DirectLink grouping exhibits a complementary congestion pattern with increasing wind power due to single transmission line (Line 16) connecting the group to the rest of NSW. This unusual topology needs consideration in congestion solutions. The MurrayLink-NSW-VIC grouping is pivotal on Node 34 (Regional VIC). This node has significant strategic value being the central hub in the NEM interconnector system. Compounding its important is its significance for wind power. Node 34 (Regional VIC) contains half of VIC's wind power; Node 34 connects SA and NSW to VIC via MurrayLink and NSW\VIC Interconnector (line 37 and indirectly to lines 35 and 36 via Dederang). These three States have the highest proportion of the NEM's wind power. The MurrayLink-NSW\VIC grouping lacks the complex topology consideration of QNI-DirectLink. Therefore, increasing the capacity of MurrayLink and NSW\VIC (Line 37) with suitable augmentation about Node 34 (Regional VIC) would solve this congestion. Currently, there is low capacity 132kV or 220 kV transmission networks connecting Node 34 to its neighbouring nodes in SA, VIC and NSW.

We recommend two further research topics into congestion management to enable higher penetrations of wind power. These are NEMLink discussed in Section 4.2 and unregulated interconnectors with energy storage discussed in Section 4.5.

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