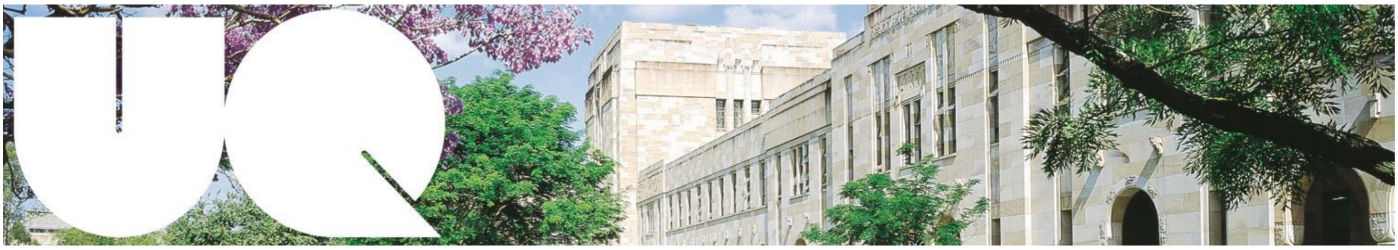

The effect of increasing the number of wind turbine generators on transmission line congestion in the Australian National Electricity Market from 2014 to 2025

EEMG Working Paper 3-2015 - Version 15

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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 transmission line congestion 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, Bell & Foster 2015). Wild, Bell and Foster (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.

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:10.5547/01956574.36.3.5

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 higher wind turbine generation*, 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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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
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 transmission line congestion 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, Bell & Foster 2015)* to model the effect of five different levels of wind penetration on transmission congestion. 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, Bell and Foster (2015)* provide a comprehensive explanation of both the ANEM model and the five levels of wind power penetration.

Section 2 discusses the methodology for the sensitivity analysis and provides an extremely brief outline of the *'Australian National Electricity Market (ANEM) model version 1.10' (Wild, Bell & Foster 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, Bell and Foster (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 penetration and the demand profiles before presenting the results in 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 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, Bell & Foster 2015, tbls. 4 & 5) within two tables *‘List of wind farm WTG by scenario and wind climate proxies’* and *‘List of summary indicators associated with operational and proposed windfarm included in the study’.*

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, Bell & Foster 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 power transmission flows on each transmission line from the three baseline years 2010 to 2012 considers the effect of differing annual weather systems on the dynamics of the NEM and the transmission network. In contrast, the projections years 2014 to 2025 consider the effect of growth in electricity demand on the dynamics of the NEM and the transmission network.

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, Bell & Foster 2015, figs. 1-6). These diagrams relate the transmission line numbers to the topology of the transmission network.

Section 1 compares transmission line congestion between transmission lines to identify system wide effects and Section 2 examines individual lines in detail to evaluate the observations made in Section 1 in higher resolution.

3.1 Inter transmission line comparison to identify system wide effects

Table 2 presents the percentage of the time that transmission lines have reached their maximum thermal capacity during the year, that is, are experiencing transmission branch congestion. 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 the proportion of the time the transmission lines are at their maximum thermal limit or congested.

- 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.

We focus on the transmission Lines 11, 14, 37, 42, 48, 60 and 64 in Table 2 in the inter transmission line comparison to identify system wide effects because the other transmission lines experience extremely little, if any, congestion and their inclusion would crowd the graphical presentation for a tiny effect. However, we examine these other transmission lines with little congestion individually in Section 3.1.4.

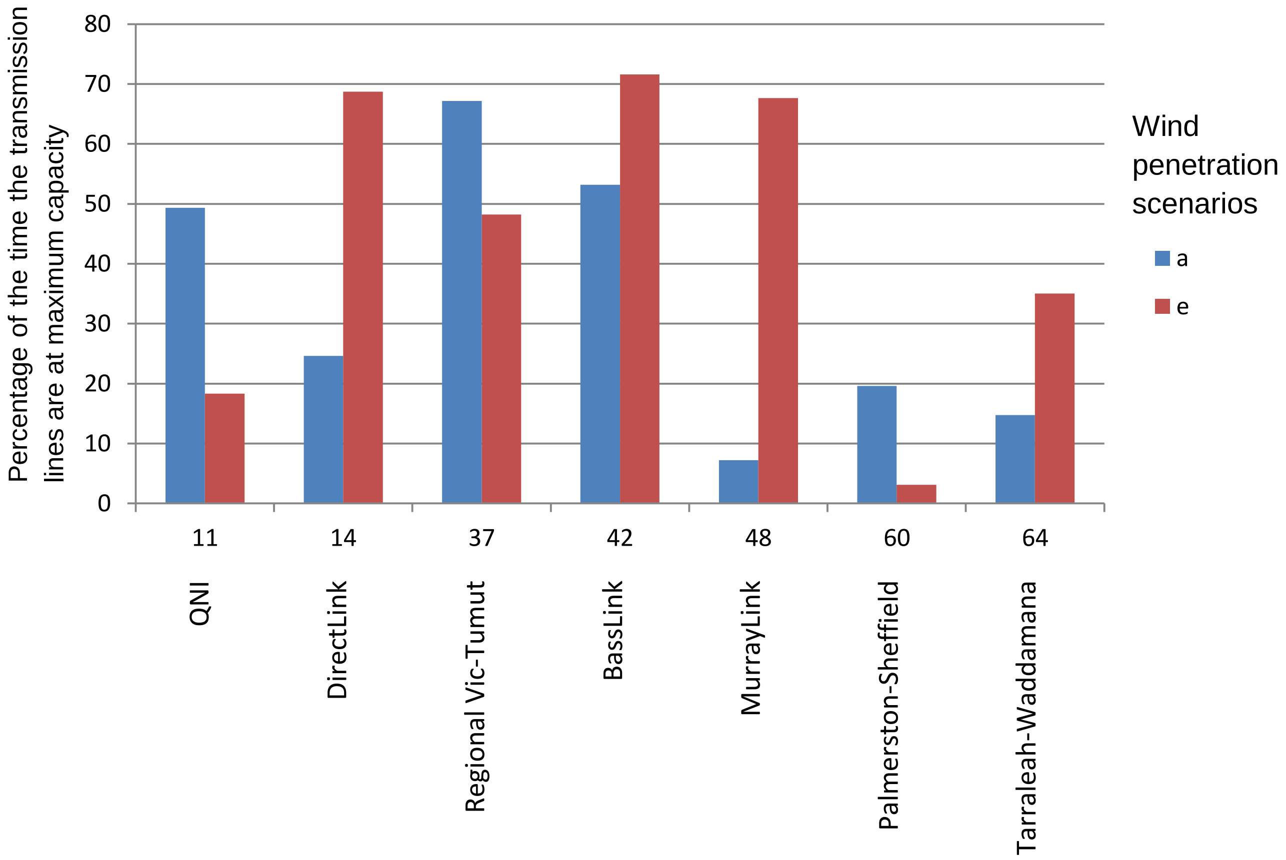
Table 2: Percentage of time transmission lines are at maximum for wind penetration scenarios A and E for the projection year 2014 and 2025

Wind penetration effect	Weather effect	Growth in electricity demand effect	Central West-Gladstone	QNI	DirectLink	Sydney-Marulan	Wollongong-Canberra	Regional Vic-Tumut, NSW	BassLink	Heywood Interconnector	MurrayLink	Riverland-South East SA	Adelaide-Mid North	Mid north-Riverland SA	Palmerston-Sheffield	Tarraleah-Waddamana
Wind scenario	Baseline Year	Projection Year	Line 4	Line 11	Line 14	Line 26	Line 30	Line 37	Line 42	Line 47	Line 48	Line 50	Line 52	Line 53	Line 60	Line 64
a	2010	2014	0.00	49.54	21.13	0.00	0.00	52.14	57.07	1.65	3.22	0.00	0.00	0.00	21.37	7.93
a	2010	2025	0.00	51.46	23.98	0.00	0.00	69.32	50.33	0.35	7.38	0.00	0.00	0.00	21.67	17.90
a	2011	2014	0.02	40.21	31.78	0.00	0.00	53.12	56.50	0.94	2.07	0.00	0.00	0.00	19.76	6.15
a	2011	2025	0.07	43.87	30.19	0.00	0.00	71.50	49.11	0.10	8.47	0.00	0.00	0.00	20.94	18.39
a	2012	2014	0.00	54.47	18.03	0.00	0.00	69.58	51.56	1.29	6.15	0.00	0.00	0.00	20.13	15.33
a	2012	2025	0.00	56.43	22.64	0.00	0.00	87.47	54.66	0.06	16.00	0.00	0.00	0.00	13.82	22.75
e	2010	2014	0.00	16.55	67.55	0.22	0.09	52.17	73.07	2.82	69.24	0.02	0.00	2.01	1.59	33.10
e	2010	2025	0.00	26.52	59.33	0.17	0.04	52.18	74.97	1.63	64.54	0.02	0.00	4.82	6.19	37.39
e	2011	2014	0.02	7.41	83.35	0.00	0.01	41.14	74.20	1.83	74.34	0.00	0.00	1.26	0.79	34.24
e	2011	2025	0.05	14.84	76.79	0.00	0.00	43.24	76.64	0.82	69.84	0.00	0.00	3.36	3.67	37.57
e	2012	2014	0.00	18.16	66.67	0.00	0.04	48.65	64.25	2.90	67.34	0.00	0.01	4.68	1.59	31.08
e	2012	2025	0.00	26.54	58.72	0.00	0.02	51.88	66.31	1.07	60.43	0.06	0.00	8.83	4.75	36.96

3.1.1 Wind penetration effect shown between scenarios A and E

Figure 1 shows the average percentage of the time the transmission lines are at their thermal maximum 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 is the average across the baseline weather years 2010 to 2012 and the projection growth years 2014 and 2025. The change in the proportion of time the transmission lines are at their maximum capacity is over 60 percentage points for MurrayLink (Line 48) and over 16 percentage points for Palmerston-Sheffield (Line 60). The other lines fall between these two extremes. The increase in wind penetration induces both large increases and decreases in the proportion of the time the transmission lines are at their maximum thermal MW ratings. The wind penetration effect is by far the largest of the three effects.

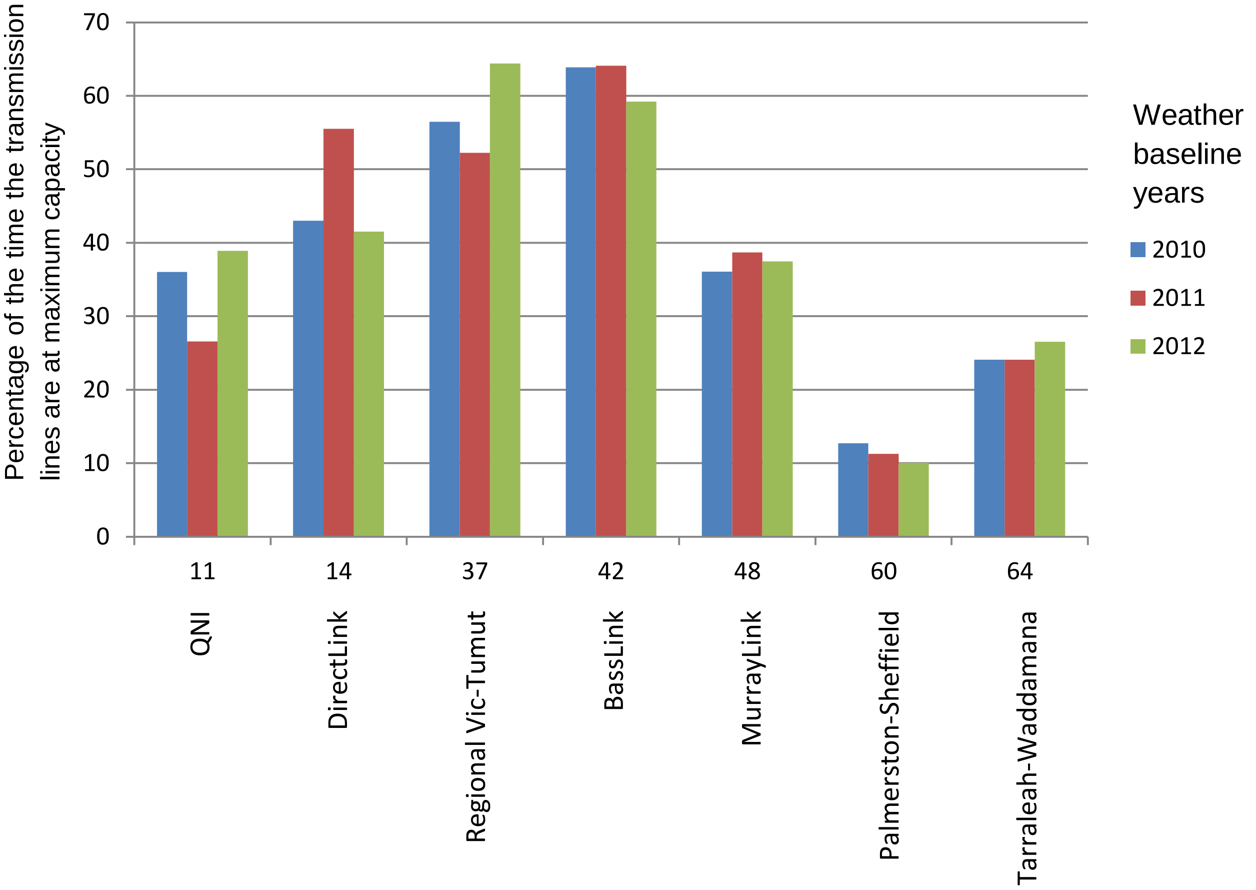
Figure 1: Average percent of time a line is at its thermal maximum for the wind power scenarios A and E



3.1.2 Weather effect shown between the baseline years 2010 to 2012

Figure 2 shows the average percentage of the time the transmission lines are at their thermal maximum 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. The weather effect can account for the redistribution of congestion. The congestion in Figure 2 is the average across the wind scenarios A and E and the projection growth years 2014 and 2025. The change in the proportion of time the transmission lines are at their maximum capacity is over 10 percentage point for QNI (Line 11), DirectLink (Line 14) and 'Regional VIC-Tumut' (Line 37) but 5 percentage points or less for BassLink (Line 42), MurrayLink (Line 48), Palmerston-Sheffield (Line 60) and Tarraleah-Waddamana (Line 64). The weather effect is the second largest effect.

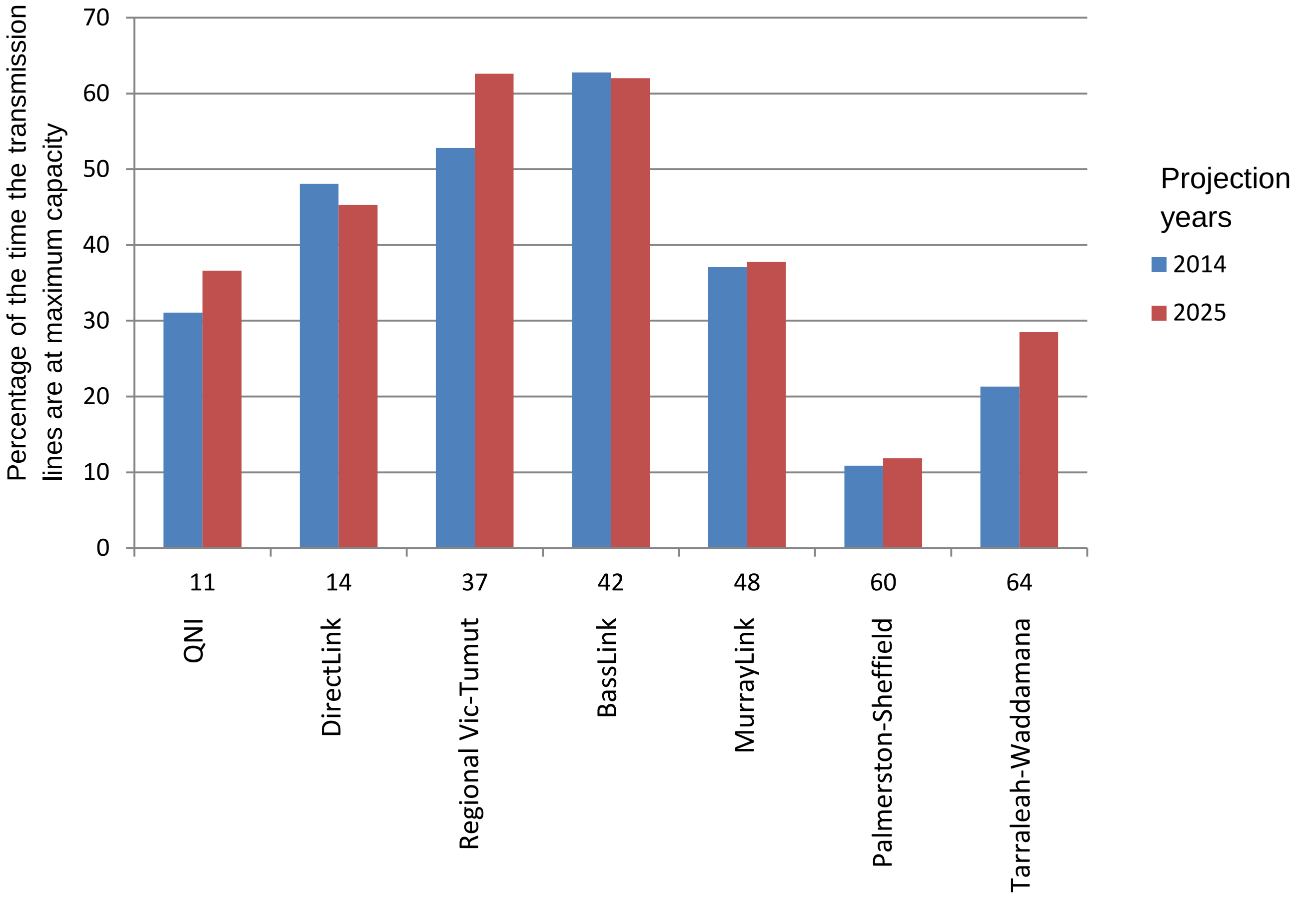
Figure 2: Average percent of time a line is at its thermal maximum for the baseline years 2010 to 2012



3.1.3 Growth in electricity demand effect shown in the difference between projection years 2014 and 2025

Figure 3 shows the average percentage of the time the transmission lines are at their thermal maximum 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 redistribution of the proportion of time the transmission lines are congested. 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 increase the proportion of time the lines are at their maximum thermal capacity. This is the case for lines 11, 37, 48, 60 and 64 but lines 14 and 42 experience a decrease. The largest growth effect is for line 37, which is slightly less than 10 percentage points. The growth effect is the smallest of the three effects.

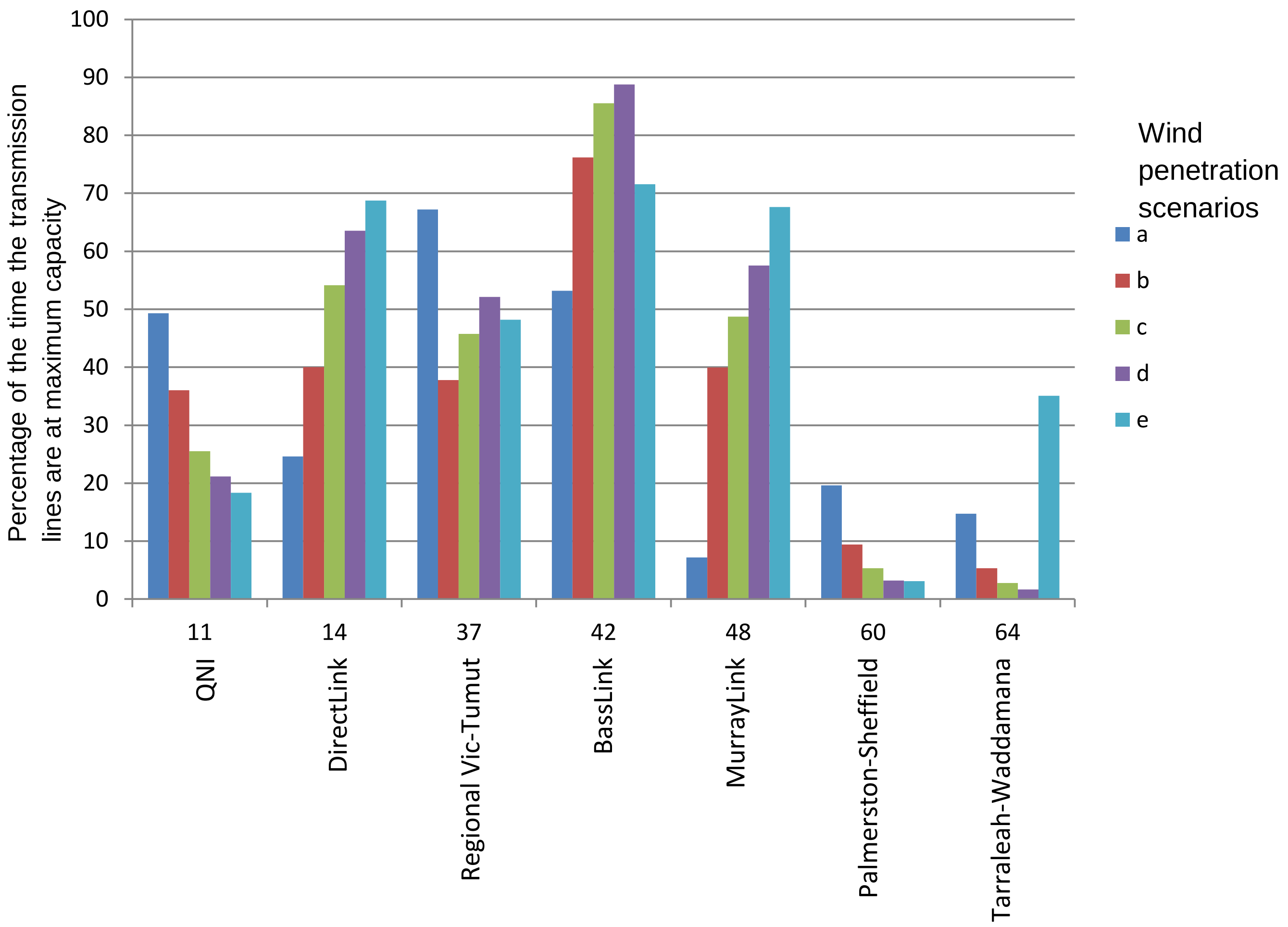
Figure 3: Average percent of time a line is at thermal maximum for the projection years 2014-2025



3.1.4 Comparing the effect of the five wind scenarios on different lines

In the previous three sections, the wind power penetration effect was by far the largest, followed by the weather effect and the smallest being the growth in demand effect. Hence, this section evaluates the larger wind power penetration effect in more detail. Figure 4 below shows the average percentage of the time the transmission lines are at their thermal maximum 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 congestion shown in both Figure 1 and Figure 4 is the average across the baseline weather years 2010 to 2012 and the projection growth years 2014 and 2025.

Figure 4: Comparing the effect of the five wind scenarios on different lines



The effect of the five wind scenarios on the seven lines varies considerably. QNI (Line 11) shows decreasing congestion with increasing wind power. In contrast, DirectLink (Line 14) shows the opposite trend, suggesting the requirement for transmission line argumentation. QNI and DirectLink are the two interconnectors between Queensland (QLD) and New South Wales (NSW). They are acting in a complementary role as the wind power increases.

The interconnector between 'Regional VIC-Tumut NSW' (Line 37) shows the most volatile congestion. Line 37 shows a large drop in congestion after the initial introduction of wind power in Scenario B. However, Line 37 shows smaller increases in congestion on further increases in wind power from Scenarios B to D. This reflects increased output from the

Silverton Windfarm in the Tumut node in NSW (Node 26). In contrast, there is a decrease in congestion with an increase in wind power penetration from Scenario D to E. This reflects increased output from the windfarms Conroy's Gap 2 and Yass Valley in the Yass node in NSW (Node 24) that interconnects with the Tumut node (Node 26). This reduction in congestion coincides with the large reduction in congestion on BassLink (line 42). This reflects increased output from Cattle Hill Windfarm in the Liapootah node in Tasmania (TAS) (Node 50).

BassLink (Line 42) shows an increase in congestion with an increase in wind power but a drop in congestion in the highest wind penetration Scenario E. Energy storage could meet this temporary increase in congestion during Scenarios B to D and redeployed after the peak in congestion has passed. In a complimentary pattern to BassLink, Tarraleah-Waddamana (Line 64) shows decreases in congestion with an increase in wind power but shows a large increase in congestion in Scenario E. This also reflects output from Cattle Hill Windfarm located in the Liapootah node in TAS (Node 50) that commences operation in Scenario E. This abrupt increase in congestion would pose a challenge for the Transmission Network without suitable augmentation or redeployment of energy storage from BassLink in Scenario E.

MurrayLink (Line 48) shows a large increase in congestion after the initial introduction of wind power and progressively increases in congestion on the increase in wind power. MurrayLink constrains the export of wind power from South Australia (SA) to Victoria (VIC) and will become more constraining without suitable augmentation or energy storage solutions.

Tarraleah-Waddamana (Line 60) shows a similar trend to its near neighbour Palmerston-Sheffield (Line 64) with the exception of Scenario E.

3.2 Detailed investigation of individual lines

This section presents a detailed evaluation of each of the transmission lines in Table 2. These transmission lines exhibit some congestion no matter how small. The previous section identified the wind power penetration effect as the largest, followed by the weather effect and the smallest being the growth in demand effects. Hence, the following presentation focuses on the larger effect but discussing each line individually also allows evaluation of the two other effects. Viewing the figures in Wild, Bell and Foster (2015, figs. 1-6) while reading this section would aid comprehension for readers who are unfamiliar with the NEM's transmission line topology.

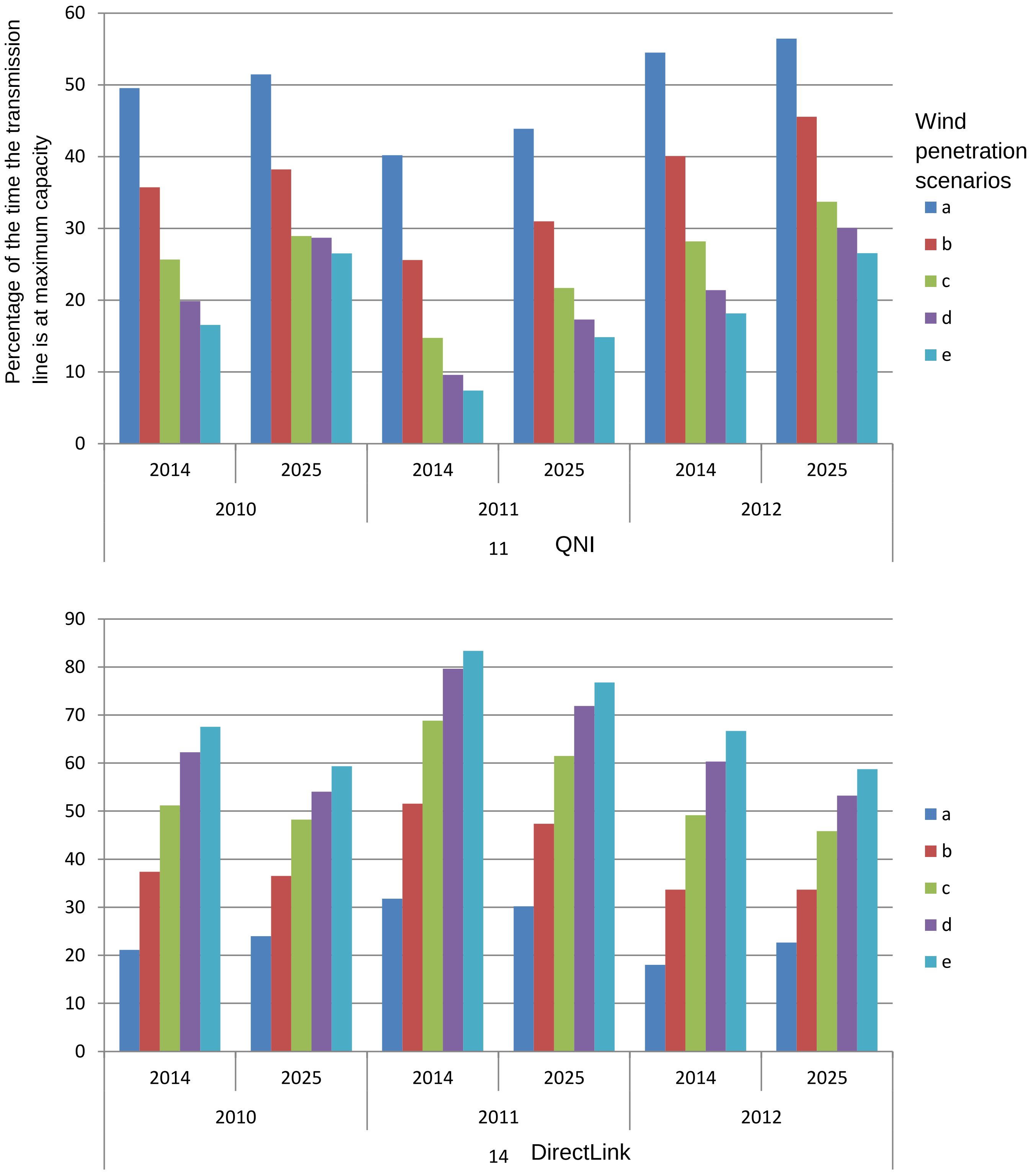
3.2.1 QLD-NSW Interconnectors: QNI and DirectLink (Lines 11 and 14)

This section and the following sections examine the lines in more detail to determine the effect of weather and demand growth on the five wind scenarios. The difference between the baseline years 2010 to 2012 shows the weather effect and the difference between the projection years 2014 and 2025 shows a demand growth effect. These baseline years and projection years are on the x-axis of Figure 5 and on the x-axis of the other figures in the following sections. We also evaluate whether the observations made in the previous sections continue to hold under examination that is more detailed.

Figure 5 shows how the weather, growth and wind-penetration effects affect the congestion on the QNI and DirectLink Interconnectors. Both these interconnectors link the QLD and NSW intrastate transmission systems. The three effects on congestion show a complimentary pattern between the two interconnectors. For DirectLink, the increase in wind power in the Armidale node in NSW (Node 13) from windfarms commencing operation in Scenarios C, D and E have increased congestion. There is a requirement to augment DirectLink. In contrast, for QNI the introduction of wind has reduced congestion ameliorating the requirement for augmentation. This reflects the increased wind power in NSW at the Armidale node and in QLD at the Tarong node, which reduces the need for NSW to import power from QLD and similarly for QLD to import power from NSW.

It is also apparent from Figure 5 that comparison of congestion rates for each wind power penetration scenario indicates an increase in congestion on QNI between projection years 2014 and 2025 (e.g. a positive growth effect). A slight reduction in congestion based upon the weather year 2011 relative to weather years 2010 and 2012 can also be discerned. In the case of DirectLink, congestion generally declines across wind power penetration scenarios in 2025 relative to 2014 indicating a negative growth effect. Congestion for weather year 2011 is also slightly higher in extent than comparable levels for weather years 2010 and 2012.

Figure 5: QLD-NSW Interconnectors: QNI and DirectLink (Lines 11 and 14)

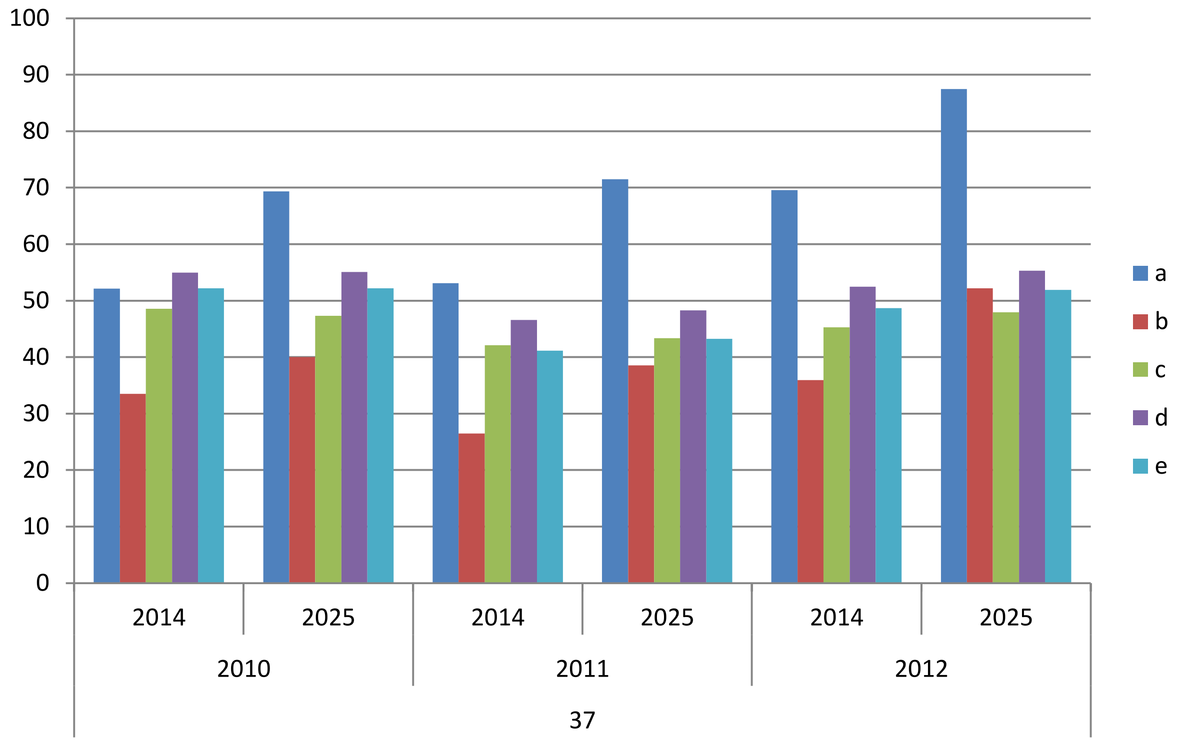


3.2.2 VIC-NSW Interconnector: 'Regional VIC'–'Tumut NSW' (Lines 37)

Figure 6 shows the congestion on the VIC-NSW Interconnector that connects 'Regional VIC' to 'Tumut NSW' (Line 37). The introduction of wind power, the move from Scenario A to B, has reduced the congestion projected in 2025 in the three weather scenarios 2010 to 2012.

It is also evident in Figure 6 that the degree of congestion across the various wind penetration scenarios is generally higher in projection year 2025 than for 2014 for all weather years, 2010-12, indicating a growth effect. The level of congestion for the weather year 2011 also appears to be slightly lower than for 2010 and 2012.

Figure 6: VIC-NSW Interconnector: 'Regional VIC'–'Tumut NSW' (Lines 37)

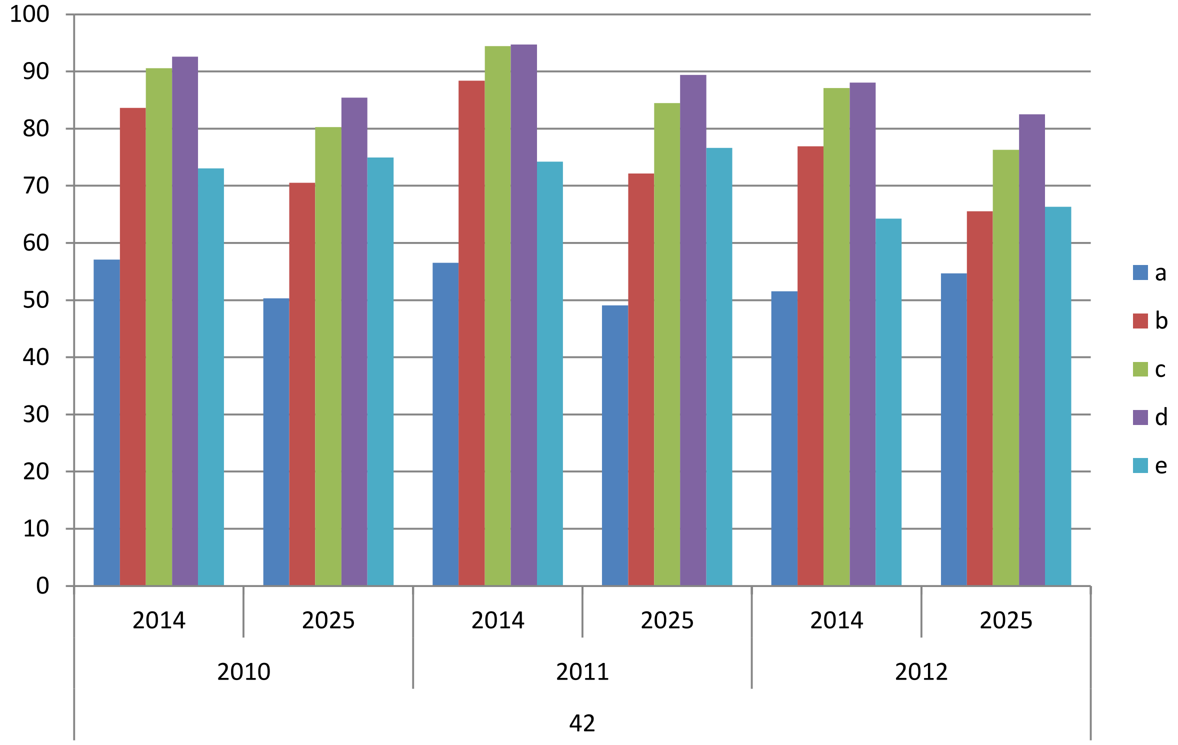


3.2.3 VIC-TAS Interconnector: BassLink (Line 42)

Figure 7 shows the congestion on the BassLink interconnector that connects the VIC and TAS intrastate transmission networks. The projected increase on congestion in BassLink from Wind Penetration Scenario A to D and decrease in congestion from Scenario D to E suggests a relocatable energy storage solution to this temporary increase in congestion.

There is slightly lower congestion in 2025 relative to 2014. This pattern holds for all the weather base years 2010, 2011 and 2012 and is particularly strong moving from Scenario B to D although harder to discern when moving from Scenario D to E. The level of congestion on BassLink also appears to be slightly higher for the weather year 2011 when compared with the two other weather years 2010 and 2012.

Figure 7: VIC-TAS Interconnector: BassLink (Lines 42)

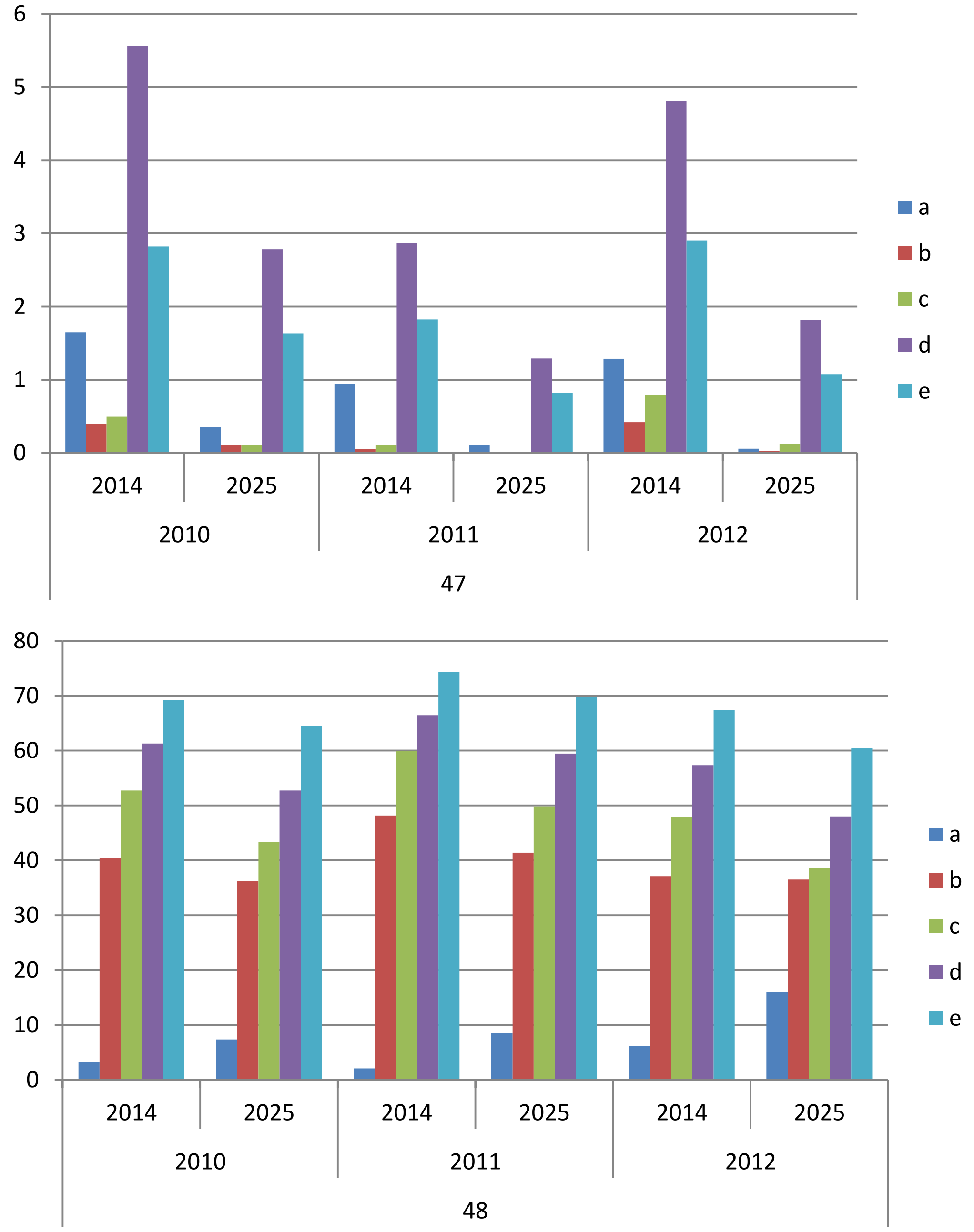


3.2.4 SA-VIC Interconnectors: Heywood and MurrayLink (Lines 47 and 48)

Figure 8 shows how the weather, growth and wind-penetration effects affect the congestion on the Heywood and MurrayLink Interconnectors. These interconnectors link the South Australian (SA) and VIC intrastate transmission networks. Unlike QNI and DirectLink, these two interconnectors fail to show any complimentary pattern. For MurrayLink (Line 47) there is a requirement to augment to allow the export of wind power from SA to VIC. For Heywood, the introduction of wind power reduces congestion that is from Scenario A to B but further penetration of wind from Scenario B to D increases congestion. This reflects the increase in windfarms on adjacent nodes to South East SA (Node 35) and particularly South West VIC (Node 33). However, increasing wind penetration from scenario D to E reduces congestion. This reflects increased wind power at Adelaide, SA (Node 37), reducing import requirements from VIC.

On Heywood, congestion declines across all wind power penetration scenarios from 2014 to 2025. Congestion on this interconnector during the weather year 2011 is also quite subdued when compared to the comparable congestion rates for weather years 2010 and 2012. On MurrayLink, apart from the no wind Scenario A the rate of congestion across all other wind power penetration scenarios declines from 2014 to 2025, representing negative growth. Note that this result is slightly at odds with the result reported in Figure 3 with the latter perhaps being masked somewhat by basing the analysis solely on Scenarios A and E. In comparison to Heywood, the congestion on MurrayLink is slight higher for weather year 2011 when compared with the other two weather years. Figure 8 confirms that the rate of congestion on MurrayLink for all positive wind-power Scenarios, B to E, is significantly greater than on Heywood.

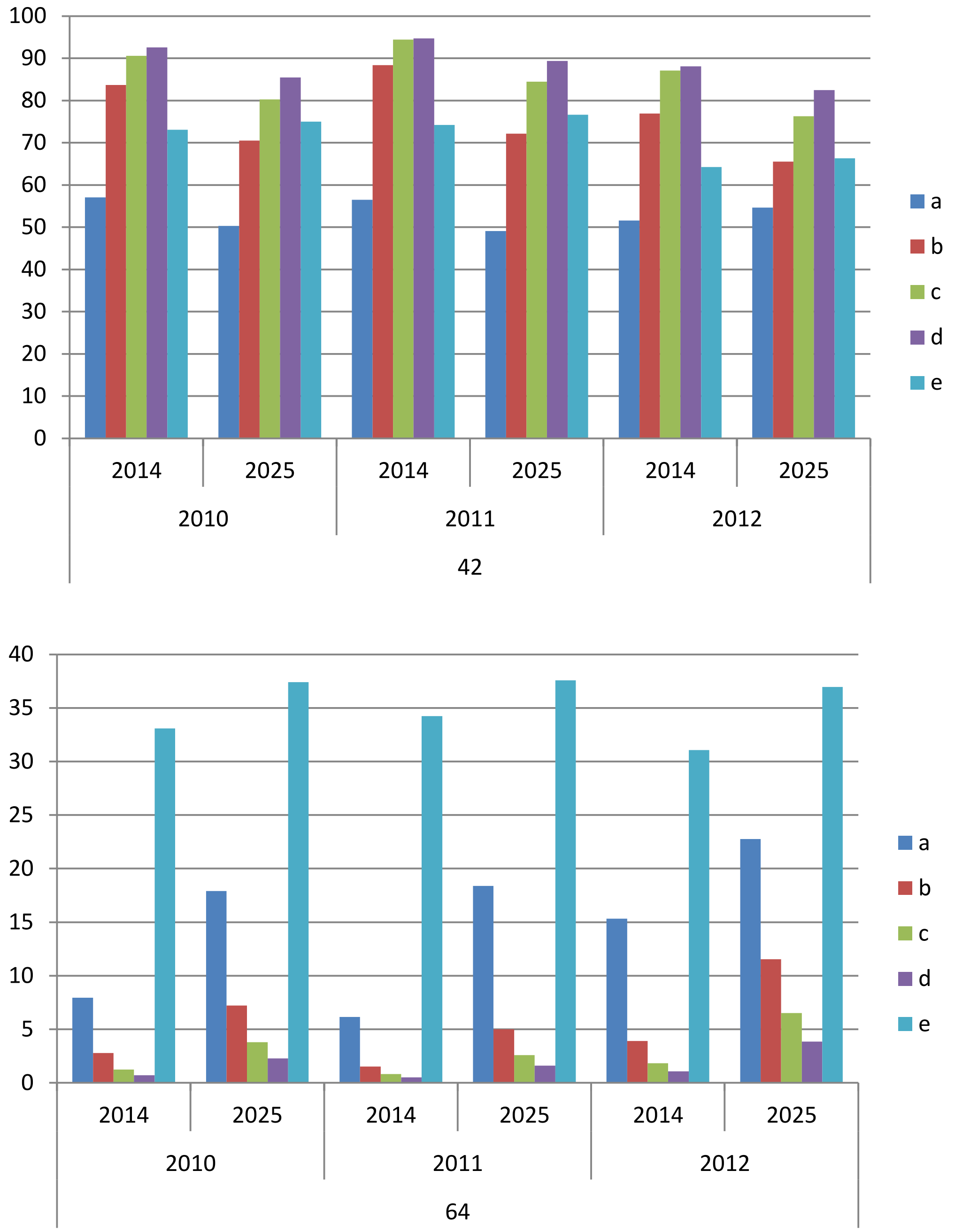
Figure 8: SA-VIC Interconnectors: Heywood and MurrayLink (Lines 47 and 48)



3.2.5 Comparing BassLink and Tarraleah-Waddamana (Lines 42 and 64)

This section compares the congestion between BassLink and Tarraleah-Waddamana in Tasmania (TAS) in more detail. Figure 9 establishes that the complimentary pattern seen in Figure 4 holds under finer resolution. As discussed, the projected increase in congestion on BassLink from Wind Penetration Scenario A to D and decrease in congestion from Scenario D to E suggests a relocatable energy storage solution to address this temporary increase in congestion and redeployment to Tarraleah-Waddamana. The decrease in congestion on BassLink from Scenario D to E reflects increased power from the Cattle Hill Windfarm located in the Liapootah node in TAS (Node 50), reducing import requirements from VIC. The same Cattle Hill Windfarm output also increases congestion on the Tarraleah-Waddamana, a transmission branch with a relatively low thermal MW limit.

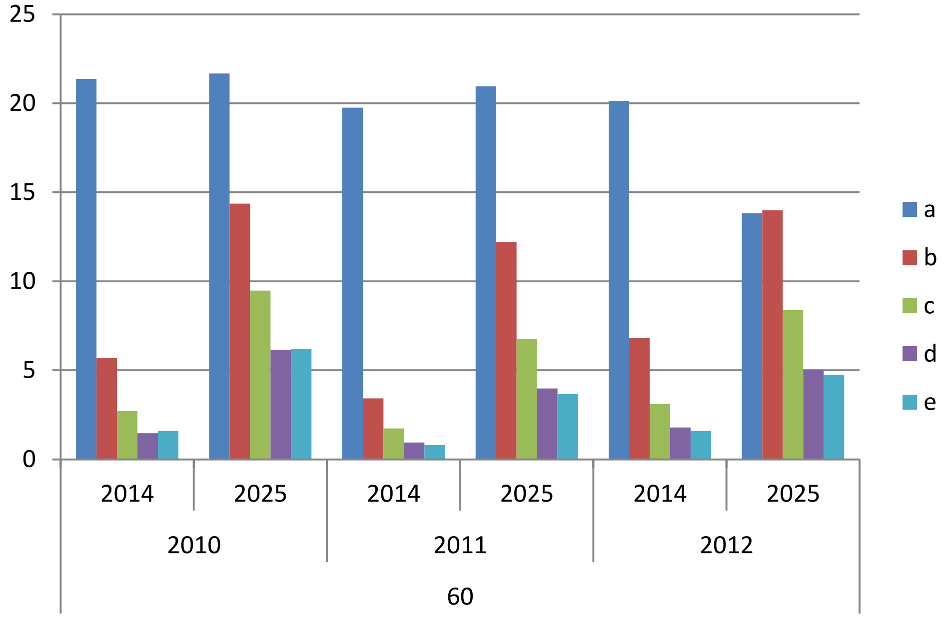
Figure 9: Comparing BassLink and Tarraleah-Waddamana (Lines 42 and 64)



3.2.6 Palmerston-Sheffield TAS (Line 60)

Figure 10 shows the congestion on the Palmerston-Sheffield line in TAS (Line 60). The increase in wind power from Scenario A to E has reduced congestion. The Granville Harbour Windfarm in the Farrell node in TAS (Node 45) commencing in Scenario D partially explains the reduction in congestion. Figure 10 also shows that the rates of congestion increases from project year 2014 to 2025 for all wind power penetration scenarios except for Scenario A in weather year 2012. Furthermore, for wind power penetration Scenarios B to E, the level of congestion is slightly lower in the weather year 2011 when compared to the equivalent results for the other two weather years 2010 and 2012.

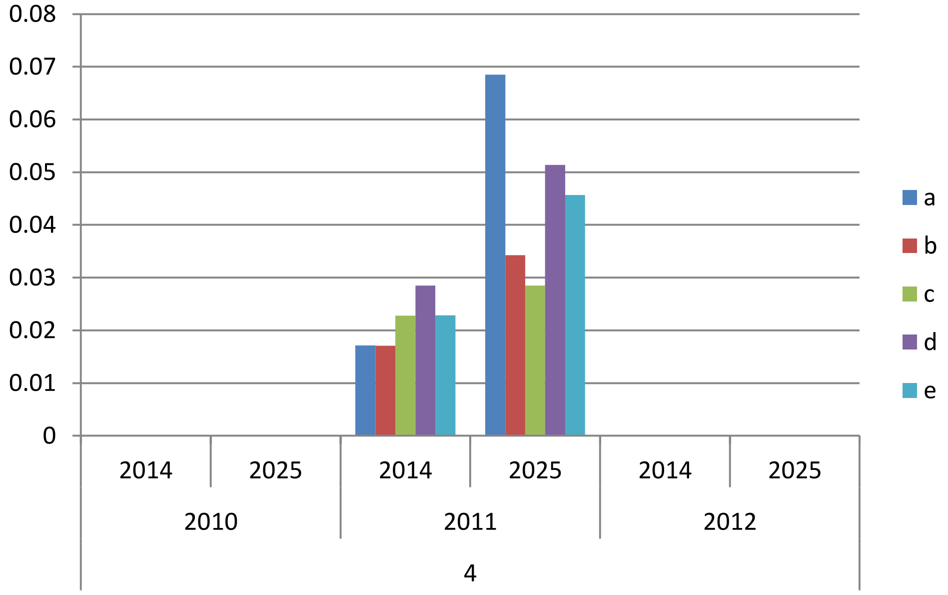
Figure 10: Palmerston-Sheffield TAS (Line 60)



3.2.7 Gladstone-Central West QLD (Line 4)

Figure 11 shows the congestion on the QLD line Gladstone-Central West (Line 4). This congestion is exceedingly small in magnitude and largely weather dependent, being only present in the weather year 2011.

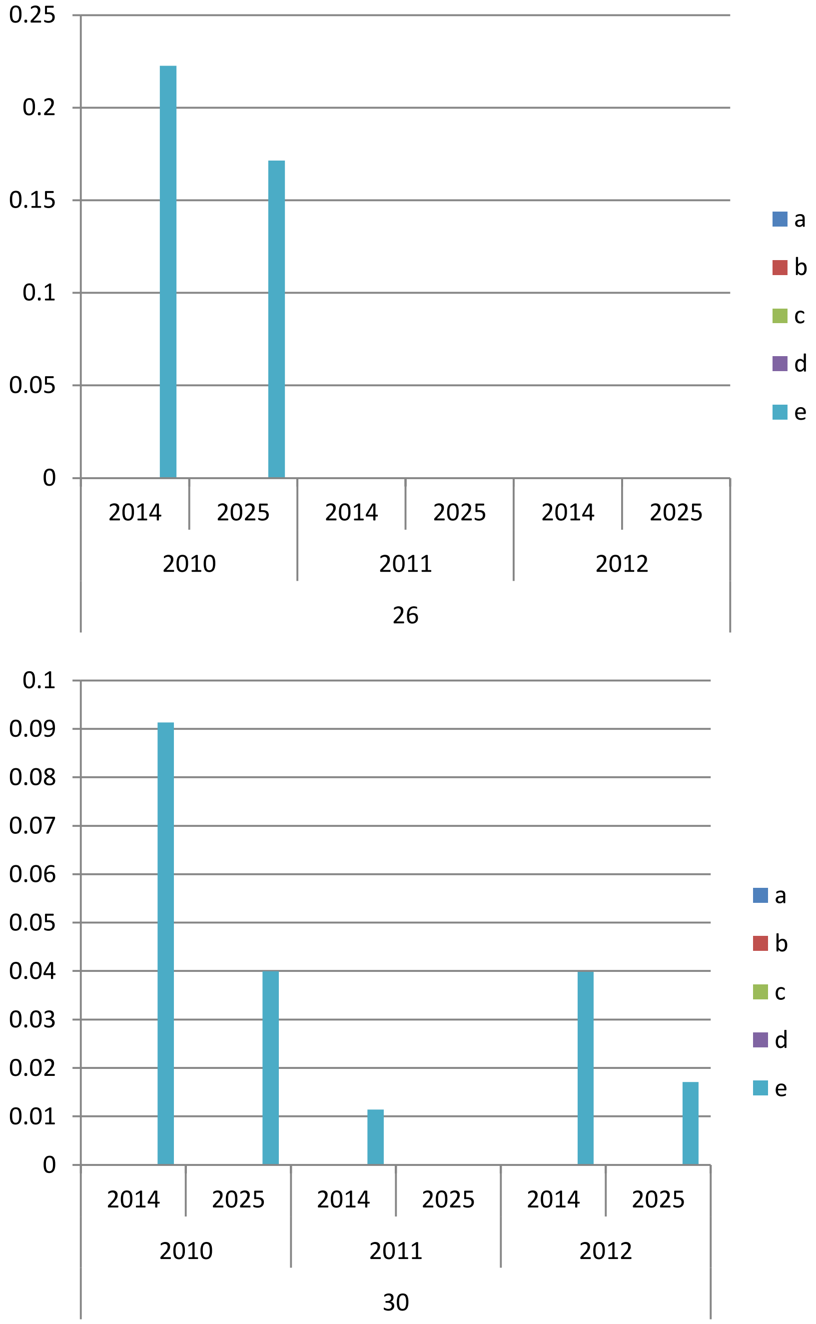
Figure 11: Gladstone-Central West QLD (Line 4)



3.2.8 Marulan-Sydney and Canberra-Wollongong NSW (Lines 26 and 30)

Figure 12 shows the congestion on the two NSW lines Marulan-Sydney (Line 26) and Canberra-Wollongong (Line 30). This congestion is also exceedingly small in magnitude and only present in the highest wind power penetration Scenario E. This reflects the extra congestion from windfarms Conroy's Gap 2 and Yass Valley at Yass, NSW (Node 24) commencing in Scenario E. This expansion in wind power at the Yass node in NSW, (Node 24) in Scenario E follows nearby wind power expansion at the Marulan, NSW (Node 23) and Canberra, ACT (Node 25) nodes in Scenarios C and D. In should also be noted that in both cases, the degrees of congestion evident in Figure 12 declines in magnitude in projection year 2025 relative to projection year 2014, depicting negative growth effects for Scenario E.

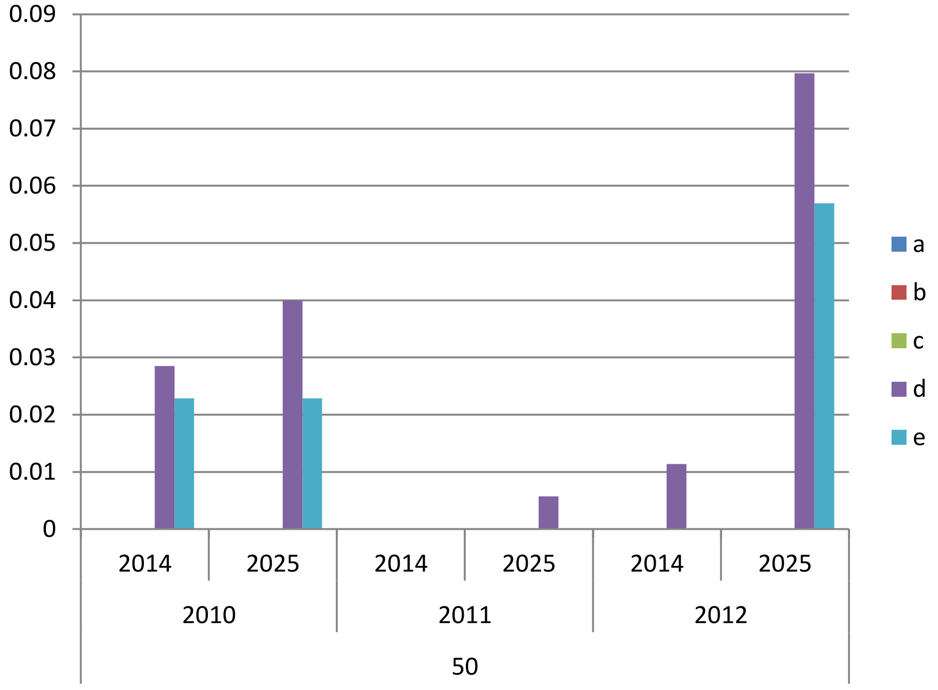
Figure 12: Marulan-Sydney and Canberra-Wollongong NSW (Lines 26 and 30)

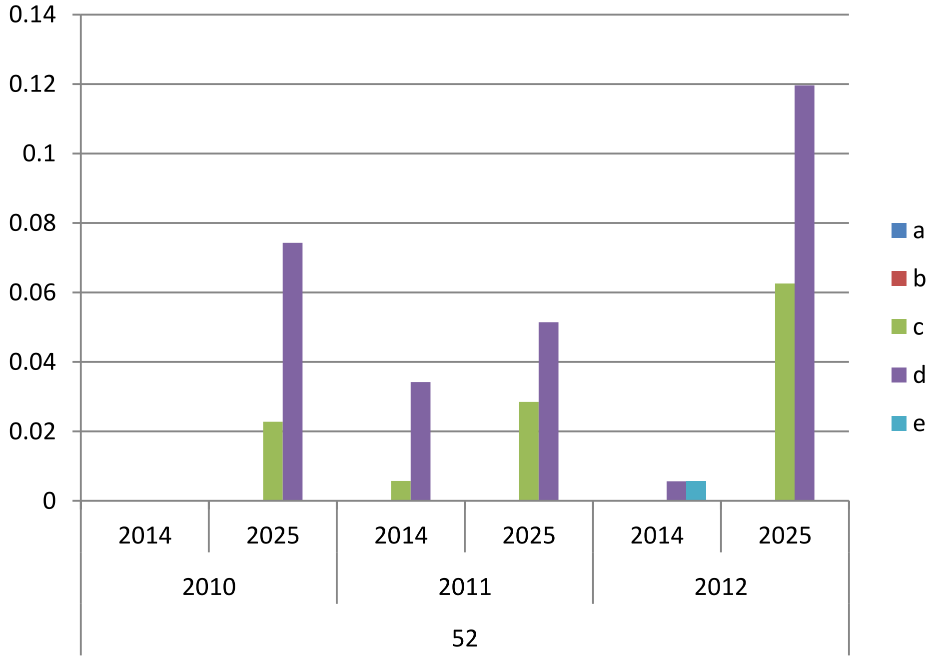


3.2.9 Riverland-South East SA and Greater Adelaide-Mid North SA (Lines 50 and 52)

Figure 13 shows the congestion on two SA transmission lines Riverland-South East (Line 50) and Greater Adelaide-Mid North (Line 52). This congestion is also exceedingly small in magnitude and only present in the higher wind penetration Scenarios. In these two particular lines congestion increases from projection year 2014 to 2015, thus depicting positive growth effects for Scenarios C, D and E (as appropriate).

Figure 13: Riverland-South East and Greater Adelaide-Mid North SA (Lines 50 and 52)

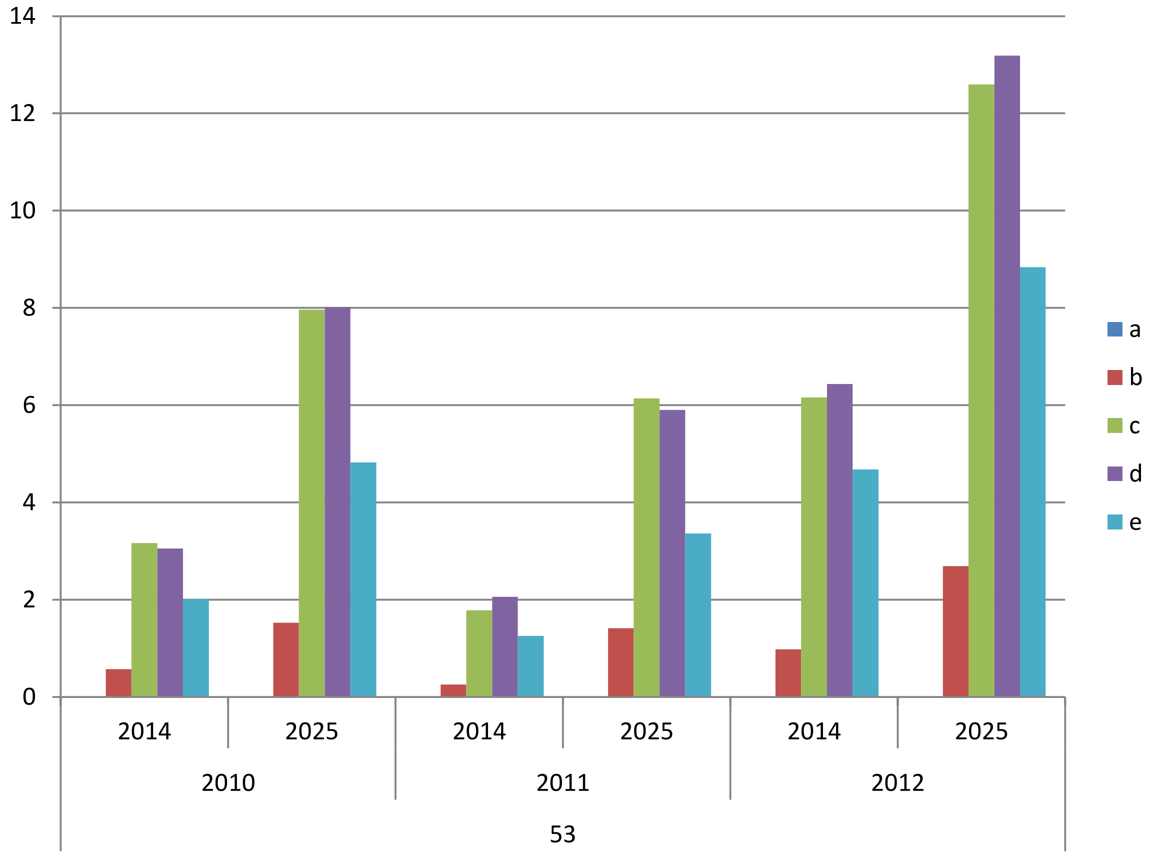




3.2.10 Mid North SA – Riverland SA (Line 53)

Figure 14 shows the congestion on the SA transmission line Mid North SA – Riverland (Line 53). This congestion is small and absent in the 'no wind' Scenario A. The increase in congestion from Scenario A to D and decrease from Scenario D to E suggests a mobile energy storage solution. The congestion increases from projection year 2014 to 2025 for all scenarios, reflecting an underlying growth in demand. Congestion is more subdued for the weather year 2011 when compared with the other two weather years 2010 and 2012.

Figure 14: Mid North – Riverland SA (Line 53)



It should be noted that while the incidence of congestion on the three intrastate SA lines 50, 52 and 53 have tended to be episodic and at higher wind power penetration rates, the actual magnitudes of the congestions rates are still relatively low, being under 13 percent. As such, they are not indicative of transmission branches experiencing serious congestion problems requiring urgent augmentation or storage solutions.

4 Discussion

We have conducted a sensitivity analysis of the effect of increasing the number of wind turbine generators (WTG) on transmission line congestion 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 congestion. We used simulations from the Australian National Electricity Market Model (Wild, Bell & Foster 2015) to perform the sensitivity analysis.

Table 2 shows congestion on only 14 of the 68 transmission lines in the ANEM Model (Wild, Bell & Foster 2015). Notably, these 14 congested transmission lines include all the NEM's six interstate interconnectors and eight of the intrastate transmission lines although only three of the intrastate transmission lines exhibited any significant degree of congestion. The other five intrastate transmission lines exhibited extremely little congestion.

Comparing Figure 1, Figure 2 and Figure 3 shows that the wind penetration effect from Scenario A to E on congestion was far larger than the growth in electricity demand effect from year 2014 to 2025 and the weather effect between the years 2010 and 2012. These figures also show that the effect of increasing wind power on congestion is anything but simple, requiring unique consideration of each line.

Figure 5 compares the congestion on the two QLD to NSW interconnectors, QNI and DirectLink. These interconnectors exhibit complimentary patterns with respect to the three effects: wind penetration, growth in electricity demand and weather. DirectLink experiences more congestion from increasing wind and QNI the converse. There is a requirement to augment the thermal capacity of DirectLink with future increases in wind penetration.

Figure 6 shows the congestion on the NSW to VIC interconnector (Tumut to Regional VIC) that proved the most volatile of all the interconnectors. The introduction of wind power from Scenario A to B reduces congestion on this interconnector. This reduction in congestion is most noticeable in 2025 when growth in electricity demand would otherwise increase congestion. Contributing to this volatility are the Silverton Stage I and II Windfarms in the Tumut node in NSW (Node 26) commencing operation in Scenarios C and D, respectively. The output from these windfarms is large compared to the capacity of this interconnector.

Figure 2 show a weather induced congestion relationship between the NSW-VIC interconnector and the interconnectors: QNI, DirectLink and MurrayLink.

In Figure 7, the congestion on the VIC to TAS interconnector, BassLink, shows an interesting pattern of increasing congestion with increasing wind power from Scenario A to D but decrease in congestion from Scenario D to E. This situation suggests using temporary relocatable energy storage as a solution rather than traditional approach of laying more lines. Figure 9 compares the Tarraleah-Waddamana and BassLink transmission lines congestion patterns. These patterns are complimentary, which would make the Tarraleah-Waddamana a suitable recipient of the relocatable energy storage but there are technological and economic limitation to relocatable energy storage solutions.

Currently, the world's largest lithium battery is 36 MWh in Zhangbei, Hebei Province, China and the largest hydrogen fuel cell park is 59 MW in Hwasung City, South Korea that uses hydrogen from converted natural gas but electrolysis can also source the hydrogen. These provide an indication of the current limitations for relocatable energy storage solutions. Thus, grid support involving relocatable energy storage capacities of hundreds of MW would remain technical and economically challenging.

Two alternative solutions involve rescheduling the deployment of windfarms and building pump-storage hydroelectricity. (1) Rescheduling the construction of the windfarm would ameliorate the spike in congestion on BassLink in Scenario D. For instance, currently, the Cattle Hill 1 and 2 windfarms within the Liapootah node (Node 50) are scheduled for construction in Scenario E. If their construction were brought forward to Scenario C, this would avoid the spike in congestion on BassLink in Scenario D. (2) The introduction of pump-storage hydroelectricity in TAS would allow better utilisation of Basslink and better manage the intermittency of wind power and the mismatch between wind speed and electricity demand (Bell, Wild & Foster 2015, tbl. 6).

Figure 8 shows little relationship between the congestion patterns on the SA to VIC Interconnectors, Heywood and MurrayLink. This is unlike the complimentary congestion patterns between the QLD to NSW interconnectors, QNI and DirectLink shown in Figure 5. The large congestion increase on MurrayLink with an increase in wind power from Scenario A to E will act as an impediment to the export of surplus wind power from SA to VIC without augmentation. The congestion pattern on Heywood is more complex. From Scenario A to B, wind power decreases congestion and from Scenario B to D congestion increases, and from Scenario D to E congestion decreases. This situation suggests a relocatable energy storage solution or rescheduling of windfarm construction.

The congestion pattern for the SA intrastate transmission line Mid North – Riverland (Line 53) is similar to Heywood. This suggests a relocatable energy storage solution is appropriate. See Figure 14.

Finally, in Figure 10 the TAS intrastate transmission line Palmerston-Sheffield (Line 60) exhibits decreasing congestion with increasing wind power.

5 Conclusion

We find the congestion landscape amongst the transmission lines in the NEM shifting 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) of 41TWh. This shifting congestion requires careful consideration of appropriate congestion solutions for each transmission line. The interstate interconnectors most strongly exhibit changes in congestion patterns. In comparison, significant changes in congestion only affected three of the intrastate transmission lines.

Australia’s 2020 renewable electricity target by 2020 (somewhere between 23% and 30% depending upon the 2020 demand projection adopted) 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 adopt a more ambitious renewable energy target more commensurate with its international responsibility. This future RET increase would exacerbate the shift in congestion patterns within the NEM evident in increasing wind power from 0% to the 20%-30% target.

The advent of more ambitious targets and shifting congestion patterns in the NEM coincides with major technological developments in energy storage. The advent of more affordable relocatable energy storage provides a valuable additional tool to solve congestion problems. This is especially the case when a decrease in congestion will follow further wind power deployment. However, currently, the largest deployment for battery storage is 36 MWh and for hydrogen fuel cells is 59 MW. Alternatives include rescheduling windfarm construction and pump-storage hydroelectricity. Adopting the new energy storage technologies and scheduling of windfarm construction present an institutional challenge for network service providers whose traditional solution to solving congestion was building more transmission and distribution lines.

A further institutional challenge for network service provides is the shift in focus from providing infrastructure to meet the increase in demand for electricity to providing infrastructure to meeting the increase in supply from renewable energy. All these changes are occurring around a fall in electricity demand, which is challenging the business model for network service provider’s revenue base.

The recent focus of network service providers was meeting demand side considerations. This requires expanding to supply side considerations to incorporate wind power more fully into the NEM, for instance the projected growth in congestion on MurrayLink and DirectLink. A precedent for supply side considerations has been set in the more distant past when coal generators were in effect subsidised to connect to the transmission grid. This changing environment for the transmission system requires reflection in the Regulatory Investment Test for Transmission (RIT-T).

Wind power has proved itself internationally as part of the solution to climate change and positioned to become a major part of a portfolio of renewable energy sources to replace the coal generation fleet in the NEM. This transformation will require careful planning of transmission augmentation and appropriate deployment of energy storage.

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