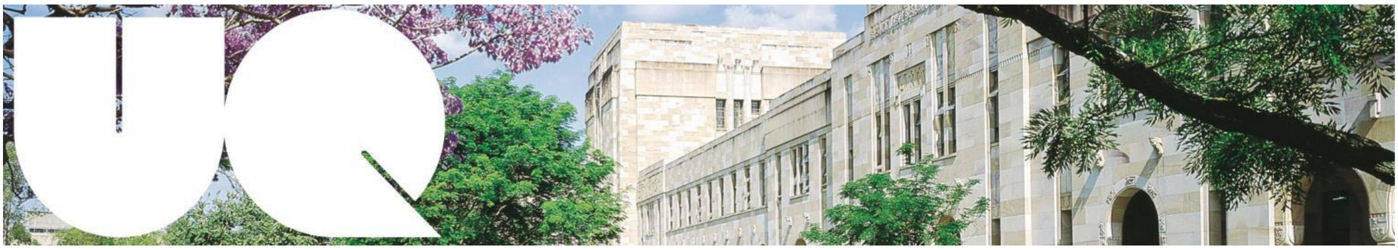

NEMLink: Augmenting the Australian National Electricity Market transmission grid to facilitate increased wind turbine generation and its effect on transmission congestion

EEMG Working Paper 9-2015 - Version 15

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Preface

This report investigates *'NEMLink: Augmenting the Australian National Electricity Market transmission grid to facilitate increased wind turbine generation and its effect on transmission congestion'.* 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 report is part of a 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 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 interim and final reports.

Table 1: The project's publications

Journal articles:
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 increased wind turbine generation and its effect on transmission congestion*, EEMG Working Paper 9-2015, The University of Queensland, Brisbane, Australia.

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

Interim reports:

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

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

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

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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
AER	Australian Energy Regulator
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
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

We identified constraints in the national electricity market (NEM) transmission grid affecting the beneficial deployment of wind turbine generation to reduce both wholesale spot prices and carbon dioxide emissions (Bell et al. 2015a, 2015b, 2015c, 2015d, 2015f). The higher penetration of wind turbine generation required to address climate change and reduce wholesale spot prices will require either energy storage or augmenting the NEM's transmission grid to overcome the limitations of grid that was primarily built to accommodate supply from a coal generation fleet. This coal generation fleet is a major source of carbon dioxide emissions in Australia and cause of climate change. The coal fleet is nearing the end of its economic life and the opportunity presents to phase out the coal fleet and replace with renewable energy but augmenting the existing transmission structure is required to ensure a smooth transition.

Our findings from a wind speed-electricity demand correlation analysis in the NEM shows that the greatest benefit from wind turbine generation comes from connecting the NEM's peripheral States: Queensland (QLD), South Australia (SA) and Tasmania (TAS) (Bell et al. 2015f). An improved peripheral connection would help both ameliorate the intermittency of wind turbine generation to improve system stability and improve wind turbine generators' ability to match changes in electricity demand. However, delivering these benefits requires improving the transmission capacity through both New South Wales (NSW) and Victoria (VIC).

This report primarily aims to investigate *augmenting the Australian National Electricity Market transmission grid to facilitate higher wind turbine generation.* Specifically we examine the effect of NEMLink on transmission congestion in the National Electricity Market. NEMLink is a proposed major augmentation of the transmission grid outlined in the National Transmission Network Development Plan (AEMO 2010a, 2010b, 2011a, 2011b). Wild et al. (2015, figs. 2-6) provides stylised topology diagrams of the transmission grid used in this project and those transmission lines that are part of NEMLink are coloured red. Wild et al. (2015, tbls. 2 & 3) provide the capacity of the lines augmented as part of NEMLink.

We consider the effect of NEMLink on transmission congestion under five different levels of wind penetration. 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. The ANEM model report (Wild et al. 2015) provides a comprehensive explanation of the five levels of wind penetration.

Bell et al. (2015c) examine the effect of the five wind penetration levels on transmission congestion without the NEMLink augmentation. We use this congestion analysis without NEMLink report as a baseline in this report.

The following outline provides a structure for the remainder of the report. Section 2 discusses the methodology for the sensitivity analysis and provides an outline of the *'Australian National Electricity Market (ANEM) model version 1.10'* (Wild et al. 2015). Section 3 presents the results from the sensitivity analysis. Section 4 discusses the results and Section 5 concludes the report.

2 Methodology:

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 weather 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 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 by each generator (half hourly),
- power flow on each transmission line (half hourly), and
- carbon dioxide emissions for each generator (daily).

2.2 NEMLink sensitivity analysis

The transmission lines augmented for NEMLink (AEMO 2010a, 2010b, 2011a, 2011b) are shown in Wild et al. (2015, Sec. 2). We analyse the sensitivity of transmission flows on NEMLink to evaluate the change in transmission congestion. Bell et al. (2015c) analyse transmission congestion in the original NEM transmission grid without NEMLink. The results in Bell et al. (2015c) form the baseline for the sensitivity analysis.

2.3 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).

2.4 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 difference between the three baseline years 2010 to 2012 considers the effect of differing annual weather systems on the dynamics of the NEM and wind generation output of the different wind power penetration scenarios. In contrast, the projections years 2014 to 2025 consider the effect of growth in electricity demand on the dynamics of the NEM.

3 Results: Transmission Congestion

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 transmission line numbers to the topology of the transmission network.

This section has the following structure. Section 1 evaluates changes in congestion induced by NEMLink and identifies those lines still congested. Section 2 compares NEMLink transmission line congestion between transmission lines to identify system wide effects and Section 3 examines individual lines in detail to evaluate the observations made in Section 2 in higher resolution.

3.1 The change in transmission line congestion induced by NEMLink

In this section, we discuss the change in transmission line congestion induced by NEMLink and identify those lines still congested in the NEMLink configuration. We identify those congested lines to evaluate the effect of three factors on their congestion. The three factors include wind power penetration, weather and demand growth effects. The project report Bell et al. (2015c) has already analysed the effect of the three factors on the original unaugmented grid.

Table 2 shows the effect of NEMLink on transmission congestion and consolidates the information in Table 3, Table 4 and Table 5. Table 2 uses "XX" to denote those transmission lines with sizable congestion. In these tables, the four lines shaded in dark grey are part of the NEMLink augmentation. The first three are Interconnectors but the last line Mid North-Riverlands (line 53) is an intrastate transmission branch in SA. The four lines shaded light grey are interconnectors but excluded from the NEMLink augmentation.

Table 2: The effect of NEMLink on congestion

Effect of NEMLink on congestion	Central West-Gladstone	QNI	DirectLink	Sydney-Marulan	Wollongong-Canberra	Tumut, NSW-Dederang, VIC	Regional Vic-Tumut, NSW	BassLink	Heywood Interconnector	MurrayLink	Riverland-South East SA	Adelaide-Mid North	Mid north-Riverland SA	Palmerston-Sheffield	Tarraleah-Waddamana
	Line 4	Line 11	Line 14	Line 26	Line 30	Line 36	Line 37	Line 42	Line 47	Line 48	Line 50	Line 52	Line 53	Line 60	Line 64
Elimination		X		X			X			X			X		
Reduction	X													XX	XX
Increase			XX		XX	X		XX	XX		X				
Mixed												X			

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Table 3 and Table 4 present transmission line congestion with and without NEMLink. We measure congestion as the percentage of the time transmission lines have reached their maximum thermal capacity during the year. In comparison, Table 5 presents the percentage point reduction in congestion induced by NEMLink. Simply, Table 5 is the difference between Table 3 and Table 4 that is Table 3 less Table 4.

Table 4 shows the transmission lines with congestion in the unaugmented original NEM grid. Those congested include Lines 4, 11, 14, 26, 30, 37, 42, 47, 48, 50, 52, 53, 60 and 64. Table 3 shows that NEMLink has eliminated congestion on Lines 11, 26, 37, 48 and 53 for all wind power, weather and demand growth scenarios. Those lines with zero congestion are no longer of interest to this report. In contrast, NEMLink has only reduced congestion in Lines 4, 60 and 64 and increased congestion on Lines 14, 30, 36, 42, 47, 50. However, the effect of NEMLink on Line 53 is mixed. Notably, the now congested NSW-VIC interconnector Line 36 had zero congestion in the original unaugmented grid.

In the following sections, we examine the effect of the three factors on the congested lines in the NEMLink augmented grid. However, some of the lines experience extremely little congestion and their inclusion would crowd the graphical presentation for such a tiny effect. Therefore, we examine those transmission lines with sizable congestion marked with “XX” in Table 2 and those with smaller congestion separately.

Table 3: With NEMLink 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	0.00	35.80	0.00	14.40	0.00	80.29	3.12	0.00	0.00	0.00	0.00	9.51	5.01
a	2010	2025	0.00	0.00	38.31	0.00	22.96	0.00	65.07	0.97	0.00	0.00	0.00	0.00	20.34	11.95
a	2011	2014	0.01	0.00	41.92	0.00	14.64	0.00	85.81	1.68	0.00	0.00	0.00	0.00	5.30	2.21
a	2011	2025	0.04	0.00	41.25	0.00	35.63	0.00	63.68	0.67	0.00	0.00	0.00	0.00	19.28	7.57
a	2012	2014	0.00	0.00	36.07	0.00	29.32	0.00	72.84	4.64	0.00	0.00	0.00	0.00	8.05	7.36
a	2012	2025	0.00	0.00	38.29	0.00	38.65	0.00	62.94	0.70	0.00	0.00	0.00	0.00	13.18	18.14
e	2010	2014	0.00	0.00	80.99	0.00	11.96	0.00	78.15	14.14	0.00	0.05	0.00	0.00	0.42	32.33
e	2010	2025	0.00	0.00	73.53	0.00	11.48	0.00	84.18	17.23	0.00	0.09	0.00	0.00	3.19	34.91
e	2011	2014	0.01	0.00	90.37	0.00	5.82	0.00	76.87	18.23	0.00	0.00	0.00	0.00	0.30	33.68
e	2011	2025	0.02	0.00	84.21	0.00	6.80	0.00	84.19	22.98	0.00	0.04	0.01	0.00	1.11	35.62
e	2012	2014	0.00	0.00	80.58	0.00	11.57	0.00	70.79	18.10	0.00	0.15	0.00	0.00	0.25	28.92
e	2012	2025	0.00	0.00	73.12	0.00	11.27	0.00	76.67	21.36	0.00	0.47	0.02	0.00	1.22	31.48

Table 4: Without NEMLink 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	49.53	21.13	0.00	0.00	52.14	57.07	1.65	3.22	0.00	0.00	0.00	21.38	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	40.22	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	54.46	18.00	0.00	0.00	69.72	51.44	1.27	6.16	0.00	0.00	0.00	20.19	15.37
a	2012	2025	0.00	56.43	22.63	0.00	0.00	87.53	54.65	0.06	16.04	0.00	0.00	0.00	13.79	22.80
e	2010	2014	0.00	16.55	67.55	0.22	0.09	52.19	73.08	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	41.15	74.20	1.83	74.33	0.00	0.00	1.26	0.79	34.24
e	2011	2025	0.05	14.84	76.79	0.00	0.00	43.25	76.64	0.82	69.84	0.00	0.00	3.36	3.67	37.57
e	2012	2014	0.00	18.21	66.60	0.00	0.04	48.69	64.42	2.89	67.37	0.00	0.01	4.69	1.60	30.89
e	2012	2025	0.00	26.57	58.65	0.00	0.02	52.02	66.49	1.07	60.46	0.06	0.00	8.85	4.76	36.79

Table 5: With and without NEMLink percentage point difference of time transmission lines are at maximum for wind penetration scenarios A and E

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	-49.53	14.67	0.00	14.40	-52.14	23.22	1.47	-3.22	0.00	0.00	0.00	-11.87	-2.92
a	2010	2025	0.00	-51.46	14.33	0.00	22.96	-69.32	14.74	0.62	-7.38	0.00	0.00	0.00	-1.33	-5.95
a	2011	2014	-0.01	-40.22	10.14	0.00	14.64	-53.12	29.30	0.74	-2.07	0.00	0.00	0.00	-14.45	-3.94
a	2011	2025	-0.03	-43.87	11.06	0.00	35.63	-71.50	14.58	0.57	-8.47	0.00	0.00	0.00	-1.66	-10.82
a	2012	2014	0.00	-54.46	18.07	0.00	29.32	-69.72	21.39	3.37	-6.16	0.00	0.00	0.00	-12.14	-8.01
a	2012	2025	0.00	-56.43	15.66	0.00	38.65	-87.53	8.29	0.64	-16.04	0.00	0.00	0.00	-0.61	-4.66
e	2010	2014	0.00	-16.55	13.45	-0.22	11.87	-52.19	5.07	11.32	-69.24	0.02	0.00	-2.01	-1.17	-0.77
e	2010	2025	0.00	-26.52	14.19	-0.17	11.44	-52.18	9.21	15.60	-64.54	0.07	0.00	-4.82	-3.00	-2.49
e	2011	2014	-0.01	-7.41	7.02	0.00	5.81	-41.15	2.68	16.40	-74.33	0.00	0.00	-1.26	-0.50	-0.55
e	2011	2025	-0.03	-14.84	7.42	0.00	6.80	-43.25	7.55	22.16	-69.84	0.04	0.01	-3.36	-2.56	-1.95
e	2012	2014	0.00	-18.21	13.98	0.00	11.53	-48.69	6.38	15.21	-67.37	0.15	-0.01	-4.69	-1.35	-1.97
e	2012	2025	0.00	-26.57	14.46	0.00	11.25	-52.02	10.18	20.30	-60.46	0.42	0.02	-8.85	-3.54	-5.30

3.2 Inter transmission line comparison to identify system wide effects

We examined system wide changes in percentage point congestion induced by NEMLink 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. We examine the NEMLink induced change in congestion under the following three effects.

- 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

3.2.1 Wind penetration effect shown between scenarios A and E

Figure 1 compares with and without NEMLink 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 41TWh LRET. Figure 1 is the average across the baseline weather years 2010 to 2012 and the projection growth years 2014 and 2025.

Panel (a) without NEMLink shows 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 thermal maximums.

In Panel (b) with NEMLink, DirectLink shows a 44 percentage points change in congestion induced by the change in wind-power penetration from Scenario A to E, which is the largest change. NEMLink has reduced the range of percentage points of congestion. The smallest change is over 16 percentage points for Palmerston-Sheffield (Line 60).

Comparing Panel (a) and Panel (b), there are some interesting dynamics occurring between the Interconnectors QNI and DirectLink and between MurrayLink and Heywood. QNI and DirectLink both interconnect QLD and NSW. These interconnectors exhibit an inverse relationship in Panel (a). Bell et al. (2015c, Sec. 3.2.1) discuss the reasons for this relationship in detail. The introduction of NEMLink has eliminated congestion on QNI but slightly exacerbated the existing high rates of congestion on DirectLink present under the 'no NEMLink' baseline. However, Directlink and its surrounding 132 kV network have a limited transfer capacity of 180 MW. Thus, it is not surprising that this line would be a serious candidate for augmentation under both the 'NEMLink' and 'no NEMLink' network structures.

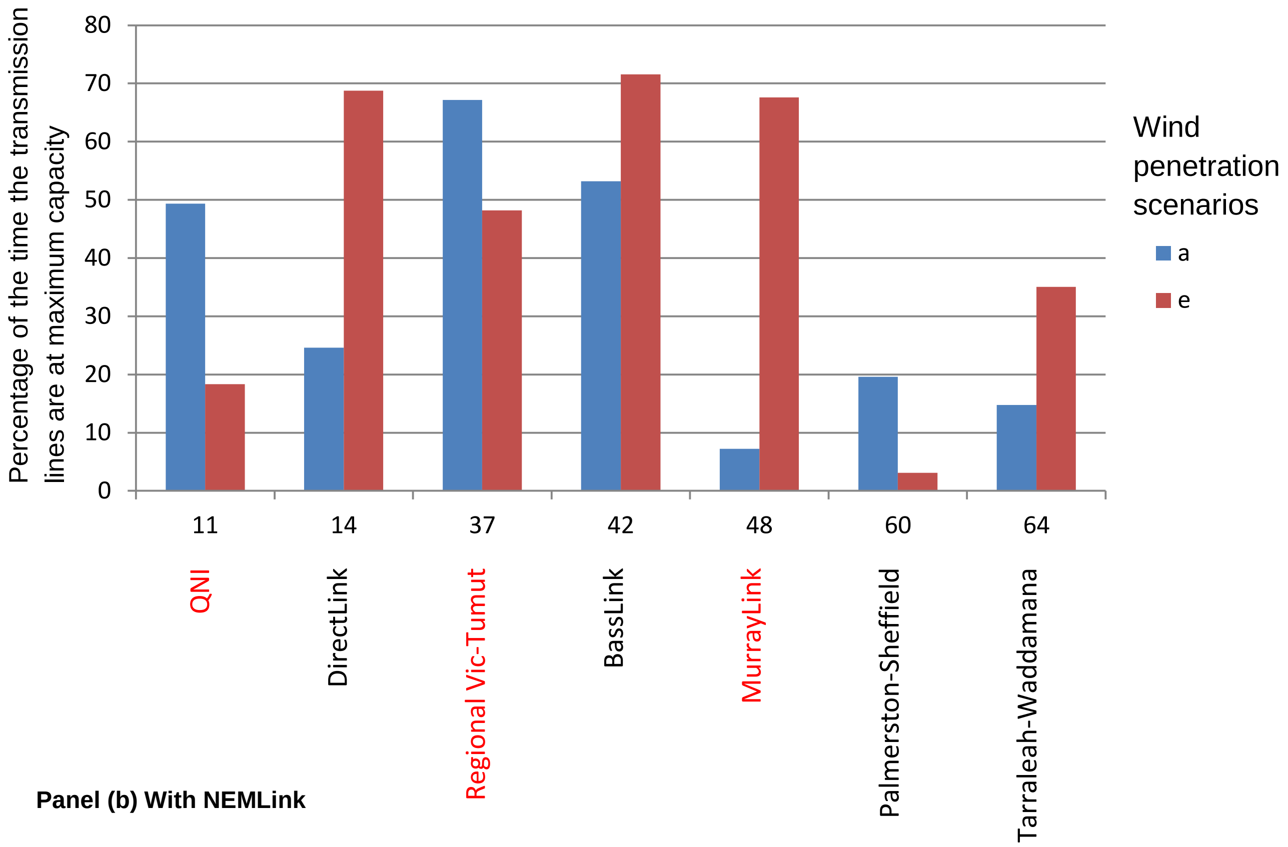
MurrayLink and Heywood both interconnect SA and VIC. Similarly, the introduction of NEMLink has eliminated congestion in MurrayLink but has slightly exacerbated congestion on Heywood particularly under Scenario E. The inclusion of the large Ceres windfarm in the Adelaide Node under Scenario E is a likely cause of the congestion on Heywood. The AER has recently approved an augmentation of the Heywood Interconnector. This would go some way to moderating or eliminating congestion effects on this line under Scenario E.

Regarding two NSW-VIC interconnectors Lines 36 and 37, the introduction of NEMLink has eliminated congestion on Line 37 but has caused slight congestion on the previously uncongested Line 36. Section 3.3.2 indicates congestion rates on line 36 are less than 6 per cent and diminish over the projection period 2014 to 2025 to a range of between 1 to 3 percent.

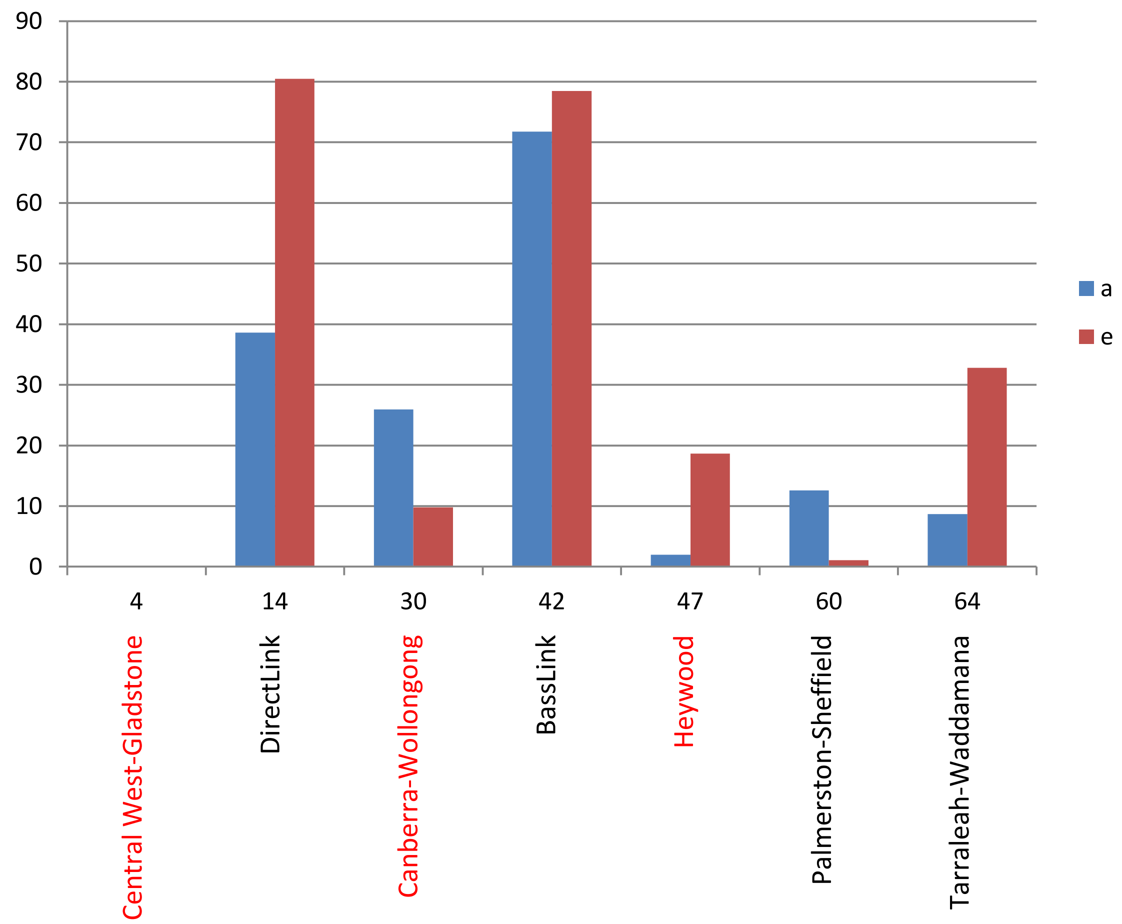
Finally, the NEMLink augmentation excludes BassLink in this report. The submarine HVDC cable is the most capital costly interconnector augmentation. However, both the higher penetration of wind and NEMLink induce slightly more congestion in BassLink, which indicate a higher benefit from augmenting BassLink. NEMLink induces a slight reduction in congestion on both TAS intrastate lines Palmerston-Sheffield and Tarraleah-Waddamana. Lastly, the wind penetration effect is by far the largest of the three effects. Our wholesale spot price report (Bell et al. 2015e) discusses the effects of this congestion on price differential between TAS and the other mainland NEM states.

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

Panel (a) Without NEMLink



Panel (b) With NEMLink



3.2.2 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.

Without NEMLink in Panel (a) shows 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).

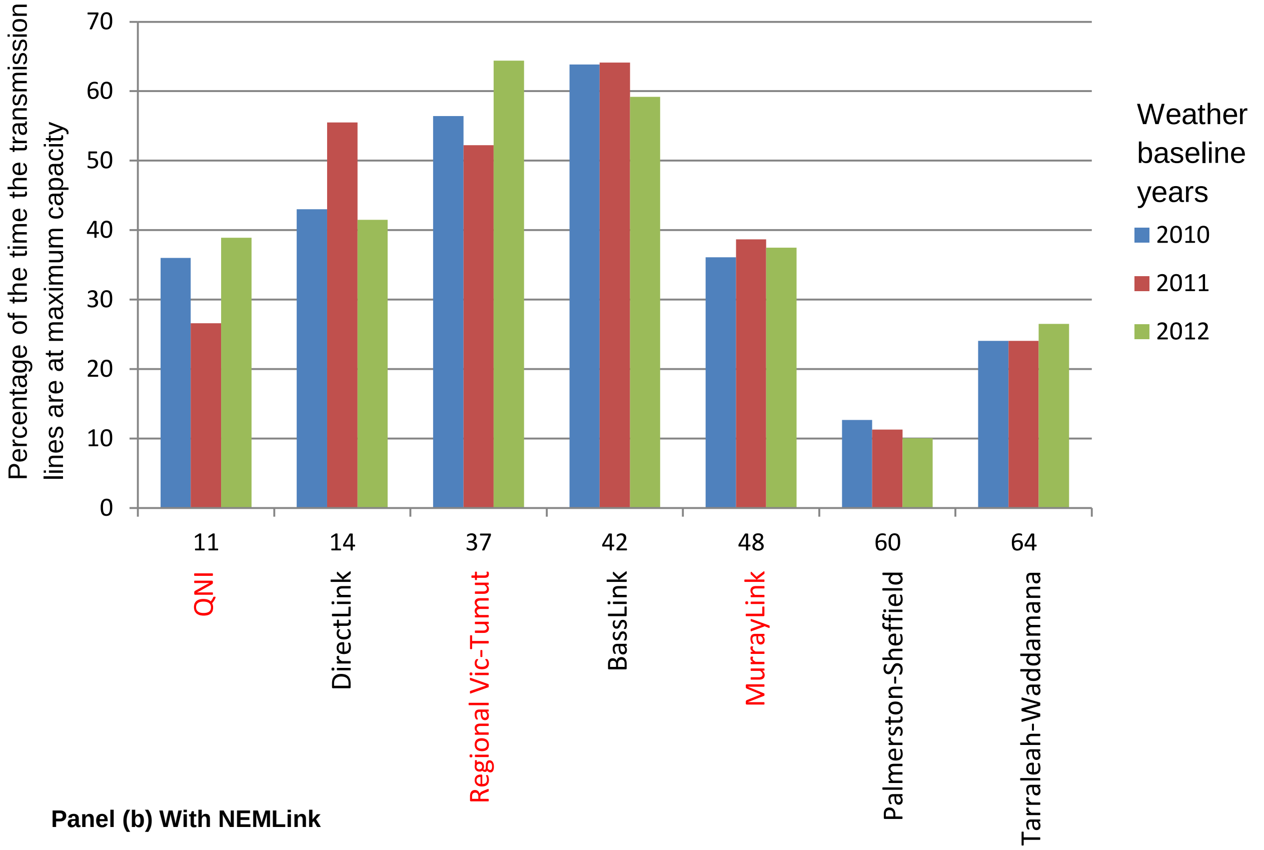
With NEMLink in Panel (b) shows the change in the proportion of time the transmission lines are at their maximum capacity is about 7 percentage points for DirectLink (Line 14) BassLink (Line 42). The effect of NEMLink on weather induced congestion on DirectLink is to reduce variability and for BassLink to increase variability. The effects of NEMLink on weather induced variability in congestion on Palmerston-Sheffield (Line 60) and Tarraleah-Waddamana (Line 64) is slight.

Comparing Panel (a) and Panel (b), the overall NEMLink effect is to increase in congestion on DirectLink and BassLink and reduce congestion on Palmerston-Sheffield (Line 60) and Tarraleah-Waddamana (Line 64).

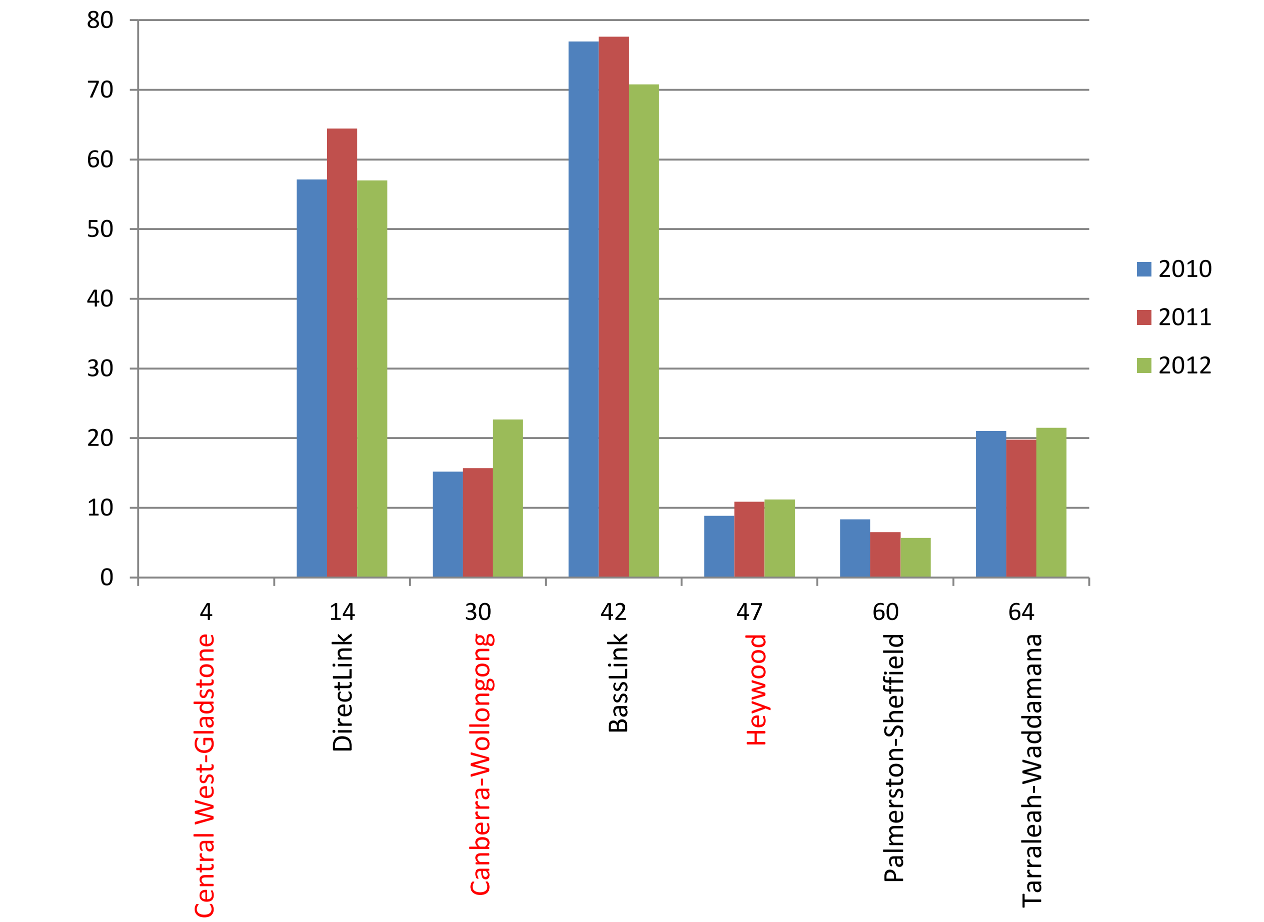
The weather effect is the second largest effect.

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

Panel (a) Without NEMLink



Panel (b) With NEMLink



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3.2.3 Growth in electricity demand effect shown in the difference between projection years 2014-25

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 at their maximums. 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.

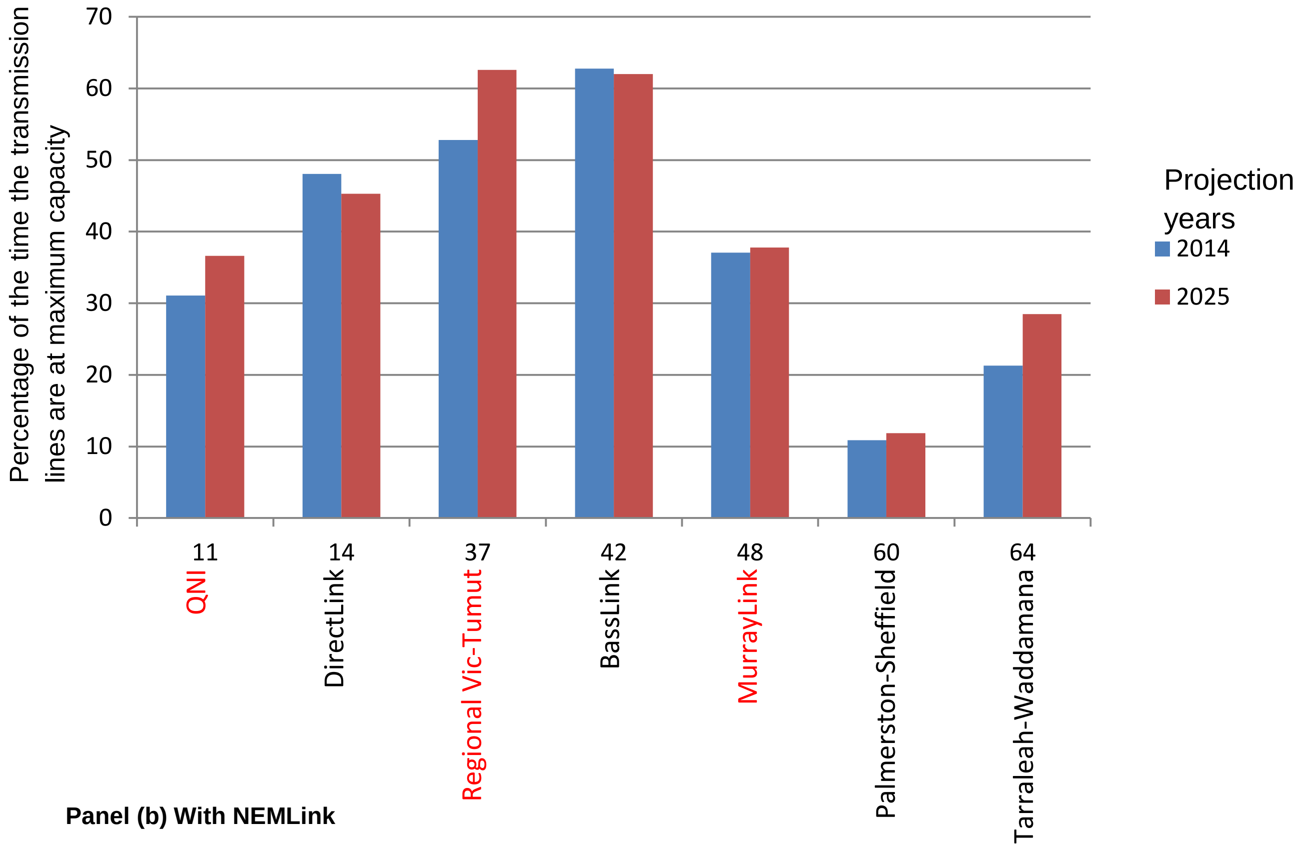
Without NEMLink in Panel (a), congestion increases for lines 11, 37, 48, 60 and 64 but lines 14 and 42 experience a decrease. The largest growth effect is for line 37, which is slightly less than 10 percentage points.

Comparing the patterns of transmission line congestion in Panel (a) and (b) shows the general direction, that is increase or decrease from 2014 to 2025, is the same with or without NEMLink. However, the magnitudes differ.

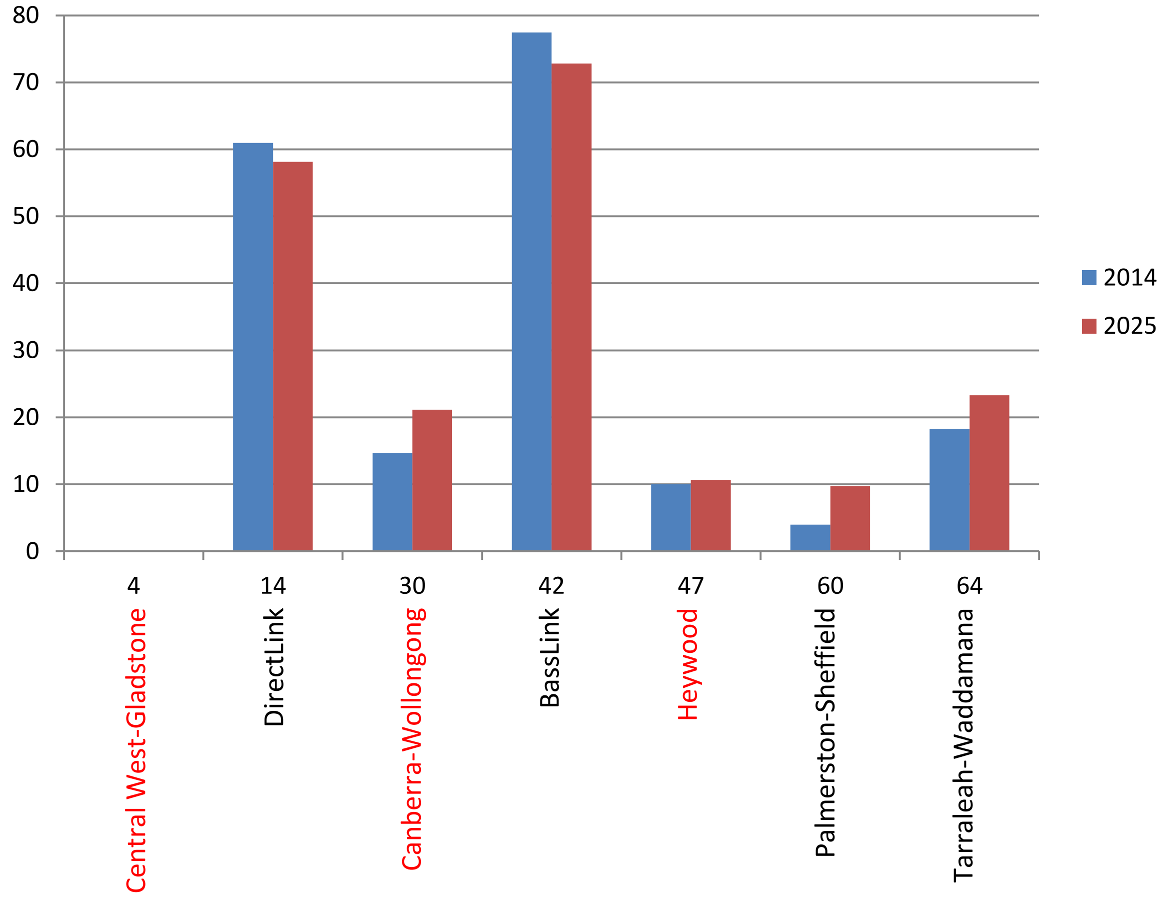
This growth effect is the smallest of the three effects.

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

Panel (a) Without NEMLink



Panel (b) With NEMLink



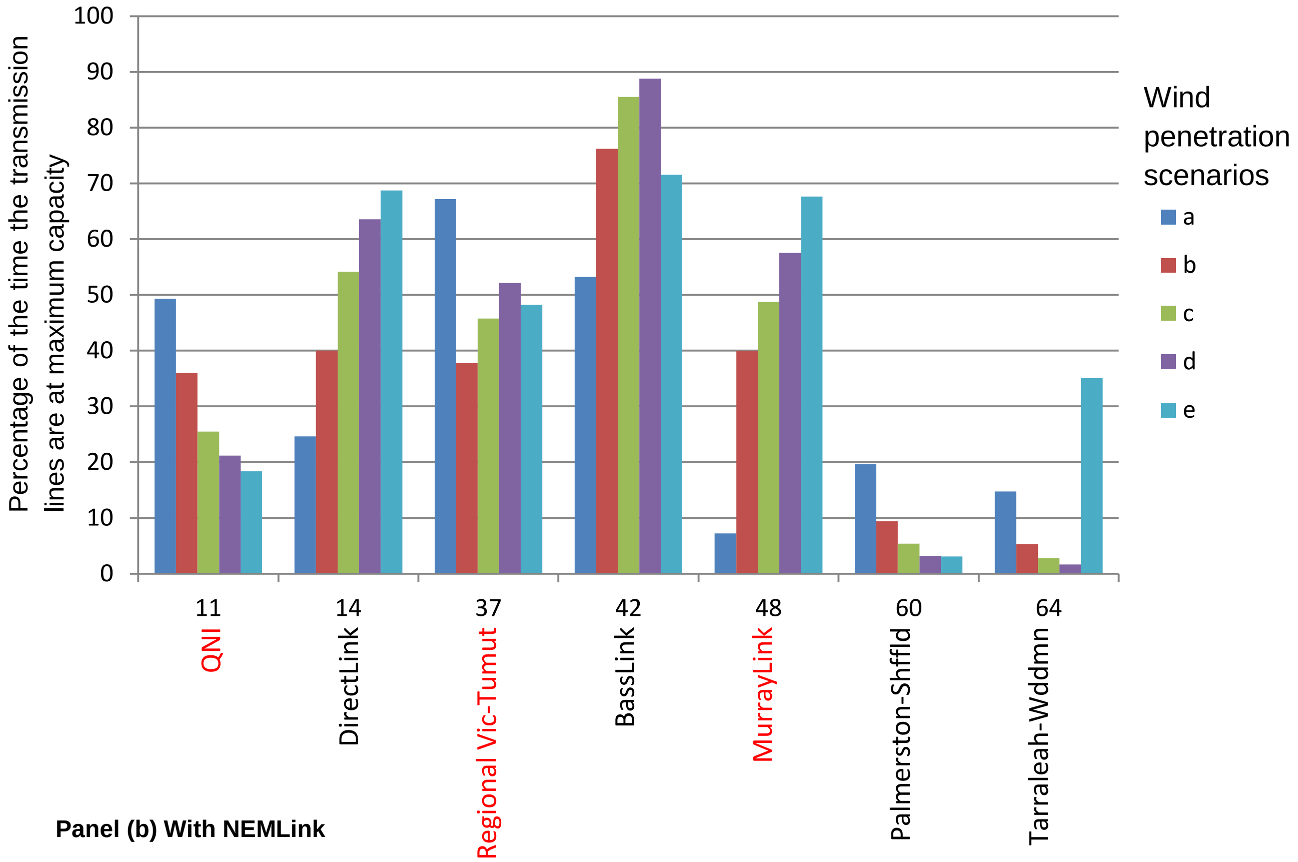
3.2.4 Comparing the effect of the five wind scenarios on different lines

In the previous three sections, the wind penetration effect was by far the largest, followed by the weather effect and the smallest being the growth in demand effects. Hence, this section evaluates the larger wind 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. The effect of the five wind scenarios on the lines varies considerably.

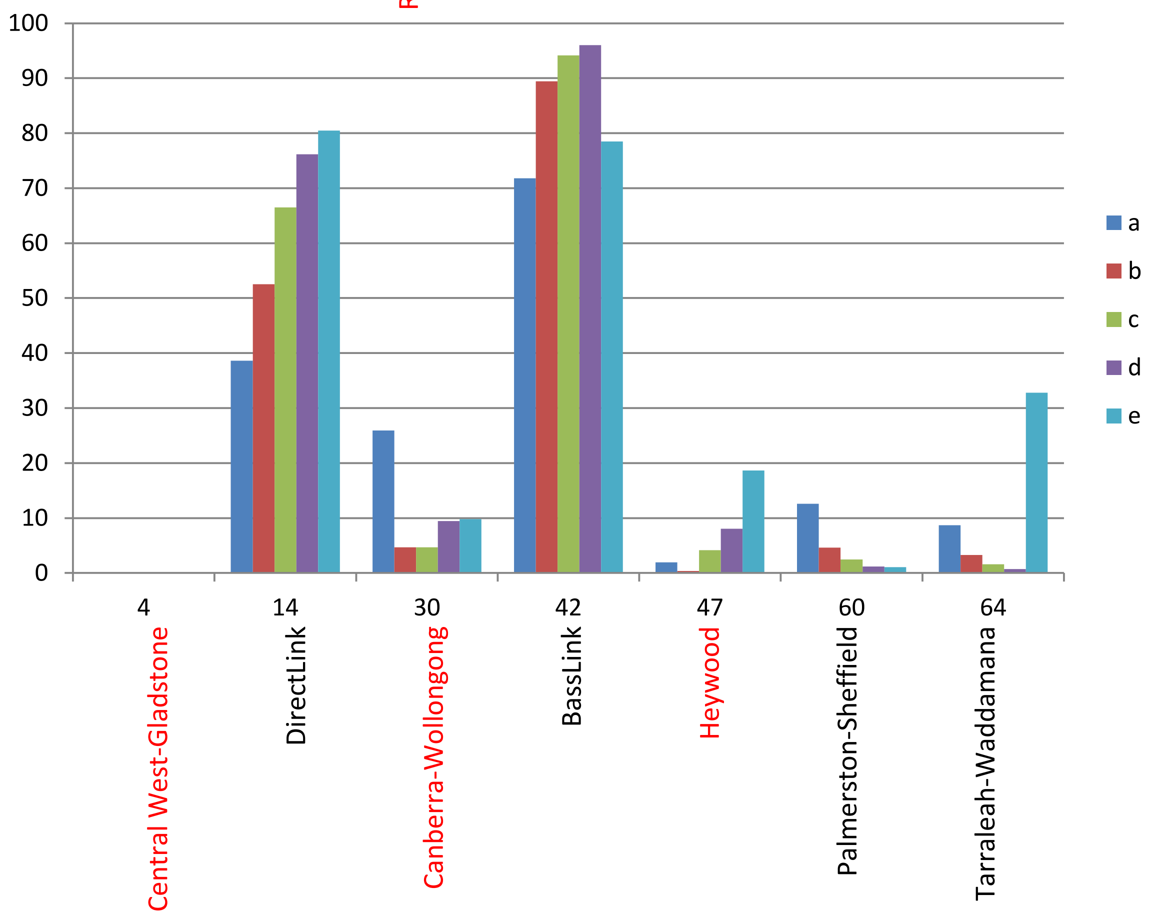
Without NEMLink in Panel (a), QNI (Line 11) shows decreasing congestion with increasing wind power. In contrast, DirectLink (Line 14) shows the opposite trend, suggesting the requirement for transmission line argumentation. QNI and DirectLink are the two interconnectors between QLD and NSW. They are acting in a complementary role as the wind power increases. The effect of NEMLink shown in Panel (b) is to eliminate congestion on QNI but increases congestion on DirectLink by 12 to 14 percentage points. Without NEMLink in Panel (b), the interconnector between ‘Regional VIC-Tumut NSW’ (Line 37) shows the most volatile congestion. The effect of NEMLink shown in Panel (b) is to eliminate congestion in Line 37. However, slight amounts of congestion appear on the other NSW-VIC interconnector Tumut-Dederang (Line 36).

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

Panel (a) Without NEMLink



Panel (b) With NEMLink



BassLink (Line 42) without NEMLink shown in Panel (a) 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 redeploy 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. The effect of NEMLink on BassLink shown in Panel (b) is to increase congestion for the wind penetration Scenarios A, B, C, D and E by 18, 13, 6, 8 and 7 percentage points respectively. This confirms our earlier observation in Section 3.1 about reconsidering BassLink augmentation as part of a NEMLink under higher penetrations of wind power. An alternative and possible more cost effective solution is augmenting TAS's hydroelectricity fleet with pump storage.

Power flows on BassLink are strongly dependent on dispatch by the Tasmanian hydro plant. In this report, the ANEM model simulates hydro dispatch according to LRMC. Modelling with other hydro dispatch strategies could produce different dispatch patterns, power flows and congestion patterns on BassLink. Alternative strategies modelling could use hydro dispatch based on SRMC or water pricing in conjunction with actual storage levels upstream of hydro plant.

MurrayLink (Line 48) without NEMLink shown in Panel (a) 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 SA to VIC and will become more constraining without suitable augmentation or energy storage solutions. The effect of NEMLink on MurrayLink is to eliminate congestion. However, congestion increases on the Heywood interconnector (Line 47), particularly under Scenario E. As noted in Section 3.2.1, the AER has recently approved an augmentation of the Heywood Interconnector. This would go some way to moderating or eliminating congestion effects on this line under Scenario E.

Without NEMLink shown in Panel (a), Tarraleah-Waddamana (Line 60) shows a similar trend to its near neighbour Palmerston-Sheffield (Line 64) with the exception of Scenario E. The effect of NEMLink is to decrease congestion on both Lines 60 and 64.

3.3 Detailed investigation of individual lines

This section presents a detailed individual evaluation of each of all transmission lines in Table 3. The previous section identified the wind 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, weather and demand growth. Viewing the network 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 transmission line topology.

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

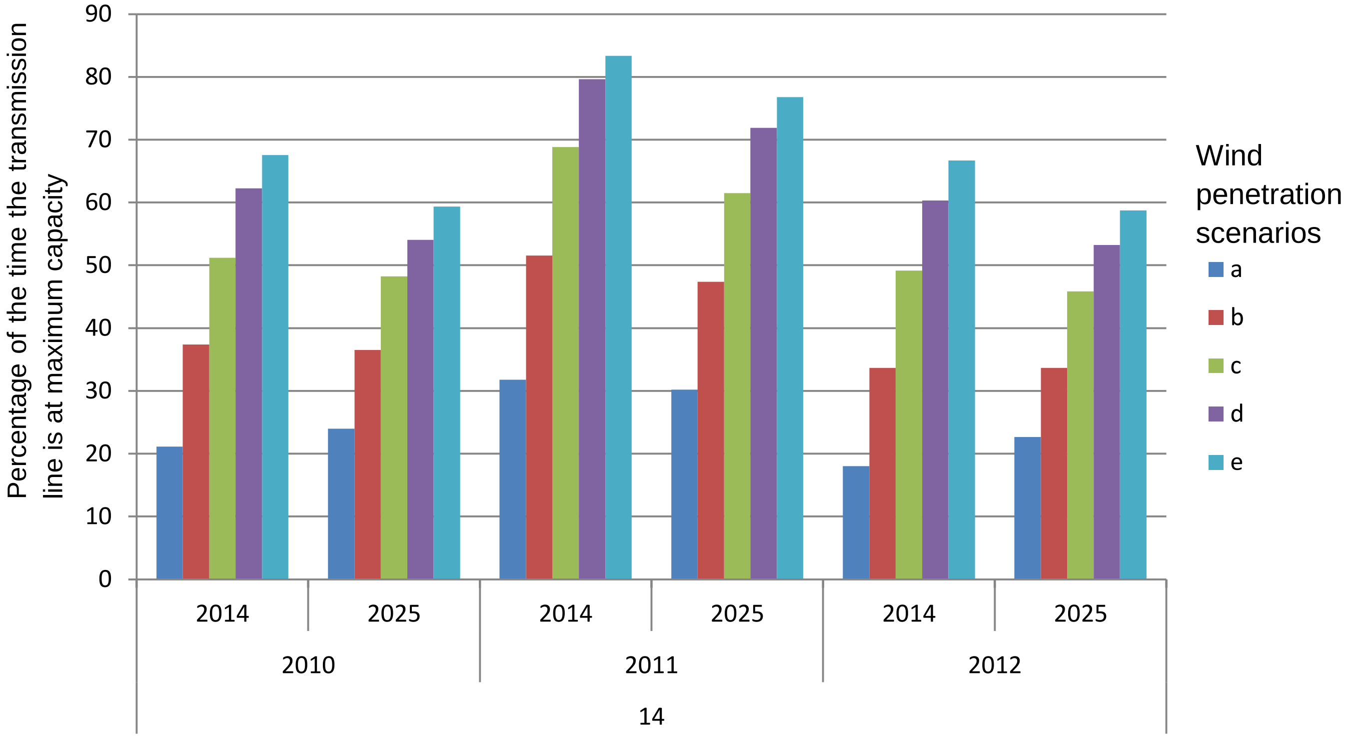
This section and the following sections examine the lines in more detail to determine the effect of weather and demand growth on the five wind scenarios. The difference between the baseline years 2010 to 2012 shows the weather effect and the difference between the projection years 2014 and 2025 shows 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 hold under more detailed examination.

Both the QNI and DirectLink interconnect the QLD and NSW intrastate transmission systems. Our transmission congestion report (Bell et al. 2015c, Sec. 3.2.1) discusses the inverse congestion relationship between QNI and DirectLink without NEMLink in detail. The AEMO's NEMLink proposal includes augmenting QNI that eliminates congestion on QNI. However, Bell et al. (2015c, Fig. 5) clearly shows an inverse congestion relationship between QNI and DirectLink where congestion decreases on QNI and increases on DirectLink as wind power penetration increases from Scenario A to E. ANEM's proposed NEMLink QNI augmentation is addressing a congestion problem that will diminish as wind power penetration increases but fails to address the increasing congestion on DirectLink.

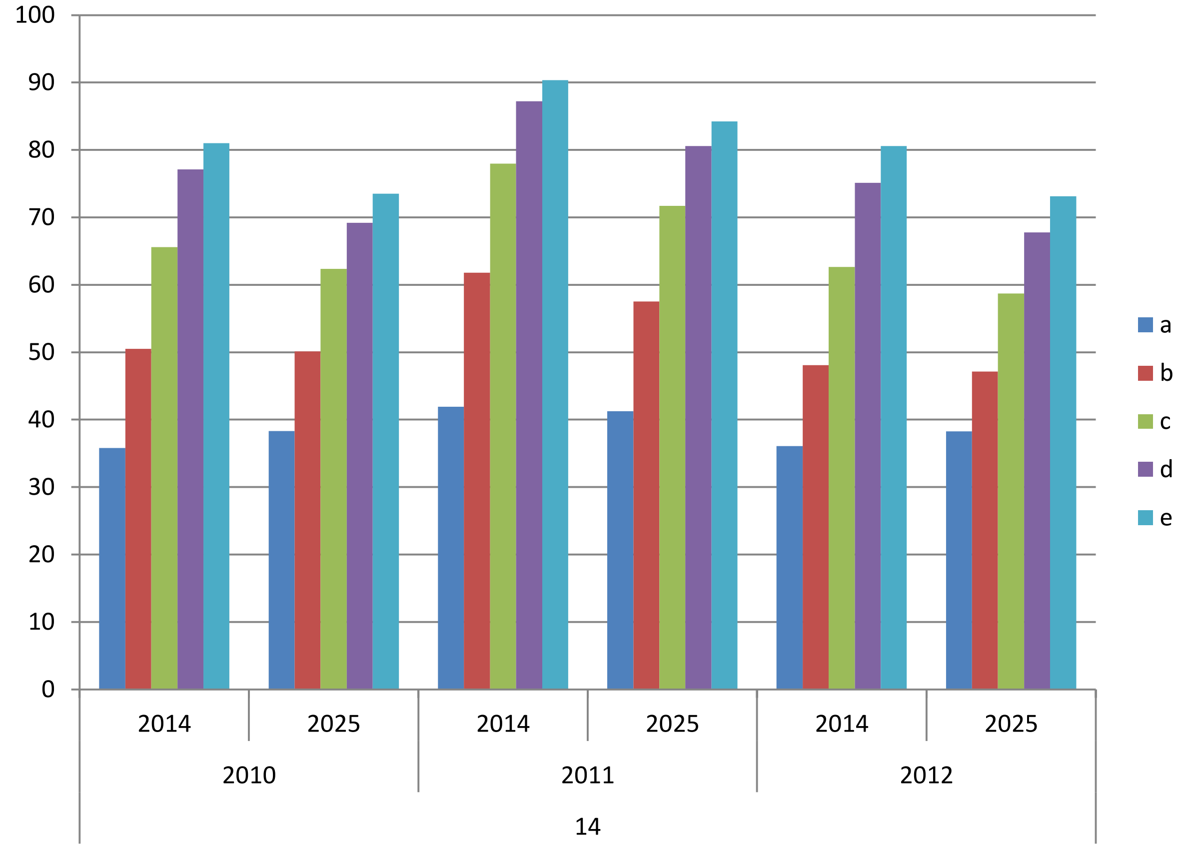
Figure 5 shows how the weather, demand growth and wind-penetration affect congestion on the DirectLink with and with NEMLink. The general patterns of these effects on congestion are similar with and without NEMLink. However, NEMLink induces a slightly higher level of congestion across all effects. This observation reinforces the argument in the previous paragraph to consider DirectLink in the NEMLink augmentation or at least as a separate augmentation proposal. As discussed in Section 3.21, Directlink and its surrounding 132 kV network have a limited transfer capacity of 180 MW. Thus, it is not surprising that this line would be a serious candidate for augmentation under both the 'NEMLink' and 'no NEMLink' network structures.

Figure 5: Comparing congestion on DirectLink (Line 14) with and without NEMLink

Panel (a) Without NEMLink



Panel (b) With NEMLink



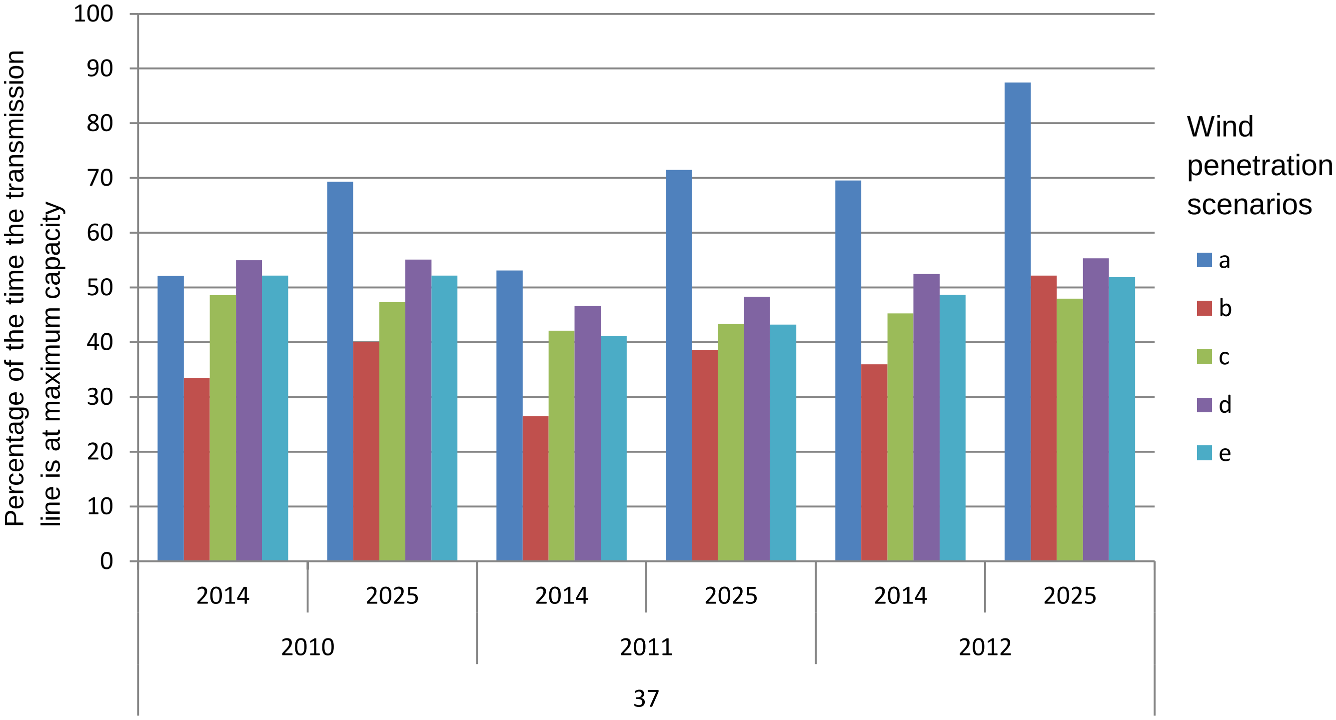
3.3.2 NSW-VIC Interconnectors: Tumut NSW to Dederang and Regional VIC (Lines 36 and 37)

Figure 6 Panel (a) shows the without NEMLink congestion on the VIC-NSW Interconnector that connects 'Regional VIC' to 'Tumut NSW' (Line 37). The introduction of wind power, from Scenario A to B, has reduced the congestion projected in 2025 in the three weather scenarios 2010 to 2012. The effect of NEMLink is to eliminate congestion on Line 37.

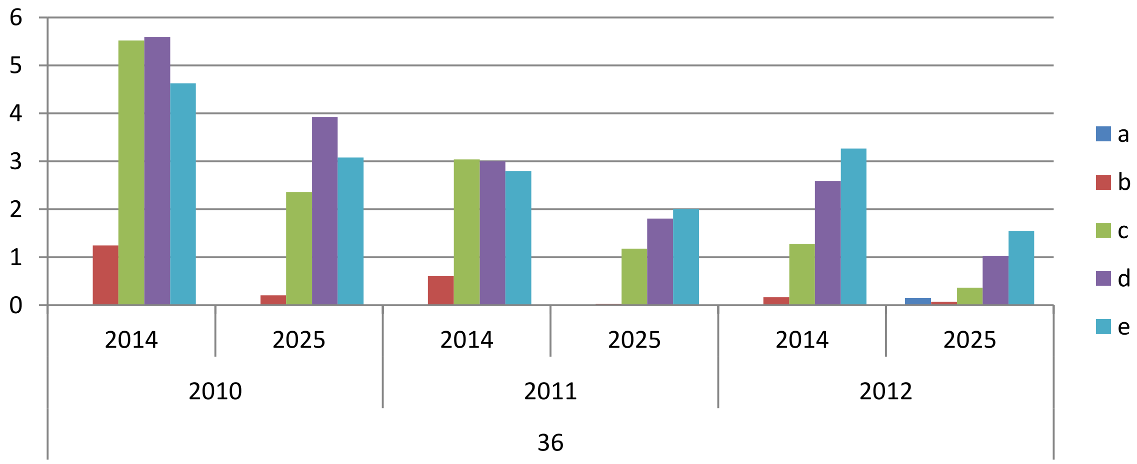
However, Panel (b) shows that the NEMLink induces a slight congestion on Line 36 that previously has no congestion. This congestion tends to diminish over time but also increases with wind power penetration. In any case, however, Line 36's congestion rates of less than 6 percent are minor, making augmentation unnecessary.

Figure 6: NSW-VIC Interconnectors

Panel (a) Congestion without NEMLink on 'Tumut NSW' – 'Regional VIC' (Line 37)



Panel (b) Congestion with NEMLink on 'Tumut NSW' – 'Dederang VIC' (Line 36)

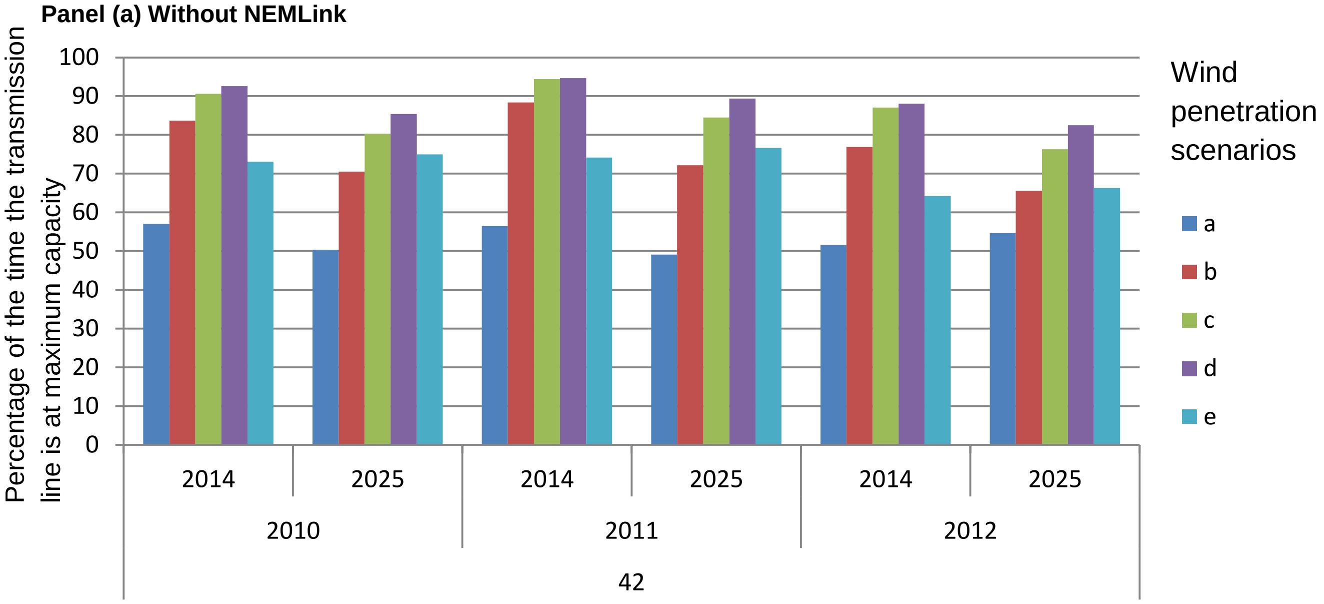


3.3.3 VIC-TAS Interconnector: BassLink (Line 42)

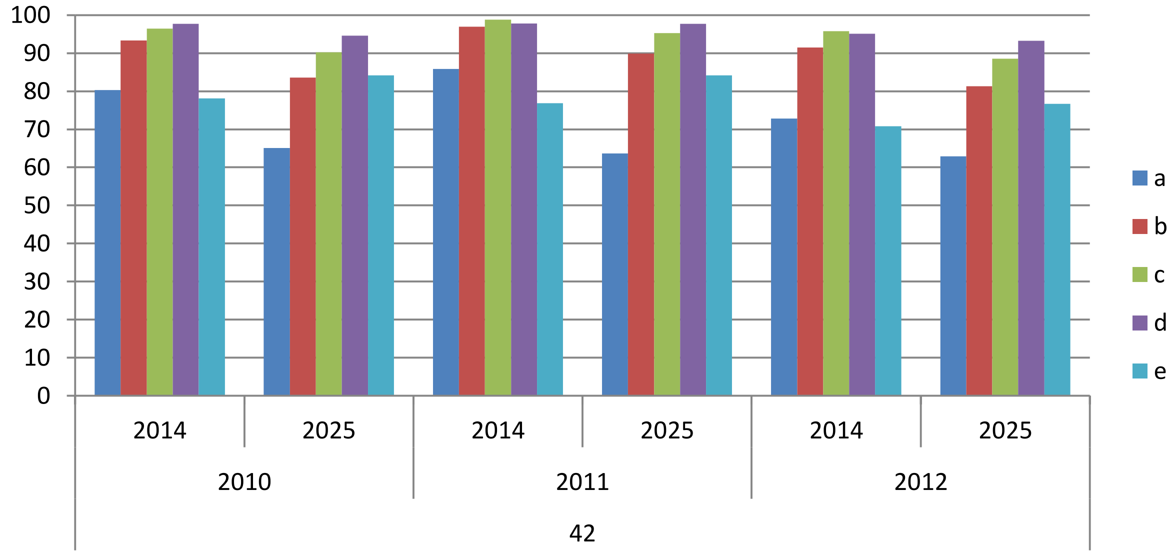
Figure 7 shows the congestion on the interconnector BassLink that connects the VIC and TAS intrastate transmission networks. The projected increase in congestion in BassLink from Wind Penetration Scenario A to D and decrease in congestion from Scenario D to E is present with and without NEMLink. Both cases suggest a relocatable energy storage solution to this temporary increase in congestion. Additionally, both with and without NEMLink there is slightly lower congestion in 2025 relative to 2014. This pattern holds for all the base years 2010, 2011 and 2012 and is particularly strong moving from Scenario B to D. Overall NEMLink has slightly exacerbated congestion on BassLink. As discussed in Section 3.2.4, the power flow on BassLink depends strongly upon the Tasmanian hydro plant dispatch. Modelling hydro dispatch with differing assumptions could produce different dispatch patterns, power flows and congestion patterns on BassLink.

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

Panel (a) Without NEMLink



Panel (b) With NEMLink



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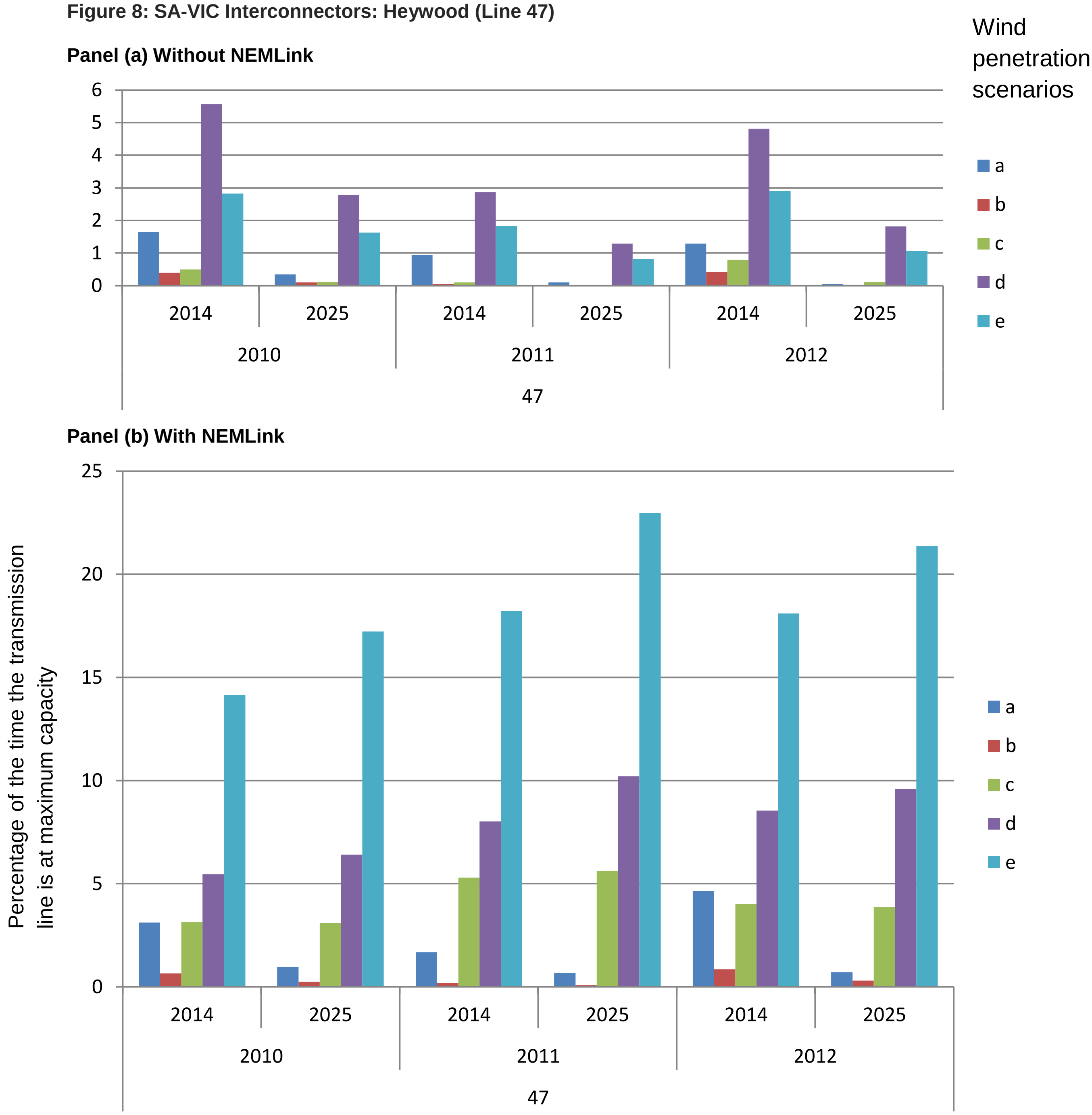
3.3.4 SA-VIC Interconnectors: Heywood and MurrayLink (Lines 47 and 48)

The interconnectors Heywood (Line 47) and MurrayLink (Line 48) interconnect the SA and VIC intrastate transmission networks. Bell et al. (2015c, Sec. 3.2.4) discuss how weather, demand growth and wind-penetration affect the congestion on these two interconnectors without NEMLink. These two interconnectors fail to show any complimentary pattern unlike QNI and DirectLink. MurrayLink augmentation is part of the AEMO's NEMLink proposal. The augmentation eliminates MurrayLink's sizable congestion to allow the export of wind power from SA to VIC. However, NEMLink also increases the congestion on Heywood particularly at the highest wind penetration Scenario E see Figure 8. However, the recent approval by the AER to augment Heywood would reduce, if not eliminate, this congestion.

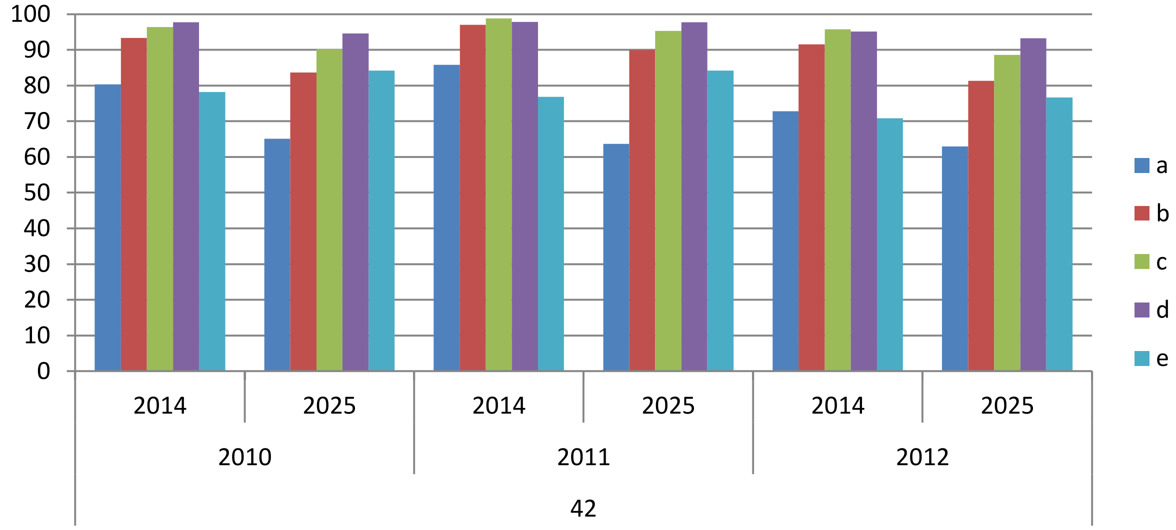
Figure 8: SA-VIC Interconnectors: Heywood (Line 47)

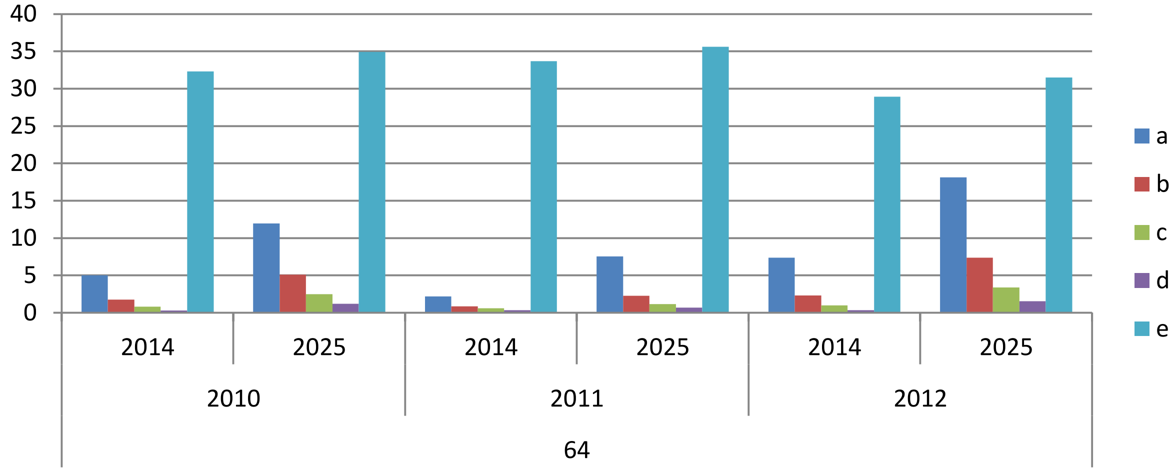


3.3.5 Comparing BassLink and Tarraleah-Waddamana (Lines 42 and 64)

Bell et al. (2015c, Sec. 3.2.5) establish a complimentary congestion pattern between the BassLink and Tarraleah-Waddamana in TAS without NEMLink. In this section, we establish if the same complimentary congestion pattern holds with NEMLink. Figure 9 shows the complimentary congestion pattern also holds with NEMLink. Additionally, NEMLink increases congestion on BassLink and reduces congestion on the Tarraleah-Waddamana Line.

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



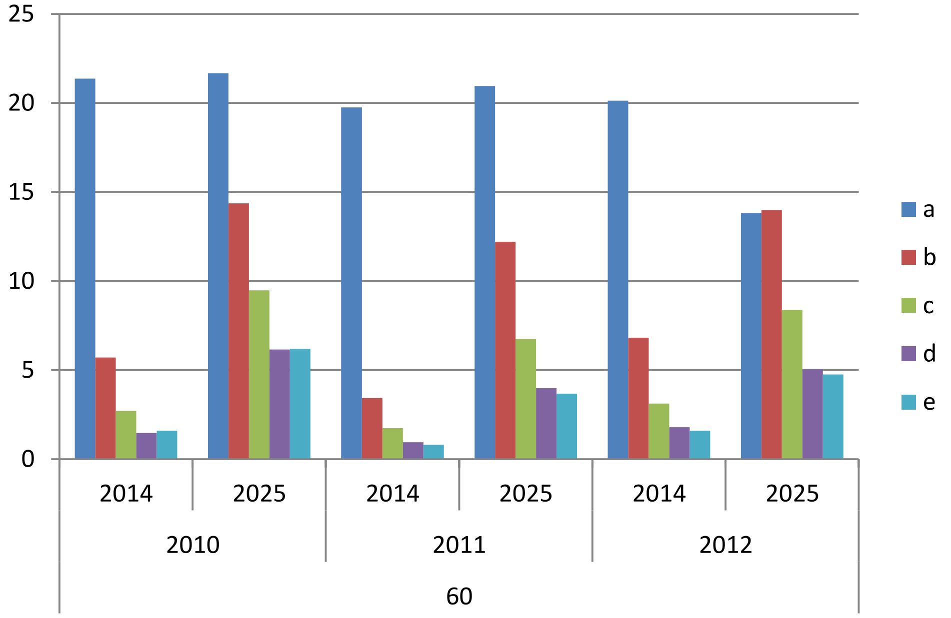


3.3.6 Palmerston-Sheffield TAS (Line 60)

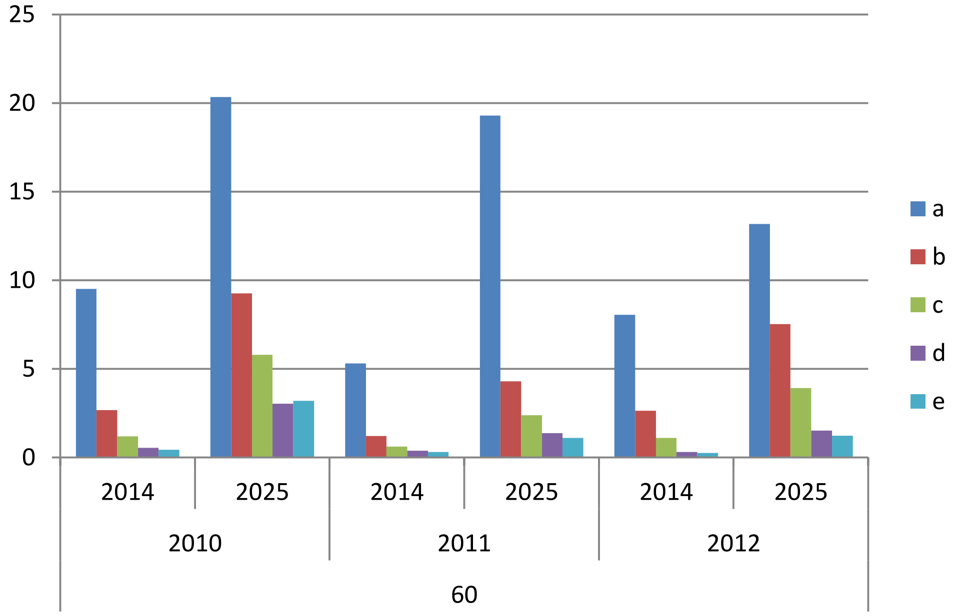
Figure 10 shows the congestion on the Palmerston-Sheffield line in TAS (Line 60). The increase in wind power from Scenario A to E has reduced congestion. The Granville Harbour Windfarm in the Farrell node in TAS (Node 45) commencing in Scenario D partially explains the reduction in congestion. This congestion pattern holds with and without NEMLink. However, NEMLink has reduced congestion overall.

Figure 10: Palmerston-Sheffield TAS (Line 60)

Panel (a) Without NEMLink



Panel (b) With NEMLink

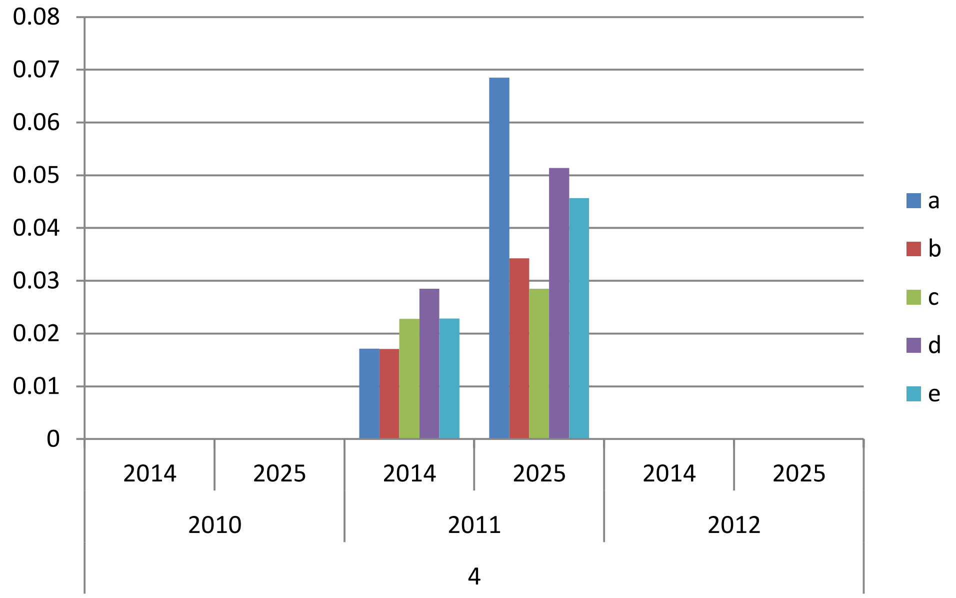


3.3.7 Gladstone-Central West QLD (Line 4)

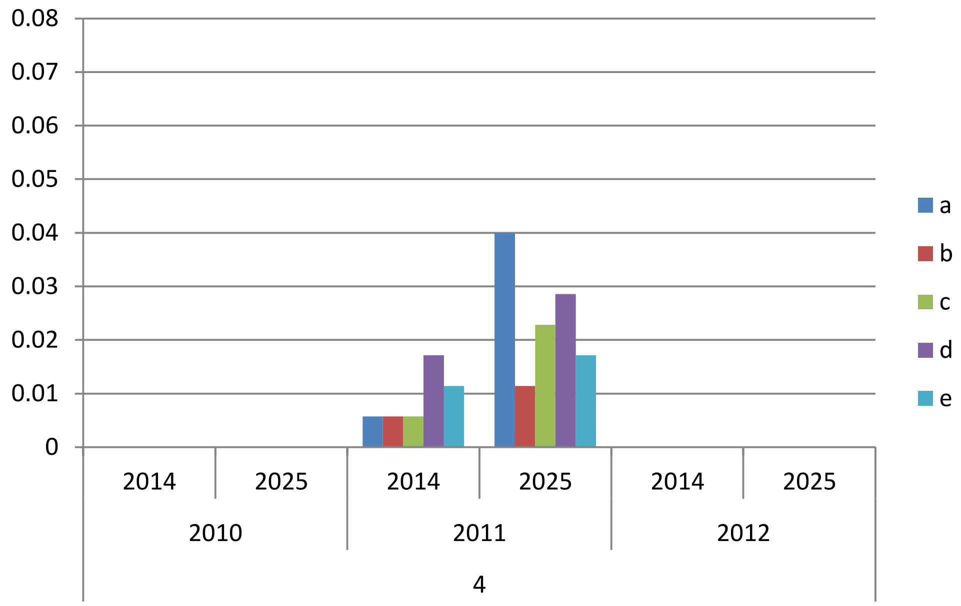
Figure 11 shows the congestion on Gladstone-Central West QLD (Line 4). This congestion is exceedingly small in magnitude and largely weather dependent, being only present in the weather year 2011. NEMLink further reduces this congestion.

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

Panel (a) Without NEMLink



Panel (b) With NEMLink



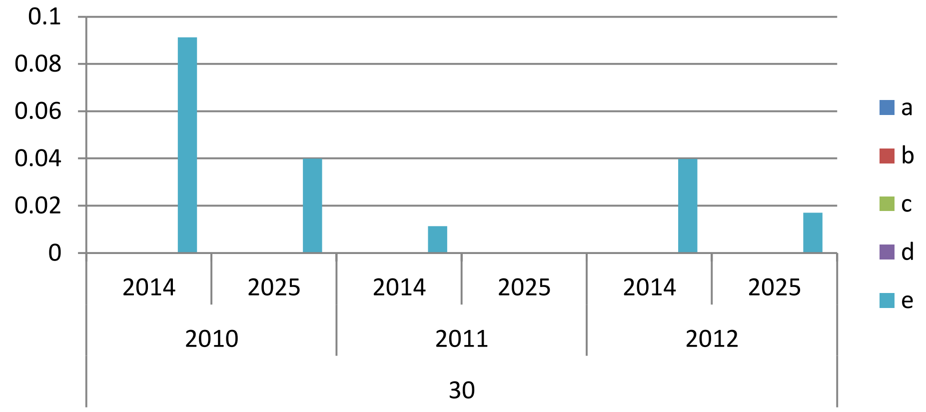
3.3.8 Marulan-Sydney and Canberra-Wollongong NSW (Lines 26 and 30)

Bell et al. (2015c, Sec. 3.2.8) discuss the exceedingly small congestion on the two NSW lines Marulan-Sydney (Line 26) and Canberra-Wollongong (Line 30) without NEMLink. This exceedingly small congestion is only present in the highest wind 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.

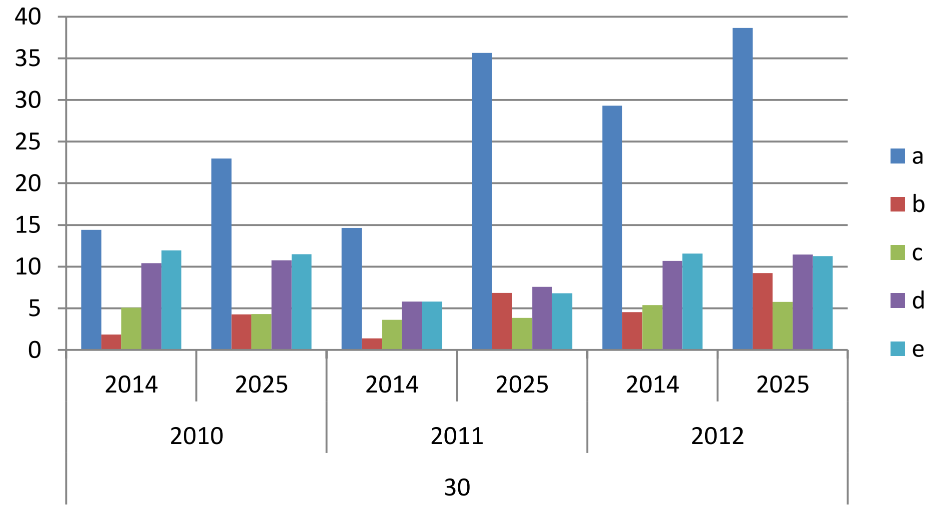
NEMLink eliminates congestion on Marulan-Sydney (Line 26) but increases congestion on Canberra-Wollongong (Line 30) significantly. Figure 12 compares the congestion on Canberra-Wollongong (Line 30) with and without NEMLink. Congestion on Line 30 becomes markedly lower under the wind power penetration Scenarios B to E when compared with the 'no wind' Scenario A. Given the wind farms already operational at the Canberra node, Scenarios B to E would represent the current and probable future windfarm deployment. Therefore, it would be unnecessary to augment Line 26 because in Scenarios B to E the congestion is minor, which is under 12 percent.

Figure 12: Congestion on the Canberra-Wollongong NSW (Line 30)

Panel (a) Without NEMLink



Panel (b) With NEMLink



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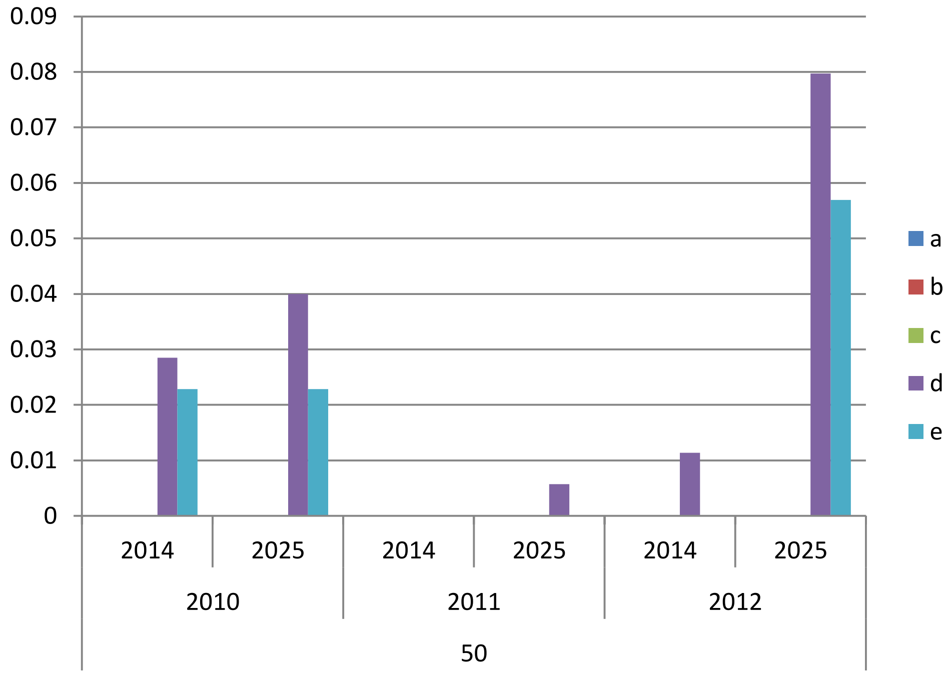
3.3.9 Riverland-SE SA (Lines 50)

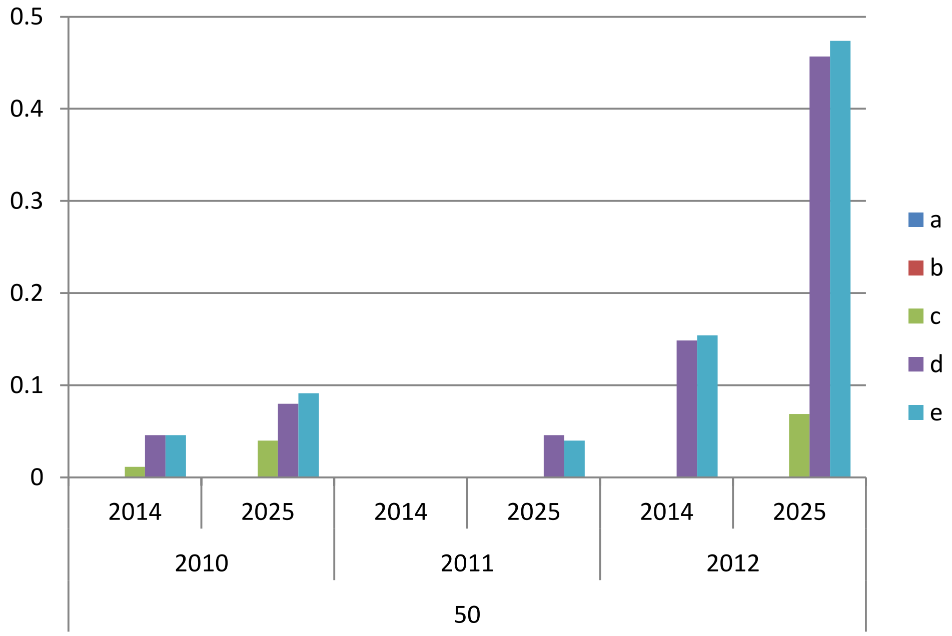
Figure 13 compares the congestion on Riverland-South East SA (Line 50) with and without NEMLink. The congestion is exceedingly small in magnitude and only present in the higher wind penetration Scenarios. NEMLink marginally increases congestion on this line. However, the rates of congestion under both transmission network structures are still exceedingly small in magnitude.

Figure 13: Riverland-South East SA (Line 50)

Panel (a) Without NEMLink



Panel (b) With NEMLink

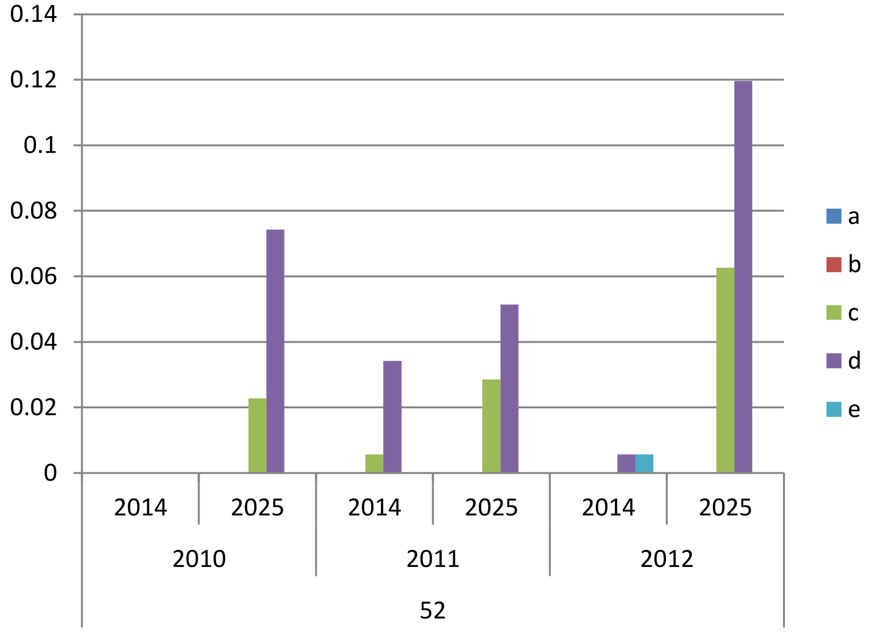


3.3.10 Greater Adelaide-Mid North SA (Line 52)

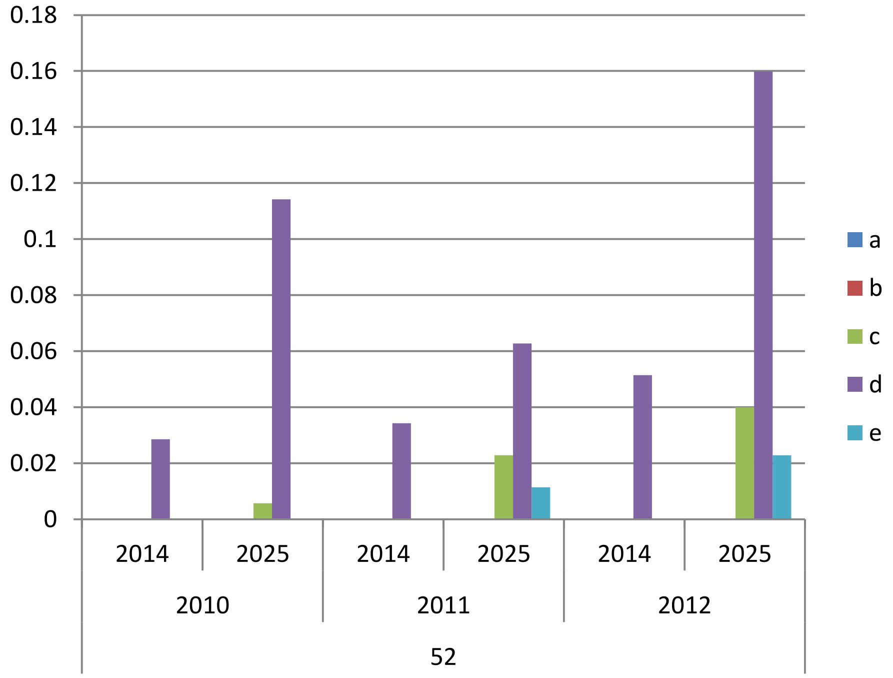
Figure 14 compares the congestion on Greater Adelaide-Mid North SA (Line 52) with and without NEMLink. The congestion is also exceedingly small in magnitude and only present in the higher wind penetration Scenarios. NEMLink slightly increases congestion on this line, although the rates are still exceedingly small.

Figure 14: Greater Adelaide-Mid North SA (Line 52)

Panel (a) Without NEMLink



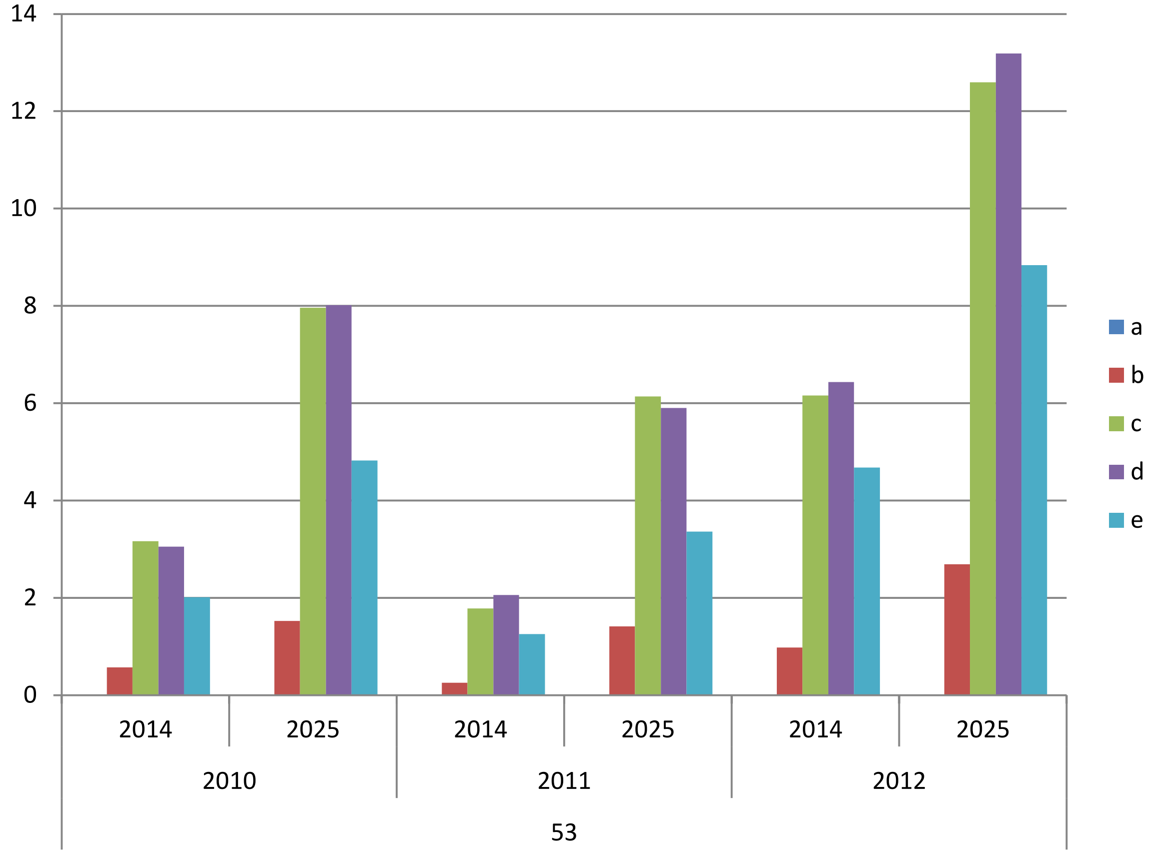
Panel (b) With NEMLink



3.3.11 Mid North – Riverland SA (Line 53)

Figure 15 shows the congestion on Mid North SA – Riverland (Line 53) without NEMLink. This congestion is small and absent in the 'no wind' Scenario A. NEMLink eliminates congestion on this line.

Figure 15: Mid North – Riverland SA (Line 53) without NEMLink



4 Discussion

We have analysed the sensitivity of the Australian National Electricity Market transmission line congestion to the introduction of NEMLink outlined in the National Transmission Network Development Plan (AEMO 2010a, 2010b, 2011a, 2011b). During this sensitivity analysis, we also considered the effect of increasing the number of wind turbine generators (WTG) on congestion from Scenario A that is no wind power to Scenario E that is sufficient wind power 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 et al. 2015) to perform the sensitivity analysis.

Without NEMLink, there is congestion on 14 of the 68 transmission lines in the ANEM Model (Wild et al. 2015). Notably, these 14 congested transmission lines include 6 of the NEM's interstate interconnectors and 8 intrastate transmission lines but only 3 of the intrastate transmission lines exhibited any significant congestion. The other 5 of the intrastate transmission lines exhibited extremely little congestion.

With NEMLink, there is congestion on 12 of the 68 transmission lines. These 12 lines include 4 interconnectors. The magnitude of the congestion on the 8 intrastate transmission lines varies from tiny to small. We focus on the 4 interconnectors that remain congested after the NEMLink augmentation, namely, DirectLink, BassLink, Heywood and Tumut-Dederang (NSW-VIC).

Both DirectLink and QNI interconnect QLD and NSW. QNI forms part of the NEMLink backbone and augmentation eliminates QNI's congestion. Our transmission congestion report (Bell et al. 2015c, Sec. 3.2.1) discusses the inverse congestion relationship between QNI and DirectLink without NEMLink in detail. Bell et al. (2015c, Fig. 5) clearly shows an inverse congestion relationship between QNI and DirectLink where congestion decreases on QNI and increases on DirectLink as wind power penetration increases from Scenario A to E. The QNI augmentation is addressing a congestion problem that will diminish as wind power penetration increases. In contrast, the congestion on DirectLink increases with increasing wind power penetration and NEMLink exacerbates the congestion on DirectLink, see Figure 5. Directlink and its surrounding 132 kV network have a limited transfer capacity of 180 MW. DirectLink is a candidate for augmentation under both the 'NEMLink' and 'no NEMLink' network structures.

Both Heywood and MurrayLink interconnect SA and VIC. MurrayLink forms part of the NEMLink backbone and augmentation eliminates MurrayLink's congestion. However, NEMLink also increases the congestion on Heywood particularly at the highest wind penetration Scenario E, see Figure 8. However, the recent approval by the AER to augment Heywood would reduce, if not eliminate, this congestion

Both Tumut-Dederang and Tumut-Regional VIC interconnect NSW and VIC. Tumut-Regional VIC forms part of the NEMLink backbone and augmentation eliminates Tumut-Regional VIC's congestion. However, NEMLink induces a slight congestion on Tumut-Dederang (Line 36) that previously has no congestion. This congestion tends to diminish over time but also increases with wind power penetration. In any case, Line 36's congestion rates of less than 6 percent are minor making augmentation unnecessary; see Figure 6 Panel (b).

BassLink interconnects VIC and TAS. BassLink falls outside the NEMLink backbone. The submarine HVDC cable is the most capital costly interconnector augmentation and subsequently excluded from a NEMLink proposal. However, both the higher penetration of wind and NEMLink induce slightly more congestion on BassLink, which indicate a higher benefit from augmenting BassLink. The congestion on BassLink increases from wind penetration Scenario A to D but decreases from Scenario D to E. Our transmission report (Bell et al. 2015c, Sec. 4) discusses the possibility of using temporary relocatable energy storage as a solution rather than the traditional approach of laying more lines to address the temporary increases in congestion. As discussed in Section 3.2.4, the power flow on BassLink depends strongly upon the Tasmanian hydro plant dispatch. Modelling hydro dispatch with differing assumptions could produce different dispatch patterns, power flows and congestion patterns on BassLink. This forms future research.

In our transmission report (Bell et al. 2015c, Sec. 3.2.5) we establish and provide reasons for a complimentary congestion pattern between the BassLink and Tarraleah-Waddamana. The congestion on BassLink increases from wind penetration Scenario A to D but decreases from Scenario D to E. The congestion on Tarraleah-Waddamana decreases from wind penetration Scenario A to D but increases from Scenario D to E. NEMLink increases congestion on BassLink and reduces congestion on Tarraleah-Waddamana but the complementary pattern still holds. Again, in this situation using temporary relocatable energy storage is a possibility.

5 Conclusion

We find that the NEMLink proposal goes some way to addressing the congestion amongst the transmission lines in the NEM when increasing wind power penetration from Scenario A that is no wind power penetration to Scenario E that meets Australia's 2020 Large Renewable Energy Target (LRET). Augmentation of both BassLink and DirectLink need considering in future augmentation proposals whether part of NEMLink or otherwise. There is a requirement to specifically model the higher penetrations of renewables to accommodate the inevitable shift from fossil fuels to renewable energy.

Our transmission report (Bell et al. 2015c, Sec. 5) has already discussed Australia's extremely modest 2020 renewable electricity target when compared to renewable electricity targets elsewhere. More ambitious targets are in keeping with other developed countries. The planned phasing out the fossil fuel fleet and replacement with renewable energy requires appropriate network infrastructure. However, developing a cost effective NEMLink is contingent on the generation mix and renewable energy benefits from using a portfolio approach to help reduce the intermittency and variability present in each form of renewable energy generation. This presents a challenge concurrently optimising a NEMLink structure and renewable energy portfolio contingent on the NEM's geographically dispersed wind and solar resources.

We (Bell et al. 2015f) assessed correlation between wind speed and electricity demand that informed the importance of the NEMLink transmission network augmentation that connects the NEM's peripheral states for the NEM to avail itself of the advantages of wind power, including systems stability and enabling wind power to better meet electricity demand without storage. The backbone concept of the NEMLink proposal fits in with this requirement. The study also discovered an unwitting portfolio effect were solar PV is meeting an increasing portion of the midday demand. The residual demand better fitted the wind generators profile.

A further change to the deployment of NEMLink is the potential massive loss in profits for the fossil fuel generators from the combination of reduced congestion from NEMLink and the merit order effect from renewable energy. The fossil fuel lobby will find it in their interest to block or hinder the development of NEMLink. However, it is possible that some coal generators especially brown coal might do well under NEMLink as brown coal is also very cheap and NEMLink would increase its geographic reach. Both brown coal and wind production shares could well increase via the merit order effect at the expense of hydro and gas generation.

Further research is required to evaluate the effect of NEMLink on emissions and dispatch patterns. If the effect of NEMLink is to increase emissions and change dispatch patterns by reducing gas and hydro generation and increasing coal generation, a carbon price signal would be required to make coal relatively more expensive.

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