The impact of climate change on generation and transmission in the Australian national electricity market

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The Impact of Climate Change on Generation and Transmission in the Australian National Electricity Market

Abstract

This paper aims to identify climate change adaptation issues in the Australian National Electricity Market (NEM) by assessing the robustness of the institutional arrangements that support effective adaptation from the supply side. This paper finds that three major factors are hindering or are required for adaptation to climate change: institutional fragmentation both economically and politically; distorted transmission and distribution investment deferment mechanisms; and lacking mechanisms to develop a diversified portfolio of generation technology and energy sources to reduce supply risk. Proposed solutions to the three factors are discussed. These proposed solutions are tested and examined in forthcoming papers.

Keywords

Climate change adaptation, electricity generation, electricity transmission, Australian National Electricity Market

1 Introduction

The objectives of this paper are to examine the adaptive capacity of existing institutional arrangements in the Australian National Electricity Market (NEM) to existing and predicted climate change conditions. Specifically the paper aims to:

- identify climate change adaptation issues in the NEM;
- analyse climate change impacts on reliability in the NEM under alternative climate change scenarios to 2030; and
- assess the robustness of the institutional arrangements that support effective adaptation.

The main motivation stems from the development of existing institutional arrangements under the premise of stable climate conditions. Environmental issues, such as drought and increased climate variability have been largely overlooked and the recent past has demonstrated that this premise is no longer appropriate. The Government's policy response has been varied and somewhat uncoordinated, which has the potential to compromise the reliability of the NEM. In support of this observation, Ford et al. [1] make a systematic review of the observed climate change adaption in developed countries using a meta search of the literature and find comparatively limited reporting from Australia. There is a need to redress this situation with the final conclusion from this paper highlighting possible ways forward.

This paper assumes a need to adapt to climate change based on the arguments in Garnaut [2] and Yates and Mendis [3] that accurate prediction of climate change is fraught with uncertainty but there is scientific consensus that climate change is highly probable and the cost of not proactively adapting to climate change is high.

Institutional arrangements in the context of this paper refer to structure, ownership and regulations where structure includes market operations, market design, spot pool and market trading. Ownership includes public versus private and regulations include pricing.

This paper informs the development of forthcoming papers within a project titled '*Analysis of institutional adaptability to redress electricity infrastructure vulnerability due to climate change*'.

2 Literature Review

An extensive literature review has been undertaken in order to identify those areas where key research overlaps. Some studies have been performed to understand the risks associated with climate change, for instance Yates and Mendis [3], however, the literature relating to Australia's electricity supply interests are significantly under-developed. Specifically, this review will consider three key points:

1. the potential impacts of more variable climate conditions on the electricity industry;
2. the effectiveness of adaptation actions being carried out in the NEM and the potential for maladaptation [4]; and
3. the flow-on effects of climate change impacts and maladaptation [4] actions in other linked infrastructure industries such as water.

This review provides focus for the research in this project by exposing gaps and informing our methodologies for investigation.

Yates and Mendis [3] note that climate change affects multiple units and functions of the electricity infrastructure, so a systematic approach is required to identify vulnerabilities and maladaption in the infrastructure to formulate a climate change adaption strategic plan. Furthermore, they recommend that any plan must be embedded into the various units and functions rather than overlayed.

This paper finds that three factors are hindering or are required for adaption to climate change:

1. fragmentation of the NEM both politically and economically;
2. accelerated deterioration of the transmission and distribution infrastructure due to climate change requiring the deployment of technology to defer investment in transmission and distribution; and
3. lacking mechanisms to develop a diversified portfolio of generation technology and energy sources to reduce supply risk.

These first three factors are interrelated, for instance, the fragmentation of the NEM has hindered the deployment of technologies to allow deferment of investment in transmission and distribution. The investment in transmission and distribution is primarily driven by peak demand, which could be mitigated with smart meters, flexible retail tariffs and consumer engagement. On the supply side, the renewable energy targets (RET) scheme has primarily driven onshore wind and solar PV uptake to the detriment of a broader portfolio. The onshore wind and solar PV each have their intermittent supply cycles that present a challenge to matching supply and demand. A broader portfolio of generation technology, storage and energy sources could both mitigate the intermittent supply cycles and aid deferment in transmission and distribution investment. However, promoting a broader portfolio of renewable energy would require modifications to the existing policy to incorporate targets for specific technologies and energy resources.

The fragmentation of the NEM has been acknowledged through the formation of a number of bodies to address coordination issues including, the Ministerial Council on Energy (MCE), Australian Energy Market Commission (AEMC), Australian Energy Market Operator (AEMO) and the Australian Energy Regulator (AER). However the underlying fragmentation and induced coordination problem still remains. Politically the NEM covers six states or territories and their legislative requirements. Economically the NEM has thirteen distribution companies and seven transmission companies. In contrast, South Korea, with two and half times the population of Australia, has a single company running both transmission and distribution within a single legislative entity. But it must be acknowledged that South Korea covers an area smaller than the NEM region. However, a single company, Telstra, manages the entire copper based telecommunications network for the whole of Australia, which covers a much larger area than the NEM. Hence the NEM's region covering a larger area than South Korea is a poor justification for fragmentation. South Korea's adaption to climate change is more advanced than the NEM because South Korea lacks the political and economic coordination overhead of the NEM. Forthcoming papers will include an international comparison to test this fragmentation observation.

The linking of the once separate state transmission and distribution networks to form the NEM's network has transformed the once natural monopoly within each state into a single NEM wide natural monopoly. So, the legacy fragmentation of the NEM's network causes coordination problems, which are a source of maladaption to climate change. In contrast, retail and generation are more amenable to numerous companies competing, so the fragmentation brings these markets closer to perfect competition to derive benefits for consumers. However the state ownership of transmission, distribution, generation and retail provides a conflict of interest for companies installing new generation to attach to the state owned networks to compete with the state owned generators. This conflict of interest is an impediment to the development of a broad portfolio of generation technology and energy sources. Both the NEM's transmission and distribution network fragmentation and the conflict of interest cause maladaption to climate change.

This section discusses the impact of climate change on electricity generation and transmission network. Stevens [5] finds three key infrastructure areas within Australia that are most vulnerable to the effects of climate change, which are generation and transmission networks, low-lying coastal areas and drainage. Stevens [5] notes that the requirement for an efficient and reliable communication system between all areas of generation and transmission is an additional susceptibility to climate change. Introducing smart grid technologies makes this reliance on communication even more intense.

2.1 Transmission and distribution

Yates and Mendis [3] provide a detailed analysis of the effect of climate change on the transmission and distribution networks in Australia. In summary they find that climate change will increase failure caused by an accelerated ageing of the infrastructure and an increase in extreme weather events such as floods, lightning strike and higher winds and temperatures. One mechanism for undermining the footings of poles and pylons is the increased duration of droughts and shorter but more intense periods of rain causing the ground to move. Another mechanism for corroding the infrastructure is the more widely dispersed sea spray. One further mechanism is the increase in severe bush fire weather increasing demand and stressing the grid, which increases the frequency of faults.

The change in sea level, temperature and acidity are significant for the NEM in undermining the concrete footing of poles and pylons and causing accelerated corrosion of infrastructure when taken in conjunction with the projected increases in wind speed.

"By 2030 the best estimate of sea surface temperature rise is 0.6-0.9ºC in the southern Tasman Sea and off the north-west shelf of Western Australia and 0.3-0.6ºC elsewhere. Allowing for model-to-model variations, the ranges are 0.4-1.4ºC in the southern Tasman Sea and 0.4-1.0ºC off the north-west coast." [6]

The increase in sea surface temperature acts to reduce the sea's absorption of atmospheric CO_2 but this effect is overwhelm by increases in atmospheric CO_2 driving the sea's absorption of CO_2 to increase ocean acidity.

"Increases in ocean acidity are expected in the Australian region with the largest increases in the high- to mid-latitudes. Under-saturation of aragonite could occur by the middle of the century in the higher latitudes, affecting the capacity for shell and endoskeleton creation by marine organisms." [6]

The wellbeing of marine organisms with shells or endoskeleton is beyond the scope of this project but the NEM and these marine organisms share a common problem in calcium carbonate dissolving under more acidic conditions.

"Global sea level rise is projected by the IPCC to be 18-59 cm by 2100, with a possible additional contribution from ice sheets of 10 to 20 cm. However, further ice sheet contributions, that cannot be quantified at this time, may substantially increase the upper limit of sea level rise." [6]

The rise in sea level in conjunction with extreme wind conditions provides two problems for the NEM. First is the increase in direct flooding of infrastructure in coastal areas. Second is the wider dispersion of sea spray inland. Both problems are compounded by the projected increases in seawater acidity. This acidity is further exacerbated by increases in air and sea temperature, which makes acids more reactive.

Sea spray and the weather undermining of footings provide example of the interrelatedness of extreme weather events to cause problems of the NEM. However, Yates and Mendis [3] claim that the term extreme weather event is unhelpful as the term lumps together many different environmental variables, which makes detailed cause and effect analysis impractical, so this review avoids the term unless the specific environmental variables are identified. For instance bushfires are another extreme weather event caused by a combination of environmental conditions.

Lucas et al. [7] use a Forest Fire Danger Index (FFDI) to estimate the degree of danger of fire in southeast Australia, which coincides with most of the NEM's region. The index combines, rainfall, evaporation, wind speed, temperature and humidity data to provide six fire danger categories shown in Table 1.

Table 1 Fire danger rating

Category	Fire Danger Index
Catastrophic	100+
Extreme	75 - 100
Severe	50 – 75
Very high	25 - 50
High	12 - 25
Low to moderate	0 - 12

The rating of 100 is calibrated against the conditions prevalent during the Black Friday fire of 1939. Lucas et al. [7] project that the number of 'very high' and 'extreme' fire danger days in south east Australia could increase by 4-25% by 2020 and by 15-70% by 2050. This presents an increased fire risk to the NEM's infrastructure. Additionally, the heatwave associated with fire risk stresses electrical components. For instance O'Keefe [8] reports on a major blackout in Victoria cutting off electricity to half a million homes and business caused by an explosion at an electrical substation in South Morang during a weeklong heatwave. In response to this event, the MCE ordered the Australian Energy Market Commission [9] to review the effectiveness of the NEM's security and reliability arrangements to extreme weather events [10].

Mitigating these factors requires both increases in preventative maintenance and redesign of transmission and distribution lines. Furthermore the increases in temperature reduce the thermal capacity of transmission and distribution.

Hence the case for deferred investment in transmission and distribution becomes stronger with climate change. Sections 2.7 and 2.12 discuss the research questions on a renewable energy portfolio to deferred transmission investment and on portfolios that cause maladaption by requiring further investment. Additionally, there are maladaptive institutional dynamics that favour heavy investment in intrastate transmission and distribution, which Garnaut [11] refers to as *"gold plating"* but he also discusses the lack of interconnectivity between states indicated by the disparity in wholesale electricity prices between states. In agreement, Stevens [5] identifies the need to improve interstate transmission as a means to better cope with regional demand, which is made more critical by climate change projections. Furthermore, Garnaut [11] states *"the recent electricity price increases have mainly been driven by increases in the cost of transmission and distribution. There is a prima facie case that weaknesses in the regulatory framework have led to overinvestment in networks and unnecessarily high prices for consumers"*.

However, Nunn [12] disagrees with Garnaut's [11] assessment on gold plating intrastate transmission and under investing in interstate transmission. Nunn [12] claims that Garnaut [11] has a *"pipeline congestion"* view where interconnectors are bottlenecks, so the implied solution is increase the capacity of the interconnectors. Nunn [12] demonstrates using binding constraint data on the transmission network that bottlenecks occur well before the pipeline limit. So, any part of the network can affect flows on the interconnectors. Importantly, studying the frequency of the binding constraints shows that there lacks an obvious solution, as the binding constraints move around the network over time. In agreement, the AEMC [13] states that empirical research from NEMMCO shows that congestion tends to be transitory and influenced significantly by network outages. So, if bottlenecks in interstate transmissions are to be resolved, deeper integration of the interconnectors within the intrastate networks is required, which requires a whole of NEM focus rather than state focus.

This difference in focus on state rather than whole of NEM appears to reconcile the gap between Garnaut's [11] view on the institutional dynamics affecting interstate and intrastate transmission investment differently and Nunn's [12] demonstration using binding constraint data. As part of the ongoing process to remedy newly identified problems on the transmission network, the AEMC [13] recommends that AEMO [14] provides information on congestion to enable participants to better manage risk. In addition the AEMO [14] provides information on proposed transmission investments to reduce congestion. However, the interactive map shows a single proposed upgrade to interstate transmission and the remainder of the proposed transmission developments are for intrastate, which is consistent with Garnaut's [11] gold plating claim. Furthermore, an AEMC [13] recommendation could account for some of this focus on intrastate development being to *"clarify and strengthen the Rules governing the rights of generators who fund transmission augmentations as a means of managing congestion risk, so that in the future connecting parties make a contribution to those funded investments from which they will benefit".* This rule leaves the interconnector used by many generators in an overtly complex situation, so favouring intrastate investment over interstate. The MCE recognises a need to address complex problems of this sort and have identified the need for a framework based on the interrelationship among the following five factors.

- the nature of network access
- network charging
- congestion
- transmission planning
- connections

These five factors are the subject of the AEMC's [15] transmission framework review. In an interim report, AEMC [16] states *"The arrangements for transmission in the [NEM] … still substantially reflect the jurisdictionally based arrangements that preceded the national market."* However the AEMC's role is as a rule maker within the existing market and political structures. Foster et al. [17 sec. 2.5.6] discusses three interrelated sources of maladaption, the AEMC as rule maker within the existing institutional structure, the state focus versus whole of NEM focus and the complexity of the institutional structure as a source of fragmentation induced maladaptation.

Regarding transmission modelling, the Transmission Network Service Providers [18] in the NEM use two methods to rate the thermal capacity of a line, normal and real-time. Understanding of these methods is important to modelling the effect of climate change on the thermal capacity of the line. Normal rating is a fixed value rating applied to normal systems operation. In comparison, real-time is a rating dependent on appropriate measurements of ambient temperature and wind conditions. The TNSP currently use the normal rating method, which is a static rating based on a fixed time interval such as the season or month and independent of daily fluctuations in prevailing ambient conditions. The normal rating method is also referred to as continuous rating method.

The real-time rating method can be calculated in five different ways but all calculations use data that is measured with acceptable frequently and accuracy. The first way to calculate real time rating is based on the ambient wind speed and temperature. The other four ways use one of the following parameters of the conductor: temperature, tension, sag or ground clearance. The TNSP are in deliberation on switching from normal rating to real-time rating. The advantage in moving to real-time are increases in carrying capacity most of the time, which helps defer investment in new transmission line and helps ameliorate the effects of increases in ambient temperature due to climate change. The disadvantage is the data collection and coordination. Foster et al. [17 sec. 2.5.5] discusses using the date of switching from static to real time rating as a measure of the ability of the institutional structure of the NEM to adapt to climate change in an international comparison. The date of switching from static to real time is unknown but is an important consideration when modelling transmission. However, the switch to real time is likely to occur well before 2030, which is during the modelling period, so, a simplifying assumption is made that the static method is used for the whole modelling period.

The real-time rating method allows higher usage of the existing overhead transmission lines but the lines are still susceptible to accelerated aging and increases in faults caused by more frequent and severe lightening, wind, temperature, hail and bushfires and reduced carrying capacity due to global warming. Stevens [5] recommends burying cables as an adaption strategy. In addition, the increase in the incidence of bushfires requires an increased clearance of vegetation around the transmission lines, which adds further to the cost of overhead transmission. Stevens [5] notes that in Queensland there is a projected increase in bushfire risk, which poses an adaption problem for Queensland, as the region previously did not face serious fire risk. Stevens [5] notes that in NSW many distribution poles are wooden, which may require replacement with steel poles but the steel poles are susceptible to bushfires, again burying is an option. North eastern Queensland also has many aged wooden poles for distribution, which are particularly vulnerable to tropical cyclones as are the transmission lines. However DRET [19] estimates that the cost of buried lines are ten times the cost of overhead lines.

High temperature superconductor (HTS) transmission lines by being buried also avoid most of the problems associated with climate change and overhead transmission. Currently, there are only a few commercial HTS transmission lines. However, this project's scope is to 2030 and given the rapid advances in HTS transmission, their inclusion provides a fuller analysis of potential adaption options [20]. The Korean Industry and Technology Times [21] reports that the Korean Electric Power Corporation (KEPCO) with LS Cable [22] installed the world's longest HTS in a real transmission grid at 500m in length. The project is part of the Korean Ministry of Knowledge Economy's plan to develop smart grid technologies by 2016. High temperature superconductor (HTS) as opposed to low temperature superconductor (LTS) technology makes their use in transmission feasible, as HTS only require liquid nitrogen whereas LTS require liquid helium.

Minervini [23] discusses further advantages of HTS over conventional transmission. The first advantage is that HTS have three times the current density, which reduces infrastructure and right of way costs, substation cost by delivering power at lower voltages and lower weight of HTS to allow less expensive deployment. Furthermore HTS DC carries only real power; has low radiated electromagnetic fields; and has no temperature excursions during normal operation and longer insulation life; and has much lower impedance when using phase angle regulators.

However Lacey [24] comments that utilities are notoriously slow at adopting new technologies, which in part is a valid approach to reduce risk but in part could be that any transmission or distribution company investing in new technology takes on the risk and cost of research and development, while the other transmission and distribution companies can wait for the results and usually obtain a proven technology more cheaply and with little risk. The KEPCO superconductor example demonstrates the advantage for R&D in a monopoly transmission and distribution company over the multiple ownership system in Australia. Foster et al. [17 sec. 2.2.6] discusses the slow smart meter deployment in the NEM, which further illustrates the effect of multiple-ownership on R&D. Foster et al. [17 sec. 2.5.6] compares the NEM's fragmentation inducing maladaptation with KEPCO's monopoly over transmission and distribution. Foster et al. [17 sec. 2.5.5] also discusses the adoption of a smart grid road map, smart meters and superconductors as further climate change adaption performance indicators.

2.2 Coal

Regarding the supply of coal, Stevens [5] discusses how intense rainfall could cause flooding of the brown coal pits but relatively little adaption would be required to meet the increased flooding due to climate change. Additionally, Stevens [5] describes the risk in Victoria to coal generators from tsunamis and sea level rise as not significant. However in NSW there are more generators in low lying areas, which could become more susceptible to flooding. This NSW flood threat requires further study. The rail supply of coal in Queensland is already interrupted by severe weather events, which is likely to increase. Adaptation could include increasing storage facilities to increase reserves and upgrade the services [5].

Regarding the operation of coal generators, NEMMCO [25] identifies water scarcity as a factor that could affect generation capacity. In agreement, Stevens [5] finds that in Victoria droughts will reduce the supply of cooling water and affect the generation capacity This water shortage situation is exacerbated in Queensland with its rapid population growth and associated growth in electricity demand [5]. Plus higher temperatures will reduce the efficiency of the generation. But, Kogan Creek Power Station [26] uses water cooling technology that reduces water requirement by up to 90% over conventional methods, which demonstrates that water shortage is a surmountable problem for thermal generators. However, coal seam gas extraction presents further demands on water, which section 2.3 discusses.

Irving [27] calculates surface relative humidity from absolute humidity where relative humidity is better for modelling human behaviour and specific humidity, readily derived from absolute humidity, is used to model gas and steam turbines, so this project uses relative and specific humidity.

The coal generators' solution to CO_2 emissions is carbon capture and storage (CCS). However AEMO [28] discusses how CSS technology is immature and estimate that the first full scale CSS installation will be operational between 2018 and 2021. In agreement, the Global CCS Institute [29] confirms that there are no operational post combustion CCS systems and internationally there is only one actively being planned, which is by SaskPower in Estevan, Saskatchewan, Canada to retrofit a coal fired plant for operation in 2014. This situation contrasts sharply with the many renewable energy technologies already operating and maturing [28]. Additionally, the Melbourne University Energy Research Institute [30] claims that investment in technology sequencing such as CCS merely diverts funds and attention away from renewable energy generation. Furthermore, MUERI [30] claims that CCS projects are unable to capture 100% of fossil fuel emissions.

An additional adaption path open to coal generators is a hybrid solution. For example the Kogan Creek Solar Boost Project [31], which uses solar thermal energy to supply additional steam to the turbine to supplement the conventional coal-fired steam generation process. The project adds up to 44 MW during peak conditions to the coal generator's 750 MW baseload power output, so the project most probably only adds less than 1% to the overall output of the coal generator. However more importantly, this hybrid solution offers two mechanisms to reduce maladaption. First is that the self perception of staff at the coal generator changes from being one of coal generator staff to being energy providers, which reduces anxiety about losing their jobs to the renewable sector and aids acceptance of the new technology, as the demarcation between renewable and fossil fuel people becomes blurred, allowing for an easier transition. Second is that staff are trained in the use of the new technology, which provides a skilled workforce to deploy the technology. In addition, the hybrid solution uses existing transmission, which would help defer further transmission investment.

Officially opened in 2007, Kogan Creek is a relatively new generator, so both technologies, the new water cooling and the hybrid solar boost, may be unsuitable for retrofitting to the older generators or to those generators nearing the end of their life. Retrofitting these technologies needs considering on a case by case basis.

Foster et al. [17 sec. 2.5.2] discusses CPRS and the link between the rapid rise in electricity price and fossil fuels prices. Section 2.12 discusses using a portfolio of energy sources to moderate price fluctuations.

2.3 Gas

Stevens [5] evaluates the susceptibility of the gas supply to climate change and finds the existing design practices would ensure robust function. However the switch from coal to gas generation in conjunction with an increased usage of air conditioners may test supply capabilities, which is an area worthy of further study. The development of the extraction of coal seam gas would improve the gas supply situation in the near future.

Brooks [32] discusses environment variables affecting gas turbine performance where a one degree Celsius increase in temperature corresponds to a 0.6% decrease in design output. Similarly, an increase in specific humidity reduces the design output where an increase of 0.01 kg water vapour per kg dry air reduces output by 0.13%. Increases in either environment variable causes a linear percentage decrease in design output, which means more CO_2 per unit of energy generated. The relationship is fairly straight forward to model.

CCS for gas contrasts with coal CCS for two reasons. The ability to extract CO_2 from the exhaust gases emitted from burning coal is far more difficult than from burning gas, as coal emit more contaminates. In addition, gas can undergo a pre-combustion removal of CO_2, which is a mature process. For example the Global CCS Institute [29] shows that the pre-combustion Sleipner CO_2 injection project in the North Sea has been operational since 1996. However, as with coal, there are also no operational post combustion CCS systems for gas generators.

One climate change adaption path to reduce carbon emissions is to use gas generation as an intermediate step towards more renewable forms of generation in a double transition. However MUERI [30] claims that a double transition merely diverts funds away from renewable energy and delays the reduction in CO_2 emissions.

This intermediate step toward renewable energy is difficult to ignore, as ABC [33] reported, the quantity of coal seam gas (CSG) in the Great Artesian Basin is quite extensive. The copyrighted interactive maps provide details of all the known CSG wells under development or appraisal and the regions covered by petroleum leases or applications. The petroleum leases and applications cover about one half of central and southern Queensland and about a quarter of NSW. There are 1,816 approved wells in Queensland in 2011 and this is estimated to grow to 4,014 wells by 2015 and to 40,000 wells by 2030. An important consideration is that CSG extraction requires large amounts of water. Currently, there is controversy over how much water CSG will use. For instance the National Water Commission (NWC) estimates that the Queensland CSG industry will use the equivalent to the water used by all Queensland households. The CSG industry estimate is one fifth of the NWC estimate. Water Group's estimate is between 2.5 times to five times the NWC estimate. So, surrounded by controversy, GSG is a huge phenomenon with great potential for maladaption and positive adaption if managed correctly. Adopting this intermediate step would place urgency on developing CCS at least for pre combustion, which implementing the CPRS will encourage. Foster et al. [17 sec. 2.5.2 & 2.5.3] further discuss CPRS, CSG, maladaption and the toxic chemicals used in the CSG extraction process. Section 2.6 discusses the CSG generator at Chinchilla in conjunction with solar power. Section 2.12 discusses gas generators role as a baseload replacement for coal or as peaking to complement renewable energy.

2.4 Diesel

Stevens [5] discusses the effect of climate change on the oil supply in North-eastern Queensland Australia, where tropical cyclones are expected to interrupt offshore oil production and exports form ports. However, only minor investment was considered necessary to improve adaptive capacity.

2.5 Biomass and Biogas

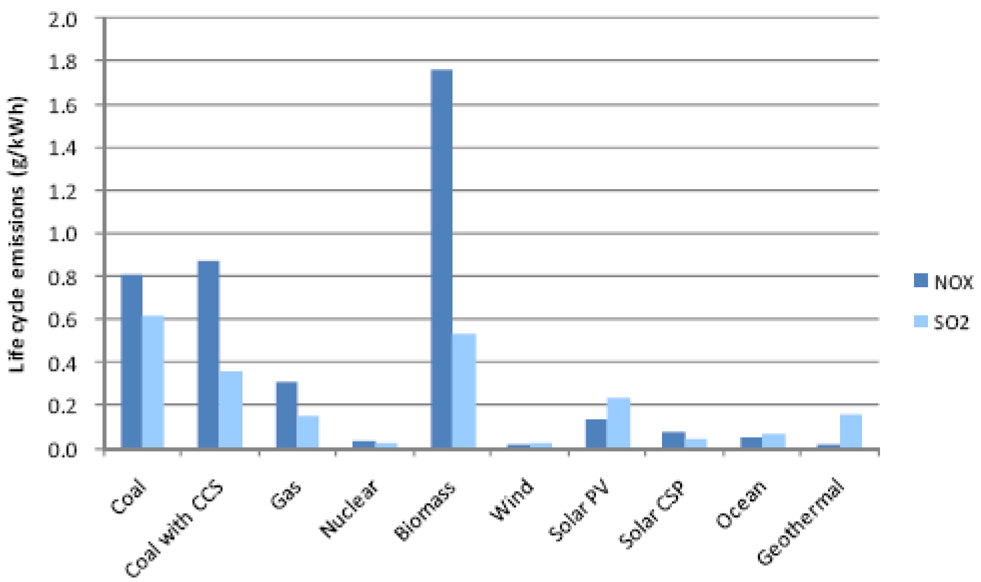
The projected effect of climate change on rainfall is discussed given biomasses' requirement for water.

"Best estimates of annual precipitation indicate little change in the far north and decreases of 2% to 5% elsewhere. Decreases of around 5% prevail in winter and spring, particularly in the south-west where they reach 10%. In summer and autumn decreases are smaller and there are slight increases in the east." [6]

The most likely projection is that the NEM less Tasmania and a small part of NSW will experience a 2% to 5% reduction in rainfall. Given biomasses' requirement for water, this reduces the potential for biomass.

Additionally, biomass is one of the most contentious of all the renewable energy sources. Biomass's future as a renewable fuel relies on the carbon neutral claim. However, burning biomass releases particulate into the atmosphere [30]. In addition, Figure 1 compares the life-cycle emissions of SO_2 and of NO_X in grams per kilowatt-hour for different power-generating technologies. The NO_X emissions of biomass are over twice that of coal and the SO_2 emission of biomass are comparable to coal. These emissions do question whether biomass has a future role as a renewable energy source. However, there are numerous sources of biomass and these emissions would be better analysed on a case by case basis.

Figure 1 Life-cycle SO_2 and NO_x emissions of power-generating technologies



[Source: 34]

Additionally, there is also an ethical problem with some forms of biomass. For example the recent episode of the US government subsiding corn for ethanol production increased the price of corn that is a staple diet for many poor people in Central America. This ethical dilemma of using food crops or arable land to produce biomass is an undesirable situation. So using crop or household waste as sources of biomass is more desirable from an ethical perspective. Furthermore, a positive aspect from using household waste as biomass is the reduction in landfill or as Bachelard and Gough [35] quoted Bioenergy Australia's Dr Stephen Schuck *"[Australia is] a world leader in biogas, and many of our large landfills and sewage treatment works catch it and burn it to feed electricity into the grid"*.

In addition to ethical considerations, Stebbins [36] reports on the farm price bubble in the Corn Belt created by the US government subsidies, which is proving politically difficult to manage, as rural communities become accustomed to higher wages and profits. This well intentioned US government policy has unintentionally created an ethical conundrums grounded in a maladaptive political economic dynamic, which provides a warning for implementing infant industry legislation without sufficient exit strategy to prevent the legislation becoming a permanent fixture. There are many infant industries in the renewable energy sector requiring R&D and initial assistance for commercialisation. Section 2.12 discusses the benefit of developing a portfolio of energy sources, which requires sharply targeted infant industry assistance with exit strategies. For instance Foster et al. [17 sec.

2.5.1] discuss the maladaptive high feed-in tariff as blunt infant industry assistance tool with the requirement to move to a more sustainable and more sharply targeted form of assistance in conjunction with CPRS. Foster et al. [17 sec. 2.5.4] discuss the maladaptive consequences of RET and RET refinement to foster a portfolio of energy sources.

Furthermore, biomass has the practical limitation of photosynthesis, which is about 3% in most plants. In contrast solar PV efficiency ranges from 4.4% to 43.4% [37]. Furthermore, solar PV installed onto existing rooftops leaves arable land unchanged. However, MUREI [30] notes that there is research into using high yielding algae to produce biomass but this endeavour is not yet commercialised. More recently, the Queensland Premier [38] announced Australia's first algae CO_2 absorption project at South Burnett power station, following successful trials at Townsville. While this avenue does address the ethical consideration of arable land use, the SO_2 and NO_X emissions require assessment.

An additional reason to avoid growing biomass for electricity is the reservation of biomass to produce substitutes for fossil fuels where the high power to weight ratio requirement precludes alternatives, for instance jet fuel. Bachelard and Gough [35] discuss how Virgin Blue wants 5 per cent of its fuel to be sourced from bio-fuel by 2020. One source is eucalyptus mallee from Western Australia, which undergoes a process to extract the oil and other by products. Eucalyptus has been used for 15 years in Western Australia to combat soil salinity and erosion problems, which provides utilisation and stabilisation of marginal land. Eucalyptus is harvest by cutting to ground level, which then re-grows from the rootstock. Currently, there are just 12,000 hectares growing but an estimated 2 million hectares would be required to fuel Australia's domestic air travel. However, using biomass for jet fuel is also contentious, as the ABC [39] reported on a Virgin test flight of bio-fuel being labelled a *"green-wash"*.

MUERI [30] suggests that biomass be restricted to crop waste, which is burnt during the lulls of solar thermal generation and is co-located with solar thermal plants to use the same electric generator. The biomass can be converted into pellets for easier storage and transportation.

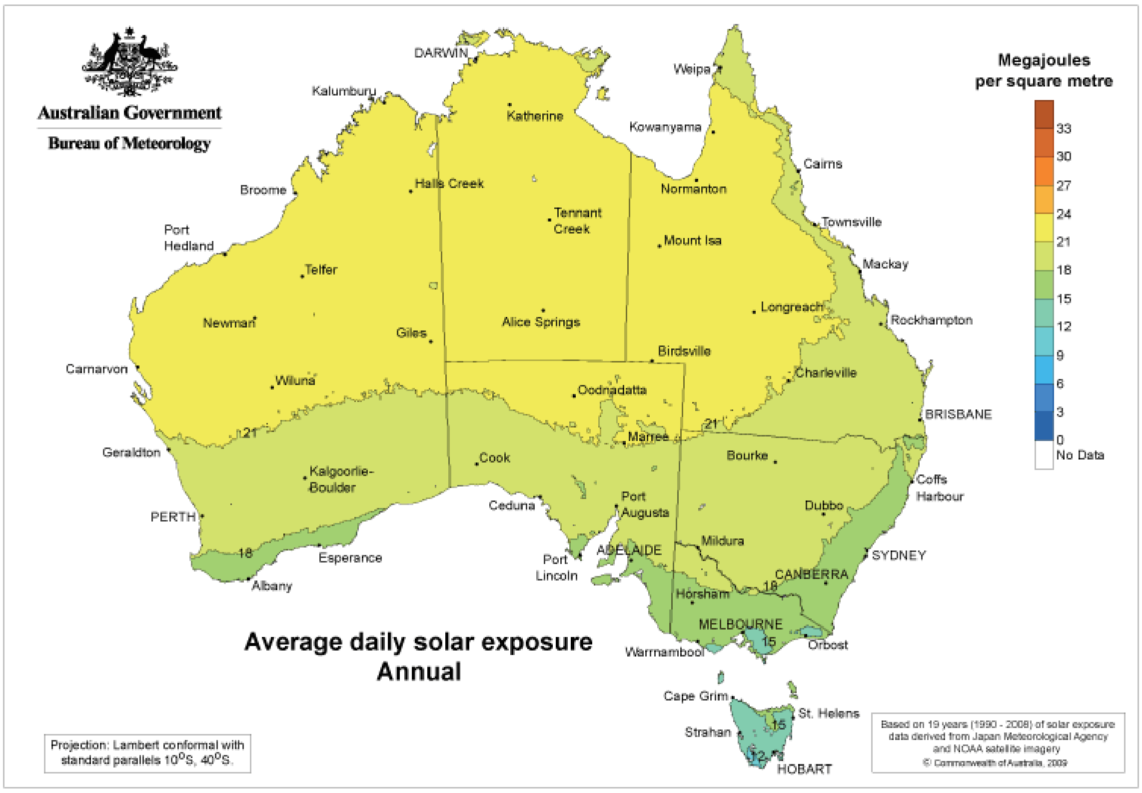
2.6 Solar

The CSIRO [6] discusses projected change in solar intensity from 1990 to 2030 and found in the most likely case there was no significant change across Australia. *"Projections of solar radiation generally show little change although a tendency for increases in southern areas of Australia is evident, particularly in winter and spring. The projected range of change is typically -1% to +2% in 2030."*

This change in solar radiation in conjunction with the projected increases in temperature affects the solar PV electricity output where a simultaneous increase in solar intensity and temperature is countervailing but the simultaneous increase in temperature and decrease in solar intensity would reduce output.

However, in the most likely case from 1990 to 2030 there is no significant change in solar radiation across Australia. Figure 2 shows the current average daily solar exposure which provides a good approximation of the solar conditions to 2030. This is significant as adding some certainty to finding the best locations for solar generation, aiding adaption. This contrasts with wind speed where there are projections for significant changes in season variations across the NEM, which makes finding the best location more difficult. Section 2.7 further discusses the seasonal variations in wind speed.

Figure 2 Average daily solar exposure - Annual



[Source: 40]

Furthermore, the highest solar exposure contour is approximately coincident with the current highest temperature contours and with the highest projected change in temperature.

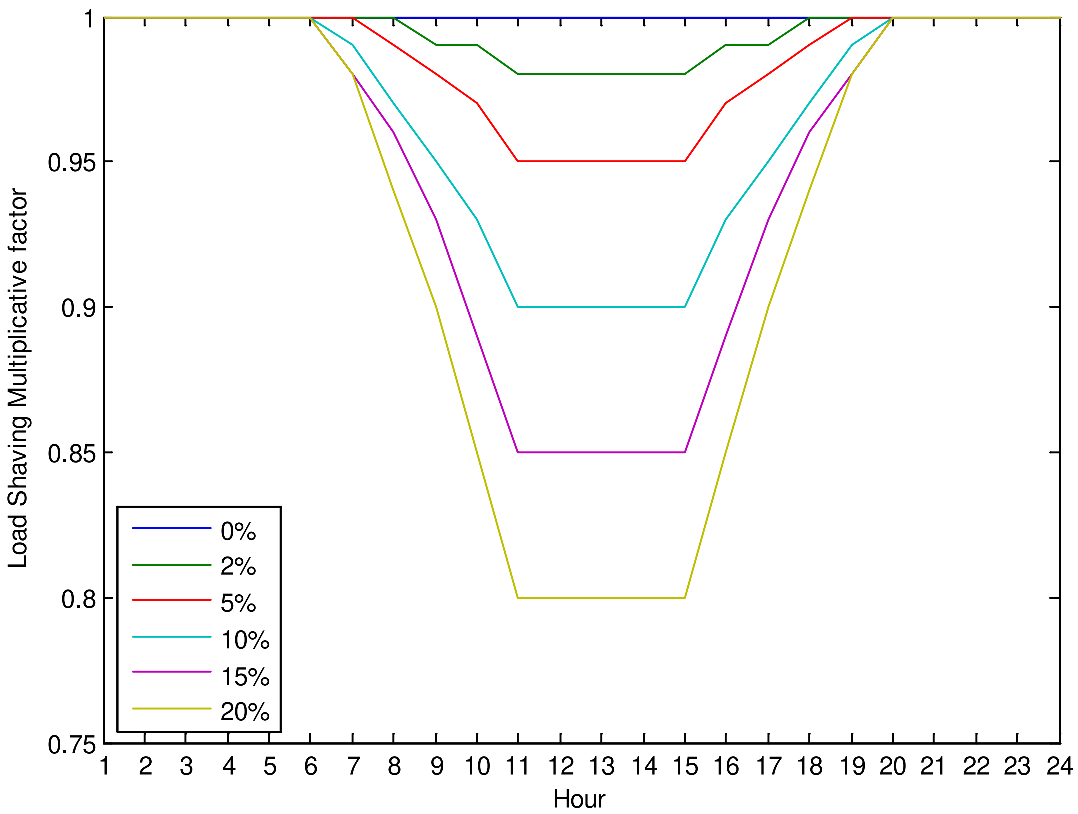
"The best estimate of annual warming over Australia by 2030 relative to the climate of 1990 is approximately 1.0ºC, with warmings of around 0.7-0.9ºC in coastal areas and 1-1.2ºC inland. Mean warming in winter is a little less than in the other seasons, as low as 0.5ºC in the far south. The range of uncertainty is about 0.6ºC to 1.5ºC in each season for most of Australia. These warmings are based on the A1B emission scenario, but allowing for emission scenario uncertainty expands the range only slightly - warming is still at least 0.4ºC in all regions and can be as large as 1.8ºC in some inland regions. Natural variability in decadal temperatures is small relative to these projected warmings." [6]

This means that the highest solar intensity areas are the hottest and projected to increase in temperature more than cooler areas. This observation has consequences for the type of solar generators. Solar PV becomes less efficient as the temperature increases whereas solar thermal is relatively immune. The highest solar intensity regions are the interior of Queensland and of Southern Australia. However both region are sparsely populated, which provides the advantage of cheaper land but the disadvantage of extra transmission costs. The remainder of the NEM region is well suited to solar generation other than Tasmania and southern Victoria. This ability to be widely distributed is an important adaptive advantage in transmission investment deferment. An often cited negative aspect to solar power is the daily cycle but this cycle is predictable and fits the demand profile of industry.

An additional negative aspect to solar is intermittency where cloudiness can suddenly reduce power output. However Tan [41] discusses how the grid can accommodate solar energy without storage by responding to changes in real time to meet intermittency but concedes that the intermittency will become a problem as the penetration of solar PV or of solar thermal without storage increases. Section 2.7 discusses reducing the contract for reserve capacity in shorter time frames to meet greater intermittency. Section 2.8 discusses storage to meet intermittency. Section 2.12 discusses a portfolio of renewable energy sources to ameliorate intermittency.

Taking advantage of predictability of solar energy, Wild and Bell [42 sec. 4.3.1] use a load shaving profile method to model PV penetration by shaving a percentage off the existing demand. This project extends the load shaving method to model solar thermal and wind generation. Figure 3 shows the summer version of the six load shaving profiles that are analysed in Wild and Bell [42], which include 0%, 2%, 5%, 10%, 15% and 20%.

Figure 3 Summer load shaving profile



[Source:42 sec. 4.3.1]

The 0% profile is the business as usual scenario with regards to load shaving that is no PV. Figure 3 shows that the load shaving profiles are well suited to modelling solar based applications where load shaving commences early in the morning, gradually increasing over mid-morning and reaching a maximum around midday before tailoring off during mid-afternoon and completing dying out during late afternoon. The winter load shaving profile is a compressed version of the summer load shaving in both extent and duration. Figure 3 provides a highly stylised profile for a daily cycle, which this project extends by using the BoM's [43] real solar intensity data where the average of a number of representative weather stations in each demand region will form the profile for each day for the baseline year .

Table 1 shows the Australian Government [44] legislated amended renewable energy targets (RET) where the years 2020 to 2030 inclusive are 41,000 GWh. This project assumes that the targets are met and investigates the effect on the NEM of differing portfolios of solar and of wind to meet the targets. This investigation endeavours to identify potential maladaptive effects from certain portfolios and to find if there is some optimal portfolio of wind and solar. Section 2.7 discusses wind generation and section 2.12 discusses wind and solar portfolios with respect to transmission investment deferment.

Table 2 Renewable energy target legislated by the Australian Government

Required GWh of renewable source electricity	
Year	**GWh**
2011	10400
2012	12300
2013	14200
2014	16100
2015	18000
2016	22600
2017	27200
2018	31800
2019	36400
2020	41000
2030	41000

[Source: Australian Government 44]

Furthermore with respect to transmission deferment, the flexibility over the geographic deployment of solar generators comes in three ways, as roof top installation, as large-scale installations adjacent to the network within high demand regions or as a replacement or complement to existing fossil fuel generators with pre-existing transmission.

The Solar Flagships Program managed by the Department of Resources, Energy and Tourism [45] provides two examples of large-scale solar power deployments that defer transmission costs. First, Moree Solar Farm in NSW is a PV installation that serves rural communities at the end of a transmission loop without generators. Second, a solar thermal installation, called Solar Dawn [46], at Chinchilla in Queensland, which is co-located along the Roma to Tarong transmission line with the Condamine coal seam gas generator. Section 2.12 further discusses the adaptive path of gas with renewable power.

The Kogan Creek Solar Boost Project [31] provide an example of solar power using pre-existing transmission as a replacement or complement to the Kogan Creek generator. In addition to transmission investment deferment, there is the potential for solar thermal to replace coal fired boilers to reuse the steam turbine and electrical generators. Section 2.2 discusses the positive social aspects of this development.

Another case of fragmentation induced maladaption is the optimal positioning of new large scale solar generators, which requires optimising across the legislation of five state governments and optimising across the best connection to the ten distribution companies and six transmission companies in the NEM. This fragmentation of infrastructure and superstructure is a reoccurring source of maladaption. The Queensland Solar Atlas and the Solar Bonus schemes in NSW provide examples of fragmentation induced maladaption.

Robertson [47], the Queensland Minister of Energy, discusses the 'Queensland Solar Atlas' hosted by the Office of Clean Energy [48], which is designed for energy businesses interested in investing in solar energy in Queensland. The Queensland solar map is a useful aid to business but indicative of the fragmented institutional structure in the NEM, which increases the difficulty of business trying to make the best investment decision across the whole of the NEM and duplicates effort across the five state governments and federal government. This fragmentation induced maladaption produces an inferior investment environment at the cost of duplicating effort.

There are differing methods to calculate the tariff in each state for instance the Auditor-General of NSW [49] proposes a 'new solar bonus scheme'. This fragmentation induced maladaption adds to the complexity of decision making and distorts the price signal for investors by using different method to calculate feed-in tariffs.

In a further source of maladaption, the bonus or high feed-in tariff is a blunt policy instrument because the tariff combines two targets being carbon emissions reduction and infant industry assistance. But in 2012 the Carbon Pollution Reduction Scheme (CPRS) will be introduced to specifically target carbon emissions. Regarding infant industry assistance, solar PV and onshore wind generation are no longer infant industries, so the high tariff only acts to reinforce their first mover advantage, which in effect blocks the development of alternative renewable infant industries. Foster et al. [17 sec. 2.5] further discuss feed-in tariffs, CPRS, RET and fragmentation induced maladaption.

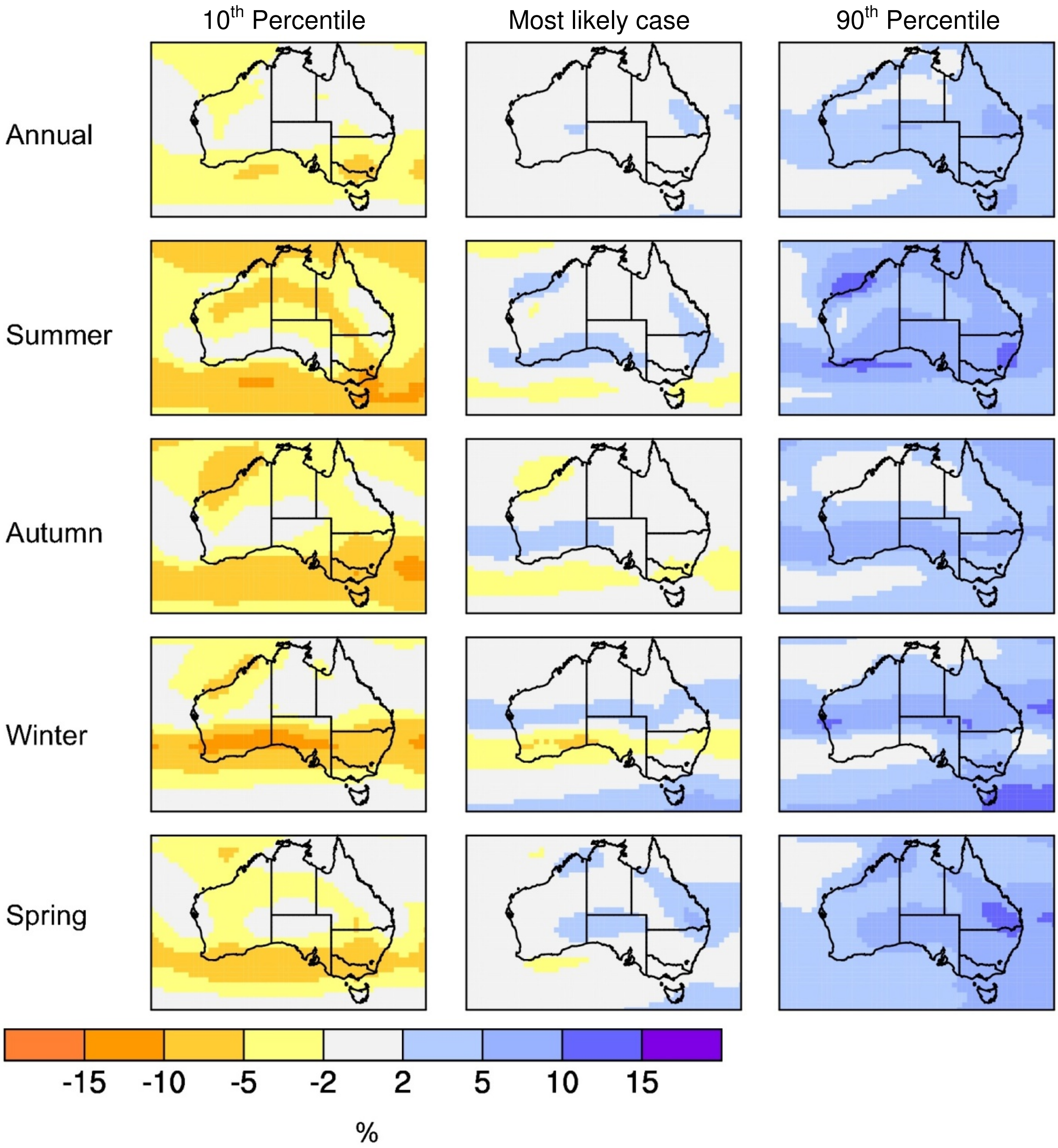
2.7 Wind

"There is a tendency for increased wind speed in most coastal areas in 2030 (range of -2.5% to +7.5% with best estimates of +2% to +5%) except for the band around latitude 30°S in winter and 40°S in summer where there are decreases (-7.5% to +2.0%, with best estimates of -2% to -5%)." [6]

Figure 4 shows the projected change in wind speed from 1990 to 2030 for the medium emission scenario that is SRES A1B. The wind projection for the SRES scenarios AIB and A1FI are nearly identical, which shows the GCMs are insensitive to these two scenarios until 2030. The change in wind speed shows considerable seasonal variation in contrast to the change in temperature and downward solar radiation.

In the most likely case, Figure 4 shows a distinct seasonal pattern where a latitudinal band of decreased wind speed moves from Tasmania in summer, to Victoria in autumn, to NSW and SA in winter where the band dissipates in spring. In tandem in winter two bands of increased wind speed appear in the latitudes about south Queensland and Tasmania, which also dissipate in spring. In the 90th percentile wind speed increases across the NEM, this would provide wind generators with more output. However, in the 10th percentile wind speed across the NEM decreases, which would reduce the output for wind generators. So, there is good reason to study the 10th percentile when considering this reduction in power from wind generators for the effect on the NEM.

Figure 4 Predicted seasonal wind speed change from 1990 to 2030 for SRES A1B



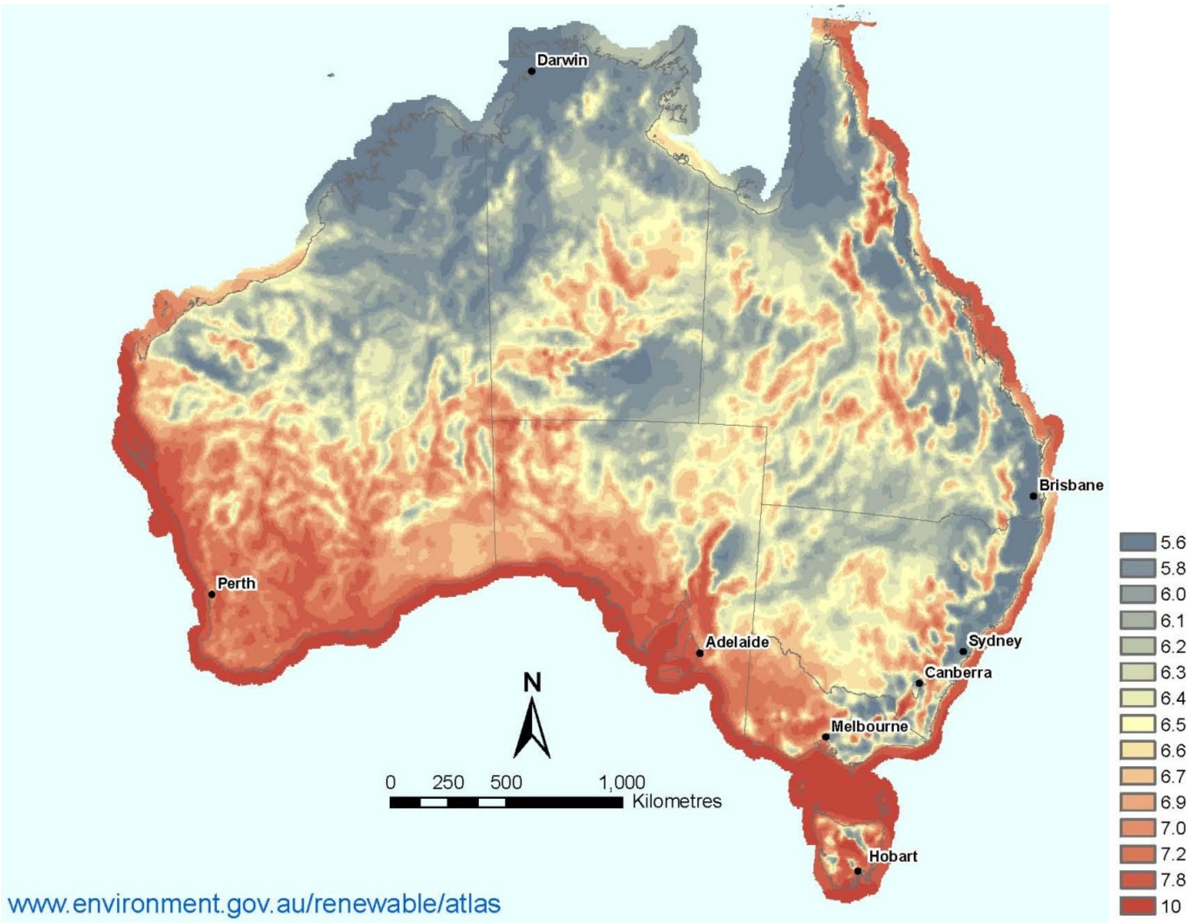
[Source: 6]

Figure 4 shows the projected change in wind speed in the most likely case would be a 2 to 5% reduction in wind speed in a narrow band that travelled northward from Tasmania in summer to northern NSW in winter where the band dissipated in spring. In addition to this band of seasonal decrease, there is a corresponding band where wind speed increases by 2% to 5% across Queensland and Tasmania in winter. These climate change induced bands of wind speed swings of up to 10% are significant but the bands only affects regions for a season, so the average effect is insignificant, as can be seen in the annual wind speed map in Figure 4.

Importantly, this band effect illustrates the need for interconnection between states to average out such variation in wind speed across the states confirming that onshore wind generation needs deeper integration of interstate transmission.

Most wind towers are 80 metres high. Figure 5 shows the wind speed at 80 metres above ground level in metres per second in 2008 where the more intense the red the higher the wind speed and the more intense the grey the lower the wind speed. Considering the climate change effects on wind are overall minimal if the states are well interconnected, Figure 5 provides an approximation to the wind speeds in 2030 to help find the best location for wind generators, which indicates that Tasmania, South Australia and Victoria are well endowed with wind energy close to the population centres. However the populated region between Sydney and south east Queensland has mild wind, which would require transmission investment to bring wind to these locations from further inland. This again confirms our earlier statement that onshore wind generation will require more intrastate transmission investment.

Figure 5 Mean wind speed in m/s at 80m above ground level



[Source: 50]

A further consideration in locating wind generators is their size. With diameters of up to 90m, placing wind farms in close proximity to population centres is unlikely for ascetic, health, environmental, land cost and safety reasons. For instance the Economist [51] reports on how the Bald Hills wind project, Victoria, in 2006 was rejected based on the danger posed to the rare orange bellied parrot. Additionally, Rapley and Bakker [52] review the literature on sound, noise, flicker and the human perception of wind farm activity, which suggests that a section of the population are adversely affected with sleep disturbance, headaches, dizziness, anxiety and depression but some experts claim that the noise levels are virtually undetectable and so low that sound cannot directly cause these symptoms. Onshore wind farm deployment is a contentious issue. As can be seen in Figure 5, Australia does have the option of offshore wind generation being adjacent to the highly populated coastal areas and large sparsely populated inland areas.

The transmission deferring ability of solar and wind contrasts sharply, as Figure 2 shows solar generators can be distributed around most of the NEM region to defer transmission costs whereas wind generation requires further interstate and intrastate transmission investment to smooth out variation and to take the power from remote locations to the grid, respectively. This comes with the caveat that onshore wind generation is transmission investment deferring to a point because the windy locations adjacent to existing transmission infrastructure are initially used to meet local demand. After which more transmission infrastructure is required to export the excess supply and more remote locations for wind farms are established, requiring new infrastructure. Simulations and current developments are consistent with the requirement of wind generations for more transmission, after an initial transmission investment deferment phase.

For instance Zhao [53] uses simulations to investigate the effectiveness of wind generators or PV in transmission deferment within Queensland and finds after the initial addition of wind generation there is deferment but subsequent addition of wind generation requires more transmission. This dynamic is a consequence of the large disparity in wind distribution in Queensland where the windiest places are on the northern edge of the grid. This project extends Zhao's [53] simulation regionally from just Queensland to the whole of the NEM and from just simulating either solar or wind penetration to different portfolios of solar and wind to meet the RET as discussed in section 2.6 and shown in Table 1.

Consistent with Zhao's [53] simulation of early deferment are the existing South Australian wind farms at Cathedral Rocks, Mt. Millar, Snowtown, Mintaro, Wattle Point, Starfish Hill, North Brown Hill, Hallett Wind Farm, and Hallett Hill, which were placed close to pre-existing transmission and population centres.

Regarding new transmission, Windlab [54] specialises in prospecting for sites most suitable for wind farms. Four sites selected for development are:

- Kennedy located 290km south-west of Townsville, Queensland
- Oakland hill located 5km south of Glenthompson, Victoria
- Coopers Gap located 65km north of Kingaroy, Queensland
- Collgar located 25km south east of Merredin, Western Australia

Kennedy provides an example of a proposed wind farm cluster built in a remote location and requiring new transmission [55]. The new transmission line will be connected to the grid southwest of Townsville. This connection point near the edge of the NEM may require further transmission investment to take the extra supply from a wind farm expansion in Kennedy. A positive aspect to this development is how private enterprise has invested in transmission from the edge of the NEM to a remote location that is suitable for a cluster of wind farms. However, there is the problem of having extra supply on the edge of the grid away from the main demand centres, with the potential for further supply expansion and with the subsequent required upgrading of adjoining transmission. This multiple ownership of a network structure where the action of one owner affects the dynamics of the network is a pricing challenge, which is particularly relevant to wind generation and the significant transformation of the network required to absorb the variability and patchy geographic spread of the resource wind.

These findings support Garnaut's [11] claim that *"there can be large gains from planning transmission for a truly national electricity market, with greater inter-state connectivity increasing competition, resilience against supply shocks, and reducing the cost of connecting new low-emissions power sources."* Foster et al. [17 sec. 2.5.6] further discuss the issue of transmission ownership in a truly national electricity market.

Furthermore, AEMC [9] recognises the need to develop a new mechanism to deal with the ownership of and payment for building new transmission into new regions of high wind suitable for clusters of wind farms. Campbell, Banister and Wallace [56] agree calling for new ideas to address this issue.

However, Banister and Wallace [57] suggest the advantage of exporting wind energy between regions may be overrated. Table 2 shows that there appears to be little correlation of regional wind generation output with regional demands but there does appear to be quite significant correlations between wind farms. However Figure 4 shows that climate change is expected to alter wind patterns, which will reduce the correlation between states and increase the coincidence of simultaneous electricity surpluses and deficits between states.

Table 3 Correlation of wind and demand

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

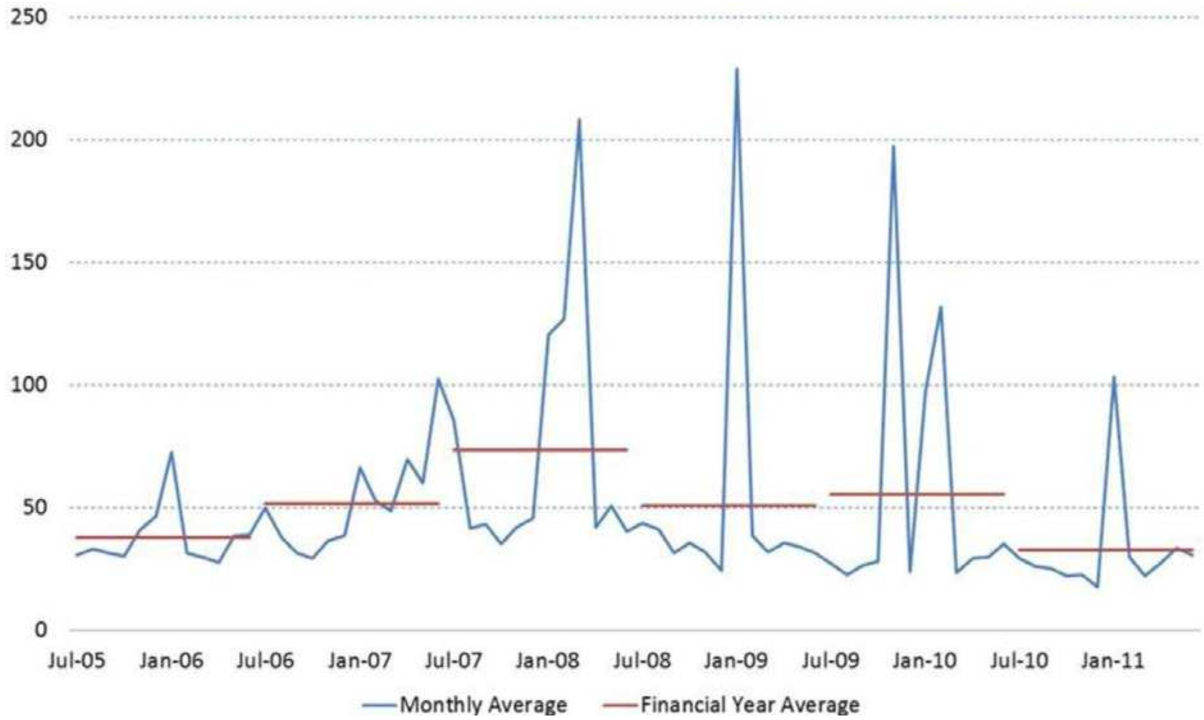
[Source: 57]

Foster et al [58] states that the evolution of efficient storage systems will be critical in solving transient stability problems associated with wind generation. Alternatively, AEMC [9] discuss a solution proposed by the reliability panel in accordance with the national electricity law, which is an increased capacity for AEMO to contract for reserve capacity in shorter time frames than has been possible to date, where OCGT and hydro could meet the transient stability problem in a peaking role. Section 2.12 discusses the role of gas in this peaking role as OCGT rather than as a baseload replacement for coal and Section 2.8 further discusses storage.

Additionally, technological innovation in the electronics of wind turbines can help combat adverse stability conditions. For instance the Finnish Technical Research Centre or *Valtion Teknillinen Tutkimuskeskus* [59] discusses how recent innovations in the electronics of wind turbines themselves and when combined with transmission technologies incorporating flexible AC transmission systems (FACTS) such as static var compensators (SVC) can combat adverse stability consequences by providing fault ride through and by suppling ramping capability for frequency control and reactive power for voltage stability. However VTT [59] notes that modification of legislation or codes in many countries is required to make use of the technology.

Furthermore, Parkinson [60] argues that the transient stability problem of wind farms may be overstated where in South Australia, which has Australia's largest penetration of wind, the requirement for OCGT or peaking gas has actually fallen, as has the spot price for electricity. The AMEC chairman [61] confirms this reduction in the average sport price for electricity in SA, see Figure 6.

Figure 6 Average Sport Price in South Australia per MWh



[Source: 61]

However the AMEC chairman also discusses the increase in volatility in spot price in Table 3 where there have been increases in half-hours with negative spot prices and increases in half-hours with spot prices above $5,000 and $300 per MWh. The increase in negative spot prices and the reduction in 2010 of high sport prices are consistent with Parkinson's [60] claim that the demand for OCGT has fallen.

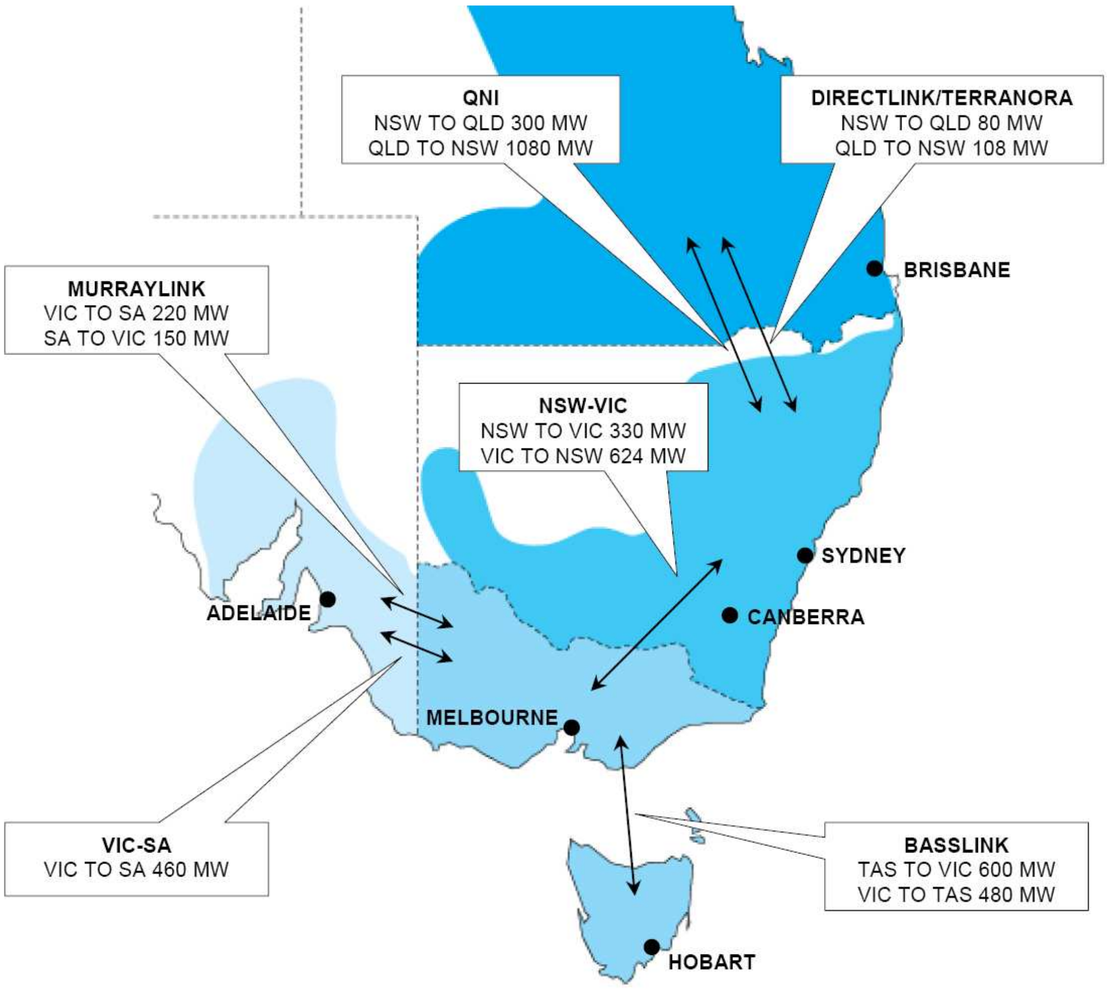
Parkinson [60] claims that there are successful large installations in a number of countries where variability has not posed a major problem. For instance Jones [62] discusses the East German company 50Hertz that has 37% of electricity supplied by wind generation. However, 50Hertz can sell and send surplus electricity to Poland, Czech Republic, Austria, Denmark or the former West Germany, which would reduce the likelihood of negative prices. In contrast Figure 7 shows that SA can only send its surplus electricity to Victoria. Additionally, examination of the interconnectors shows a 150 MW thermal capacity from SA to VIC but a 680 MW thermal capacity from VIC to SA. This large VIC to SA thermal capacity is a legacy of the cheap electricity generation in Victoria using brown coal. Exacerbating the situation, Parkinson [60] notes that there are legislative moves in Victoria to block interconnector expansion from SA to VIC, which is a source of maladaption to climate change.

Table 4 South Australian wholesale prices

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

[Source: 61]

Figure 7 Interconnectors on the NEM

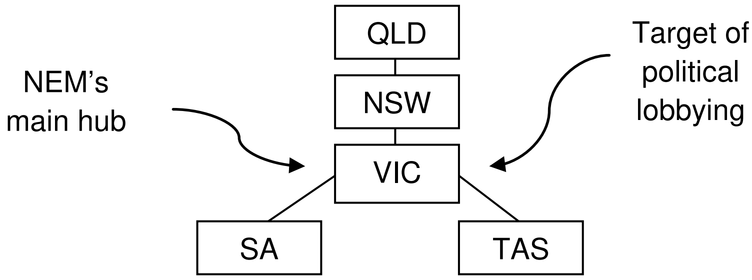


[Source: 63]

Additionally, Parkinson [60] notes legislative moves in Victoria to hinder the installation of new wind generation, which is a further source of maladaption. Together the legislation blocking the interconnector expansion and hindering further wind generation installations will promote the continued use of brown coal in Victoria's state own power stations, which produces the highest CO_2 emissions per unit of electricity of any other fuel.

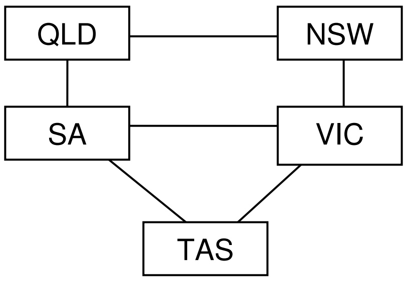
Figure 8 shows that the politically lobbying and conflict of interest is targeted at the main hub in the NEM. By targeting the main hub in the NEM, the role for wind generation is especially undermined and generation from renewable sources generally.

Figure 8 NEM's main hub targeted by political lobbying and conflict of interest



However, NEMLink provides a solution to the maladaption in Victoria exacerbated by Victoria's position as the main hub in the NEM. Figure 9 shows the topology of NEMLink. Garnaut [11] discusses NEMLink [64] as providing a truly national grid by adding interconnectors between SA and QLD and between SA and TAS. The current grid topology in Figure 8 lacks redundancy where breaking the interconnectors between two states isolates parts of the grid. In comparison, the NEMLink topology in Figure 9 can lose the interconnectors between any two states and the grid stays connected. This redundancy provides technical advantages [65] but also provides redundancy against political maladaption. Foster et al. [17 sec. 2.5.6] further discuss the conflict of interest of state involvement in interconnector management.

Figure 9 NEM's topology under NEMLink



NEMLink was not justifiable in the short term but came close to break even in a strong carbon price scenario in 2021. NEMLink is currently under review [65]. The forthcoming papers use sensitive analysis to investigate NEMLink. Furthermore, the SA-TAS interconnector of NEMLink provides the opportunity to develop pumped hydro storage in Tasmania from the excess electricity from onshore wind generators in SA. Section 2.8 further discusses pumped hydro storage.

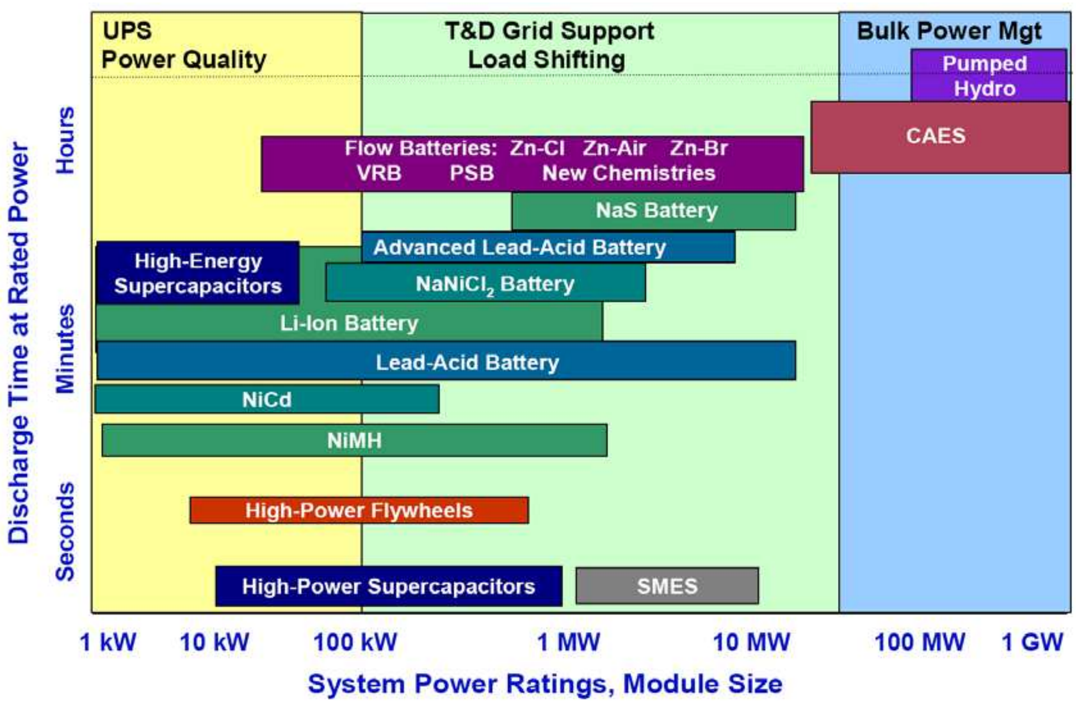
The forthcoming papers simulate different solar and wind portfolios to meet the RET to test the NEM's ability to cope with the projected increases in variability of wind by 2030. Additionally, the report investigate relaxing the constraints on interstate transmission to test Garnaut's [11] claim regarding inadequate interconnectors and to test the integration of further onshore wind generation into the NEM.

2.8 Storage

Energy storage offers the benefit of 'time shifting' that is allowing electricity to be produced for consumption at a later time. Time shifting has at least two major bulk applications. Firstly, generators have the ability to store energy off peak for release onto the grid during peak time, which provides investment deferment for generation. Secondly, storage located adjacent to net demand regions on the grid stores energy during off peak to meet peak demand, which provides investment deferment potential for both transmission and generation.

EPRI [66] claims that over 99% of storage capacity worldwide is pumped hydro. Figure 10 shows the positioning of energy storage types where pumped hydro provides bulk power management to occupy the highest system power rating and longest discharge time combination and compressed air energy storage (CAES) the next largest bulk power management system. Other forms of storage find alternative roles such as Li-ion batteries in frequency regulation. EPRI [66] compares the cost of various bulk energy storage options to support systems and large renewable integration and finds CAES is currently about half the price of pumped hydro. EPRI [66] expects Li-ion batteries to reduce dramatically in price after mass production to meet the demand in the automotive industry. CAES and in future Li-ion batteries will provide renewable energy generators with suitable technology to smooth out power output fluctuations and defer investment in transmission and generation.

Figure 10 Positioning of energy storage technologies



[Source: 66]

While pump hydro is a mature technology and well established on the NEM, the legal and technical aspects of time shifting for other storage technologies is the subject of further research. Foster et al. [17 sec. 2.5.5] further discusses grid linked storage that this project uses as an adaption to climate change performance indicator. A forthcoming papers will model the transmission and generator investment deferring ability of storage. The next section discusses pumped hydro storage in more detail.

2.9 Hydro

Section 2.5 discusses the projected 2% to 5% decrease in rainfall due to climate change by 2030 for the NEM region less Tasmania and a small part of NSW. In addition, rainfall in far north Queensland is projected to be unaffected. Consistent with the projected decreases in rainfall for the majority of the NEM region, Stevens [5] finds that hydro capacity will be adversely affected. However, the projected rainfall in Tasmania and far north Queensland is unaffected, which bodes well for the substantial hydro facilities in Tasmania. In far north Queensland, Stevens [5] suggests that hydro could be considered as a distributed energy source to ameliorate the combined effect of the remoteness on the NEM and of the projected increases in storms that could increases the frequency of power failure due to loss of transmission or distribution. In contrast, MUREI [30] sees no role in expanding hydro and MUREI [30] suggests the role of backup for existing hydro to meet peak demand with an expansion in pumped hydro to increase storage. Tasmania is the most likely candidate for the introduction of pumped hydro for three reasons. First is the existing extensive hydro development. Second is the projection for no appreciable change in rainfall in 2030 discussed in Section 2.5. Third is a projected increase in wind speed for most of Tasmania other than a slight decrease in summer in northeast Tasmania in 2030 discussed in Section 2.7. These three factors make the combination of expanding wind generation and of introducing pumped hydro storage very attractive for the export of electricity. The forthcoming papers propose using a simulation to investigate an expansion of onshore wind generation in conjunction with introducing pumped hydro storage in Tasmania.

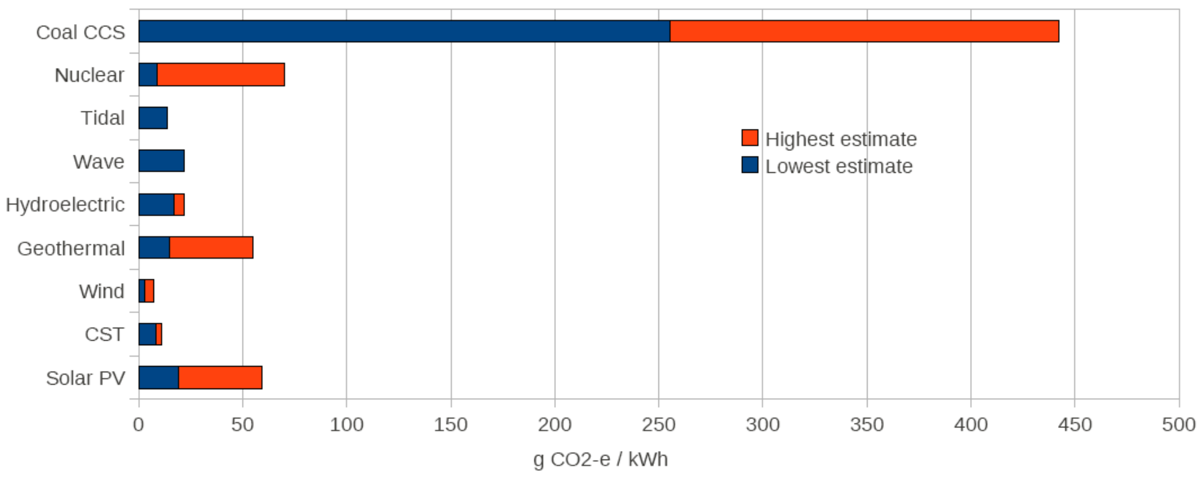
2.10 Geothermal, wave, tidal and other renewable energy sources

At the time of writing, the previous sections complete a discussion all the renewable energy generation technologies with at least one planned commercial installation in Australia. There are many other forms of renewable energy at varying stages of development around the world. Bachelard and Gough [35] describe a key problems with comparing large-scale renewable energy is a "beauty parade" of dozens of different options where the costs and reliability are relatively untested and are therefore argued vigorously. So, rather than trying to pick winning technologies, an alternative approach is developing a framework to treat each technology on an equal footing that is to acknowledge the requirement for infant industry assistance until the first commercialised operation when equal access to the grid and remuneration at the locational marginal price is provided and where the CPRS acts as the mechanism to address CO_2 emissions, as suggested by Garnaut [2]. Noting even the coal generators received assistance from the states in an infant industry stage. Foster et al. [17 sec. 2.5] discuss maladaption and institutional structures impeding the development of a suitable environment to assist a wider range of renewable energy technologies through their infant industry stage to achieve a broader portfolio of energy sources. Section 2.12 discusses the benefits of a broader portfolio of energy sources.

2.11 Lifecycle carbon footprint of generating technologies and transmission

Figure 11 shows the expected CO_2 emissions per kilowatt hour averaged over the life cycle of the generating technology. Figure 11 could be extended to include OCGT and CCGT in combination with and without CCS. Gas generators provide a potential intermediate step to a more balance portfolio of renewable energy. Furthermore, if the lifecycle CO_2 emissions of transmission and distribution is add to all the generator types other than rooftop installed solar PV, this would help reduce the CO_2 emissions gap between solar PV and the other forms of renewable energy.

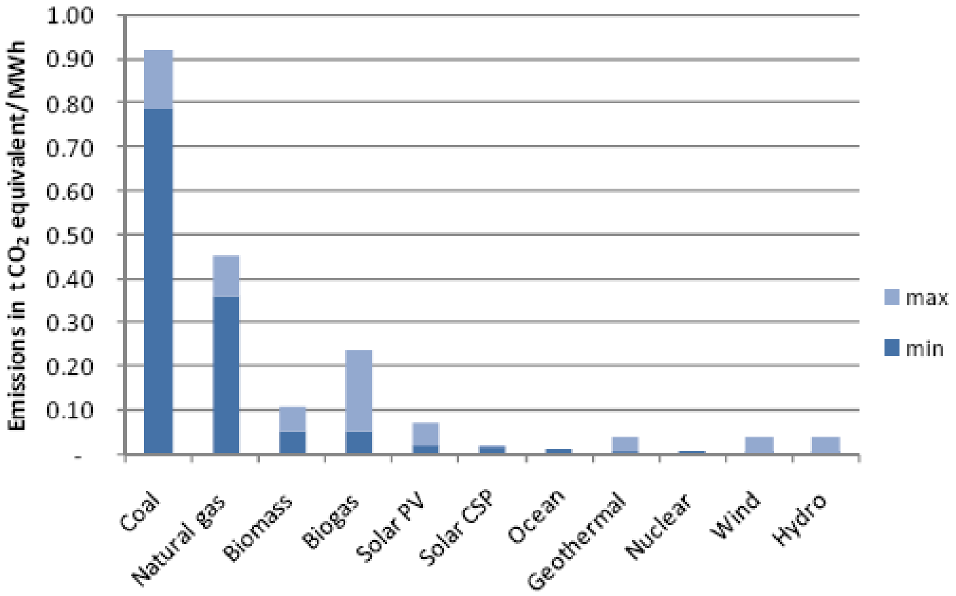
Figure 11 MUREI's life-cycle CO_2 emissions of power generating technologies



[Source: 30]

Like Figure 11, Figure 12 compares the life-cycle CO_2 emissions of power generating technologies but includes natural gas, biomass and biogas.

Figure 12 IEA's life-cycle CO_2 emission of power-generating technologies



[Source: 34]

Figure 12 shows that natural gas offers half the CO_2 per unit of power than coal, so using gas in an intermediate step does provide an avenue to reduce CO_2. This ratio of coal to gas emissions per unit of power would be amplified under CPRS when the older more CO_2 emissions intensive coal generators close and are replaced by more efficient gas generators. Furthermore, biomass and biogas do offer substantial reductions in CO_2 emissions but there are additional ethical and emission problems that Section 2.5 discusses. But rather than selecting the source of energy with the lowest CO_2 emissions, there are advantages to a portfolio of energy. In addition, as the technologies mature, the relative ranking of lifecycle CO_2 emissions will alter and only with hindsight can one select the lowest lifecycle emissions technology, so prematurely selecting a technology and terminating the evolutionary path of other technologies is unadvisable.

2.12 Portfolio of energy sources and baseload as a source of maladaption

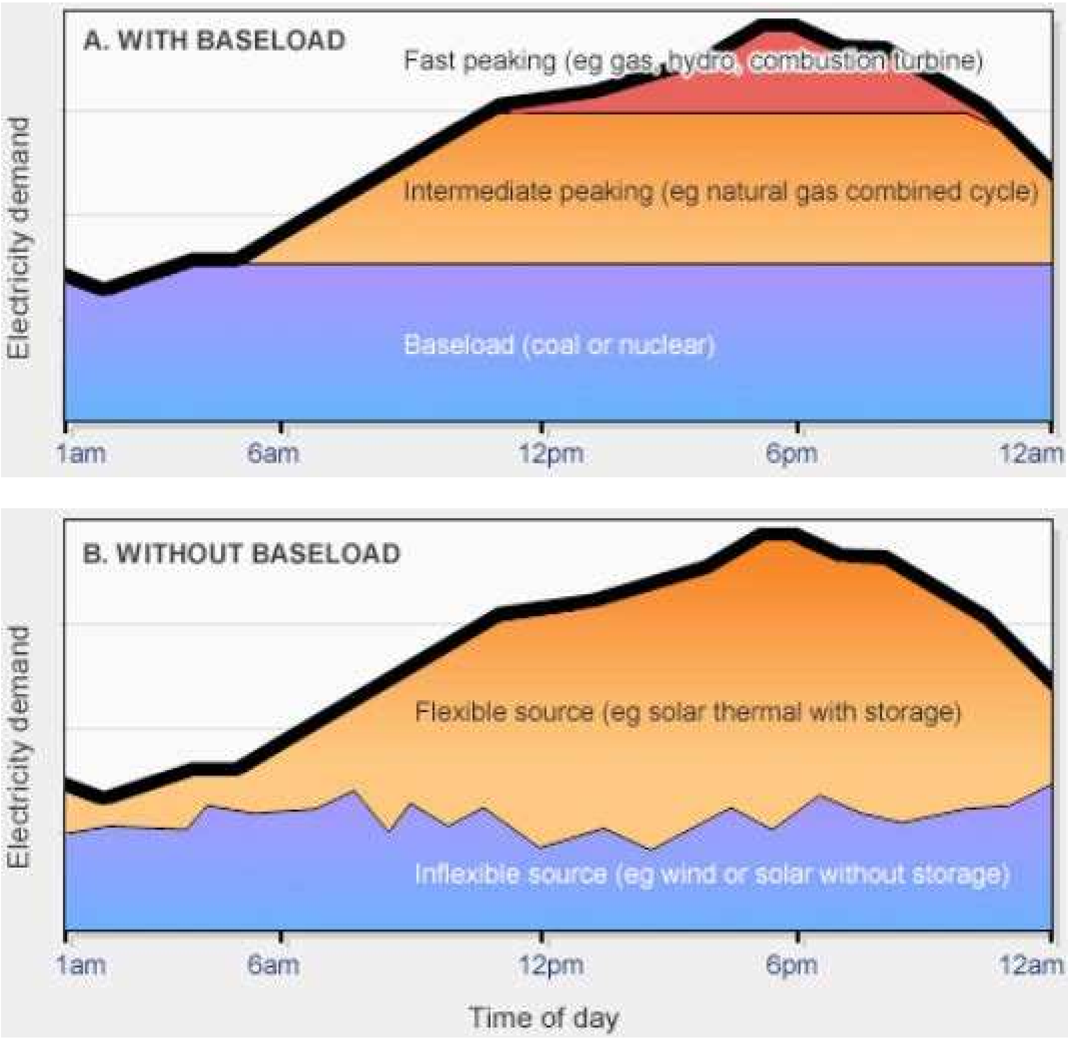
This section discusses energy as a portfolio, the implications for infant industry targeting and the baseload concept as a source of maladaption.

IEA [34] finds that having a significant share of renewable energy in a country's energy portfolio can increase energy availability and reduce supply risk. Renewables in an energy portfolio reduce the volatility associated with the price of fossil fuels and reduce supply disruption risk. For instance, the Queensland floods in late 2010 hit the coal mining sector, which reduced supply globally. Similarly, Hurricane Katrina in the US in 2005 put oil prices under upward pressure due to the loss of refining capacities.

In addition to a portfolio between fossil fuels and renewables, there is diversification among renewables, currently the main two main forms are onshore wind and solar PV, other than the traditional hydro. Herein lies the maladjustment, the existing RET schemes and feed-in tariffs reinforce the first mover advantage for onshore wind and solar PV. In addition, solar PV is near market parity [67] without feed-in tariffs. Similarly, onshore wind in New Zealand is being deployed without dedicated support for renewables. However Watt [67] concedes that parity is insufficient to induce investment in solar PV as people expect a much quicker payback on capital than calculated by NPV. So, there is a policy requirement to address people's myopic investment behaviour and to provide a more targeted infant industry assistance to encourage renewables that offer energy profiles differing to solar PV and onshore wind, such as, wave and offshore wind to reduce risk. Foster et al. [17 sec. 2.5.1] further discuss feed-in tariffs and financing investment in renewables and Foster et al. [17 sec. 2.5.4] further discuss RET and encouraging diversification by more selectively targeting infant industries.

A further source of maladaption to introducing a renewable energy portfolio is the baseload concept that could form psychological anchoring, which detracts focus from developing a renewables energies portfolio to searching unnecessarily for a baseload generator replacement. Figure 13 shows how traditionally coal generators produced the baseload power and other forms of generation fit around this baseload. Baseload coal is required to maintain a minimum stable operating level, which has two negative aspects. First is that this minimum stable operating level puts an effective floor on the minimum level of carbon emission reductions that can be secured. Second is that this minimum level produces overnight negative spot prices, which drives out other forms of generation and in particular makes wind generation less economic viable, see Table 3. Furthermore, these negative spot prices indicate that coal generators are producing unwanted electricity to maintain their minimum operating output and the associated unwanted carbon dioxide.

Figure 13 Meeting demand with and without baseload



[Source: 68]

Farrell [68] discusses how baseload is unnecessary to meet demand. Figure 13 compares the baseload coal scenario in panel A with a renewable alternative that is without baseload in panel B. Panel A shows the relatively inflexible but more constant coal generation or baseload. Panel B shows the inflexible but variable sources of renewable energy such as solar and wind without storage. These variable sources are accommodated by flexible sources such as such as solar with storage. However until sufficient storage and solar thermal capability is developed, there remains an important peaking role for gas along with hydro and pumped hydro [68]. Similarly, MUREI [30] discusses the potential for solar thermal to balance the variability of wind and to accommodate demand peaks in conjunction with biomass and hydro technologies.

Furthermore, this anchoring effect of baseload provides uncertainty over the future role for gas generators as meeting peak or baseload demand. The uncertainty of the role of gas is illustrated in the following example. Bligh [69], the Queensland Premier, discusses the building of two new gas power stations by TRUenergy in Gladstone and Ipswich. Bligh [69] quotes McIndoe, the Managing director of TRU energy, *"A final decision on the most appropriate technology to match the electricity demand can be taken prior to construction. If open cycle technology is used it will be flexible enough to be converted to combined cycle at a later stage as required."* The choice over OCGT or CCGT reflects a choice in role whether peaking or baseload, respectively. This choice has important implications for other generators. For instance Watt [70] discusses how the inflexible coal generation base makes Australia least able to accommodate solar PV. If the baseload function of coal is replaced by baseload gas, this transformation could lockout the full potential of a portfolio of renewable energy to replace baseload generation and to reduce price and supply risk, where the commodity boom in coal and gas intensifies the supply and price risk.

2.13 Conclusion

This section finds institutional structure as the source to many maladaptions to climate change. However three are singled out as major sources of maladaption.

First is the requirement for investment deferment in the transmission and distribution as climate change will accelerate the depreciation of this asset. However, there are dynamics in place that cause over investment in the intrastate transmission and distribution and underinvestment in the interstate transmission. Foster et al. [17 sec. 2.5] further discuss these maladaptions in relation to institutional structure. In addition, the forthcoming papers will using simulations and sensitivity analysis to investigate investment deferment options in conjunction with energy portfolios of peaking gas, wind, solar and storage where various combinations of solar and wind meet the RET.

Second is the climate change maladaption induced by fragmentation of the NEM's institutional structure. Foster et al. [17 sec. 2.5] discuss fragmentation maladaption in relation to transmission and distribution, smart grid, RET and feed-in tariffs with a view to developing climate change adaption performance indicators. The forthcoming papers will develop climate change adaption indicators to form a testable proposition about political and market structure best suited to climate change adaptation.

Third is the RET reinforcing the first mover advantage of onshore wind and solar PV and the requirement to adjust the policy to develop a portfolio of energy technologies. Foster et al. [17 sec. 2.5] further discusses the first mover advantage problem for diversified portfolios.

3 Discussion

This section proposes solutions to the climate change adaption issues found in the previous sections. The three main issues found hindering climate change adaption are:

1. institutional fragmentation both economically and politically;
2. distorted transmission and distribution investment deferment mechanisms; and
3. lacking mechanisms to develop a diversified energy portfolio.

The proposed solutions to the issues are interdependent but the issues are discussed in turn for clarity of exposition.

3.1 *Institutional fragmentation both economically and politically*

The NEM is extremely fragmented both economically and politically, which continues to hinder the NEM's adaption to climate change. To address political fragmentation, the states of the NEM cede legislative power to the federal government over matters pertaining to the NEM. To address economic fragmentation, the proposed solution is to transfer the ownership of all transmission and distribution in the NEM into a single holding company owned by the states, federal government and privately. This produces alignment between single company ownership and the NEM's transmission and distribution as a natural monopoly. The governments maintain a controlling minimum stake of 51 % in the monopoly. To address conflict of interest between government and private entities on connections to the NEM grid, the government privatises all generation. Similarly to address conflict of interest over retail, the government privatises all retail. Foster et al. [17 sec. 2.5.7] discusses caveats to privatisation of generation and retail. A forthcoming paper tests the proposition that the NEM's slow adaptation to climate change is due to political and economic fragmentation.

3.2 *Distorted transmission and distribution investment deferment mechanisms*

The accelerated deterioration of transmission and distribution due to climate change makes the deferment of investment more pressing. Mechanisms for deferment include energy efficiency, smart meters, and modified feed-in tariffs.

Other than for MEPS and the star ratings, energy efficiency in the NEM is uncoordinated and lacks a national scheme. The solution in the previous subsection addresses the lack of coordination and of a national scheme. Furthermore, people make myopic investment decisions by expecting shorter payback period than is economically optimal, which hinders the deployment of energy efficiency equipment. . Foster et al. [17 sec. 2.5.1] discusses in detail the solution of interest free loans to address this market failure. The loans will also address equity concerns.

The NEM with a single monopoly transmission and distribution company within a single legislative area as proposed in the previous section would aid a NEM wide role out of smart meters, providing monopoly buying powers and reducing coordination costs. A NEM wide rollout of smart meters is trivial compared to Italy's national rollout of smart meters. Following the NEM wide rollout of in-house-display equipped smart meters, deregulation of retail pricing will enable a price signal for peak demand period to moderate demand during peak period and so defer investment in transmission. Smart meters and deregulated retail prices have positively engaged customers in other countries and have considerably reduced peak demand.

In this project a prosumer is an entity that produces and consumes the same item. For example the term prosumer is particularly useful to describe a household with solar PV that produces and consumes electricity.

Foster et al. [17 sec. 2.5.1] also discusses the requirement for a gross feed-in tariff based on the locational marginal price for prosumers to maximise generation capacity but prosumers still try to conserve electricity because prosumers will pay the normal tariff for electricity consumed. To aid transmission and distribution investment deferment, the prosumer only pays the transmission and distribution costs for electric supplied from the grid, which provides an extra incentive for the prosumer to install generation via a price signal. This price signal to install more generation is higher where the transmission and distribution cost are higher. Additionally, for the suggested gross feed-in to be effective, any solar bonus should be removed as the solar bonus causes cross subsidies generally from poorer households to richer households.

Embedded generation such as solar PV requires a substantial capital investment with a long payback period. As mentioned under such circumstances people make myopic investment decisions. Interest free loans are justified to address the market failure of myopic investment decisions, to address equity concerns and to capture the positive externalities, such as transmission investment determent.

A forthcoming paper will investigate the investment deferment potential of storage, pumped hydro storage and solar PV.

3.3 Lacking mechanisms to develop a diversified energy portfolio

A portfolio of energy is required to reduce supply risk. The NEM's current coal generation would gradually switch to gas generation under a functional CPRS, doing little to broaden the portfolio of energy. The RET ensures a mix between fossil fuels and renewable energy but the current RET has exacerbated the first mover advantage of onshore wind and solar PV to the detriment of a wider portfolio of energy sources and technologies. A modified RET that allocates targets to alternative technologies and energy sources would help develop a wider portfolio of energy sources with different energy profiles to solar PV and onshore wind. An adjunct or alternative approach is the feed-in tariff reverse auction planned by the ACT Minister for the Environment and Sustainable Development [71] for two large scale solar PV plants discussed in Foster et al. [17 sec. 2.5.1].

A forthcoming paper investigates the various energy portfolios of solar PV and onshore wind to find an optimal mix to aid deferred investment in transmission and distribution. NEMLink is also investigated for the better integration of onshore wind into the NEM. NEMLink would require a major investment in transmission, so compromise is required between the objectives of investment deferment and of broadening the energy portfolio. This compromise is particularly relevant to high concentrations of onshore wind.

4 Conclusion

The literature review in Section 2 finds three factors contributing to the NEM's maladaption to climate change:

1. institutional fragmentation both economically and politically;
2. distorted transmission and distribution investment deferment mechanisms; and
3. lacking mechanisms to develop a diversified portfolio of generation technology and energy sources to reduce supply risk.

Section 3 provides a set of recommendations to address these factors of maladaption and forthcoming papers will test these recommendations.

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