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

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6. THE IMPACT OF CLIMATE CHANGE ON GENERATION AND TRANSMISSION: REVIEW

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This chapter discusses the impact of climate change on electricity generation and transmission network. Stevens (2008, p. v) 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 (2008, p. 41) 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.

Chapter 2 discusses climate change projections of environment variables where this chapter discusses climate change implications for each type of generator and the transmission network and whether and how these changes are modelled in Chapter 4. Additionally, Chapter 9 discusses institutional structure and policy maladaptation in detail but this section does introduce a discussion of maladaptation when relevant.

This chapter discusses the impact of climate change on generation and transmission in the following subsections.

6.1 Transmission and distribution

Yates and Mendis (2009) 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 discussed in Section 2.10. One further mechanism is the increase in severe bush fire weather increasing demand and stressing the grid, which increases the frequency of faults as discussed in Section 2.11.

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. So, Section 6.7 discusses the research questions on a renewable energy portfolio to deferred transmission investment and on portfolios that cause maladaptation by requiring further investment. Additionally, there are maladaptive institutional dynamics that favour heavy investment in intrastate transmission and distribution, which Garnaut (2011, p. 38) 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 (2008, p. 39) 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 (2011, p. 2) 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 (2011) disagrees with Garnaut's (2011, p. 38) assessment on gold plating intrastate transmission and under investing in interstate transmission. Nunn (2011) claims that Garnaut (2011, p. 38) has a *"pipeline congestion"* view where interconnectors are bottlenecks, so the implied solution is increase the capacity of the interconnectors. Nunn (2011) demonstrates using binding constraint data on the transmission network that bottlenecks occur well before the pipeline limit. 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 (2008, p. viii) states that empirical research from the National Electricity Market Management Company (NEMMCO) shows that congestion tends to be transitory and influenced significantly by network outages. So, if bottlenecks in interstate transmissions are to be resolved, deeper integration of the interconnectors within the intrastate networks is required, which requires a whole of NEM focus rather than state focus.

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

These five factors are the subject of the AEMC's (2011a) transmission framework review. In an interim report, AEMC (2011b, p. i) 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. So, Section 9.6 discusses three interrelated sources of maladaptation, 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 (TNSP 2009, p. 4) 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. 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 TNSPs 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. Section 9.5 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 (2008, p. 38) 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 (2008, p. 39) 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 (2008, p. 39) 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 the Department of Resources, Energy and Tourism (DRET) (2011a, p. 21) estimates that the cost of buried lines is 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 (Banks 2009, p. iii). The Korean Industry and Technology Times (2011) reports that the Korean Electric Power Corporation (KEPCO) with LS Cable (2011) 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. 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 (2009) 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 (2011) 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 Research & Development (R&D) in a monopoly transmission and distribution company over the multiple ownership system in Australia. Section 4.6 discusses the slow smart meter deployment in the NEM, which further illustrates the effect of multiple-ownership on R&D. Section 9.6 compares the NEM's fragmentation inducing maladaptation with KEPCO's monopoly over transmission and distribution. Section 9.5 discusses the adoption of a smart grid road map, smart meters and superconductors as further climate change adaption performance indicators.

6.2 Coal

Regarding the supply of coal, Stevens (2008, p. 38) 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 (2008, p. 39) 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 (Stevens 2008, p. 39).

Regarding the operation of coal generators, NEMMCO (2008) identifies water scarcity as a factor that could affect generation capacity. In agreement, Stevens (2008, p. 24) 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 (Stevens 2008, p. 39). Plus higher temperatures will reduce the efficiency of the generation. But, Kogan Creek Power Station (CS Energy 2011a) 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 6.3 discusses.

Irving (2010) 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 (2011e, pp. 12-3) 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 (2011) 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 (AEMO 2011e, p. 14). Additionally, the Melbourne University Energy Research Institute (MUERI 2010, p. 4) claims that investment in technology sequencing such as CCS merely diverts funds and attention away from renewable energy generation. Furthermore, MUERI (2010, p. 50) 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 (CS Energy 2011b), 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 maladaptation. 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.

Section 9.2 discusses CPRS and the link between the rapid rise in electricity price and fossil fuels prices. Section 6.12 discusses using a portfolio of energy sources to moderate price fluctuations.

6.3 Gas

Stevens (2008, pp. 38-41) 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 (1994, pp. 8-10) 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 (2011) 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 the Melbourne University Energy Research Institute (MUERI) (2010, p. 4) 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 (2011a) reported, the quantity of 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. ABC (2011a) reports that the WaterGroup's (2013) estimate is between 2.5 times to five times the NWC's estimate. So, surrounded by controversy, CSG is a huge phenomenon with great potential for maladaptation 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. Sections 10.2 and 10.3 further discuss CPRS, CSG, maladaptation and the toxic chemicals used in the CSG extraction process. Section 6.6 discusses the CSG generator at Chinchilla in conjunction with solar power. Section 6.12 discusses gas generators role as a baseload replacement for coal or as peaking to complement renewable energy.

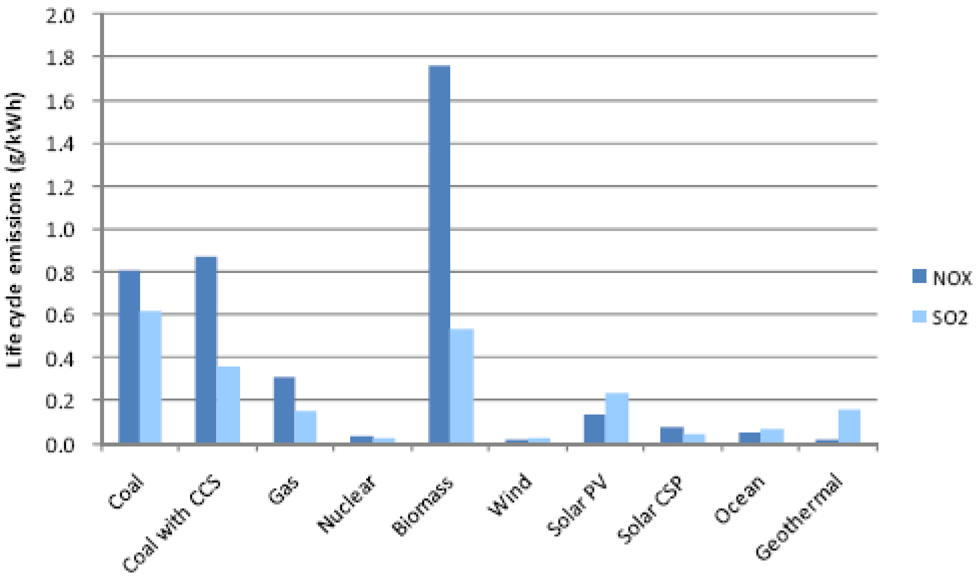
6.4 Diesel

Stevens (2008, p. 31) discusses the effect of climate change on the oil supply in North-eastern Queensland, where tropical cyclones are expected to interrupt offshore oil production and exports from ports. However, only minor investment was considered necessary to improve adaptive capacity.

6.5 Biomass and Biogas

Section 2.9 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. Given biomass' requirement for water, this reduces the potential for biomass. Additionally, biomass is one of the most contentious of all the renewable energy sources. Biomass' future as a renewable fuel relies on the carbon neutral claim. However, burning biomass releases particulate into the atmosphere (MUERI 2010, p. 32). In addition, Figure 6-1 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 6-1 Life-cycle SO_2 and NO_x emissions of power-generating technologies



(Source: IEA 2011a, p. 22)

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 (2011) 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 (2011) 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 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 6.12 discusses the benefit of developing a portfolio of energy sources, which requires sharply targeted infant industry assistance with exit strategies. For instance Section 9.1 discusses 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. Section 9.4 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% (NREL 2011). Furthermore, solar PV installed onto existing rooftops leaves arable land unchanged. However, MUREI (2010, p. 32) 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 (Bligh 2011b) 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 (2011) discuss how Virgin Blue wants five 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 harvested 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 Australian Broadcasting Corporation (ABC) (2008) reported on a Virgin test flight of bio-fuel being labelled a *"green-wash"*.

MUERI (2010, p. 10) 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.

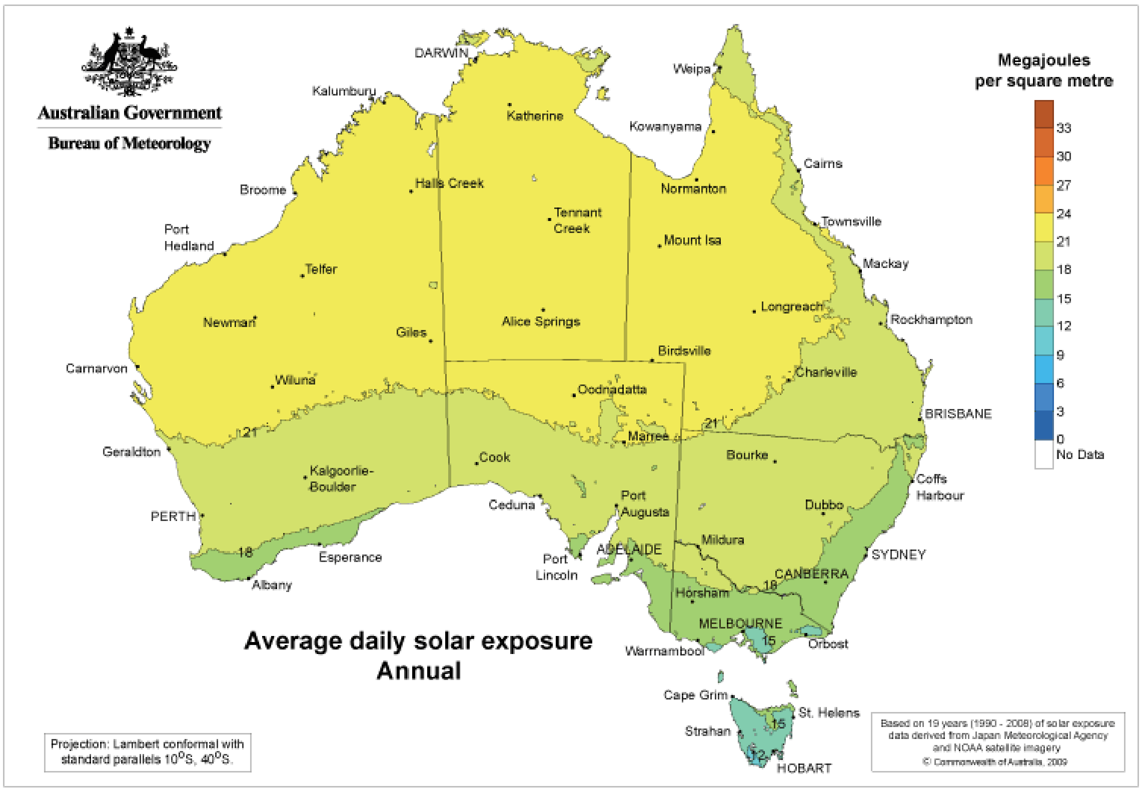
Renewable and other gases derived from waste such as the gasification of municipal, commercial, industrial and biomass waste and the anaerobic digestion of agriculture and farming waste, landfill and sewage gases can be injected into the gas grid rather than burning biomass at power stations. Renewable gases from both syngas (methanation) and biogas (upgraded) injected into the gas grid delivers much higher efficiencies (typically 80%) than electricity only generation (typically 20-35%) is growing in Europe, particularly in Germany, Scandinavia, UK, Netherlands and Austria.

6.6 Solar

Section 2.6 discusses the projected change in solar intensity from 1990 to 2030 and found in the most likely case there was no significant change across Australia, with a 1 to 2% increase in the 90^{th} percentile across Australia but in the 10^{th} percentile a 1 to 2 % decrease across Queensland and north eastern NSW and no significant change elsewhere in the NEM region. As mentioned in Section 2.6, in the 90^{th} percentile case the simultaneous increase in solar intensity and temperature is countervailing but in the 10^{th} percentile case the simultaneous increase in temperature and decrease in solar intensity would reduce solar PV electricity output.

However, in the most likely case from 1990 to 2030 there is no significant change in solar radiation across Australia. Figure 6-2 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 6.7 further discusses the seasonal variations in wind speed.

Figure 6-2 Average daily solar exposure - Annual



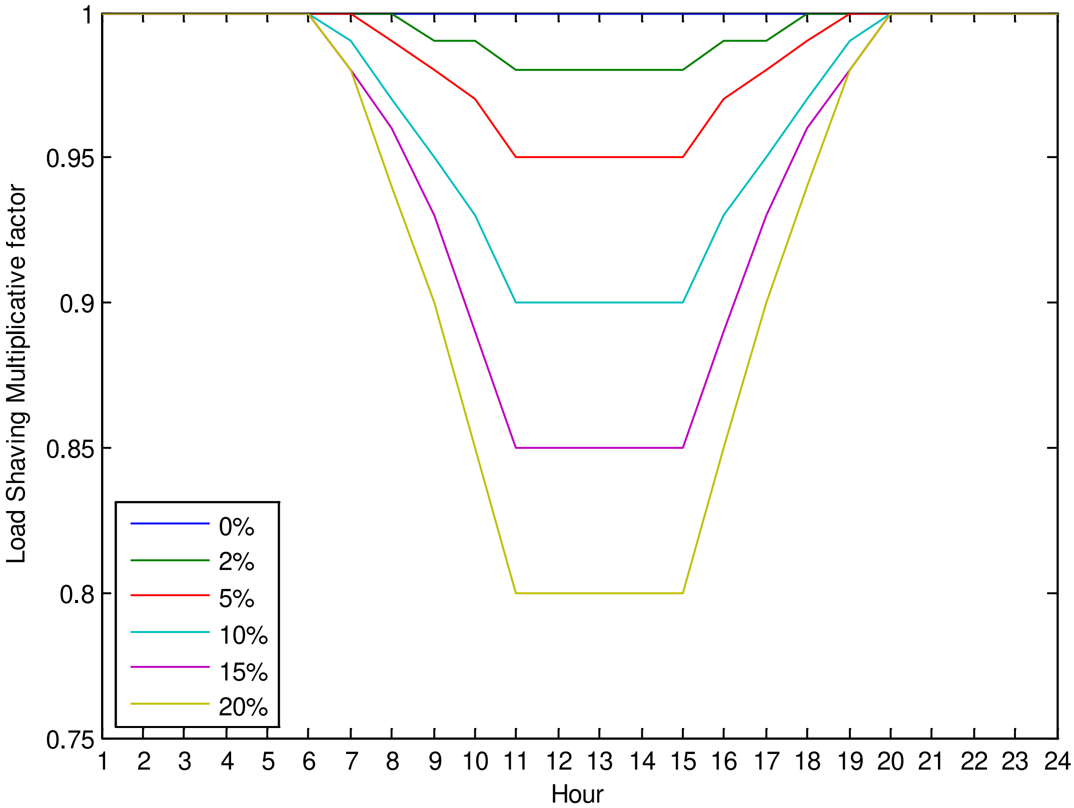
(Source: BoM 2011b)

Furthermore, the highest solar exposure contour is approximately coincident with the current highest temperature contours and with the highest projected change in temperature in Figure 2-4, which means 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 (2011) 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 6.7 discusses reducing the contract for reserve capacity in shorter time frames to meet greater intermittency. Section 6.8 discusses storage to meet intermittency. Section 6.12 discusses a portfolio of renewable energy sources to ameliorate intermittency.

Taking advantage of predictability of solar energy, Wild and Bell (2011 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 6-3 shows the summer version of the six load shaving profiles that are analysed in Wild and Bell (2011), which include 0%, 2%, 5%, 10%, 15% and 20%. The 0% profile is the business as usual scenario with regards to load shaving that is no PV. Figure 6-3 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 6-3 provides a highly stylised profile for a daily cycle, which this project extends by using the BoM's (2011c) 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.

Figure 6-3 Summer load shaving profile



(Source:Wild & Bell 2011 sec. 4.3.1)

Table 6-1 shows the Australian Government (2011) legislated amended RETs 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 6.7 discusses wind generation and section 6.12 discusses wind and solar portfolios with respect to transmission investment deferment.

Table 6-1 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 2011, pp. 80-1)

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 (DRET 2011b) 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 (2011), at Chinchilla in Queensland, which is co-located along the Roma to Tarong transmission line with the Condamine coal seam gas generator. Section 6.12 further discusses the adaptive path of gas with renewable power.

The Kogan Creek Solar Boost Project (CS Energy 2011b) 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 6.2 discusses the positive social aspects of this development.

Another case of fragmentation induced maladaptation 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 thirteen distribution companies and six transmission companies in the NEM. This fragmentation of infrastructure and superstructure is a reoccurring source of maladaptation. The Queensland Solar Atlas (Queensland Government 2013) and the Solar Bonus schemes in NSW (NSW Government 2013) provide examples of fragmentation induced maladaptation.

Robertson (2011b), the Queensland Minister of Energy, discusses the ‘Queensland Solar Atlas’ hosted by the Office of Clean Energy (2011), 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 maladaptation produced 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 (Achterstraat 2011) proposes a 'new solar bonus scheme'. This fragmentation induced maladaptation adds to the complexity of decision making and distorts the price signal for investors by using different method to calculate feed-in tariffs.

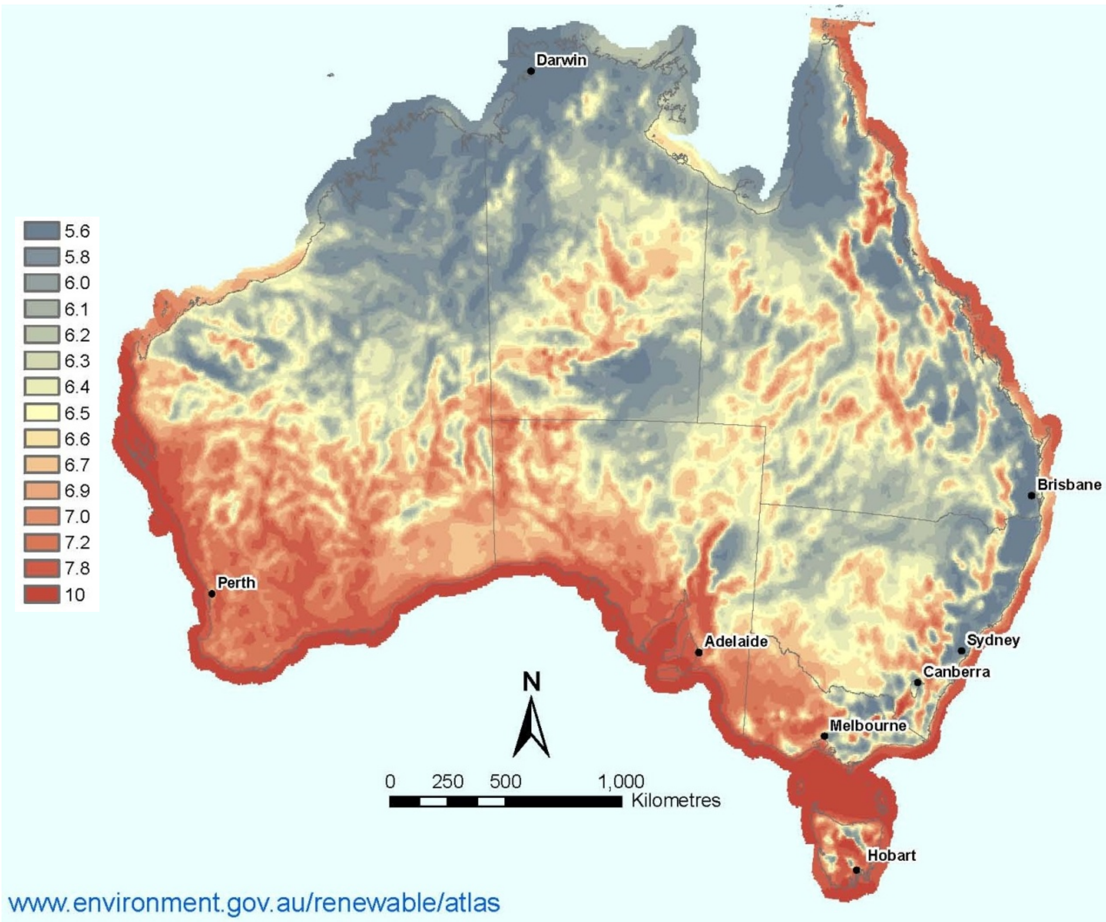
In a further source of maladaptation, the bonus or high feed-in tariff is a blunt policy instrument because the tariff combines two targets being carbon emissions reduction and infant industry assistance. But in 2012 the CPRS was introduced to specifically target carbon emissions. Regarding infant industry 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. Chapter 9 further discusses feed-in tariffs, CPRS, RET and fragmentation induced maladaptation.

6.7 Wind

Section 2.7 discusses the projected change in wind speed from 1990 to 2030 and found in the most likely case there would be a 2 - 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 - 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 2-5. 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 6-4 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 6-4 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 (SEQ) 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 6-4 Mean wind speed in m/s at 80m above ground level



(Source: Department of Environment Water Heritage and the Arts 2008)

A further consideration in locating wind generators is their size. With diameters of up to 90 metres, placing wind farms in close proximity to population centres is unlikely for aesthetic, health, environmental, land cost and safety reasons. For instance The Economist (2010) 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 (2010) 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 6-4, 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 6-2 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 (2011) 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 (2011) 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 6.6 and shown in Table 6-1.

Consistent with Zhao's (2011) 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 (2003) 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 (Leighton Contractors 2010). 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 (2011, p. 2) 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."* Section 9.6 further discusses the issue of transmission ownership in a truly national electricity market.

Furthermore, AEMC (2009, p. vi) 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 (2011) agree calling for new ideas to address this issue.

However, Banister and Wallace (2011, pp. 15-6) suggest the advantage of exporting wind energy between regions may be overrated. Table 6-2 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 2-5 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 6-2 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

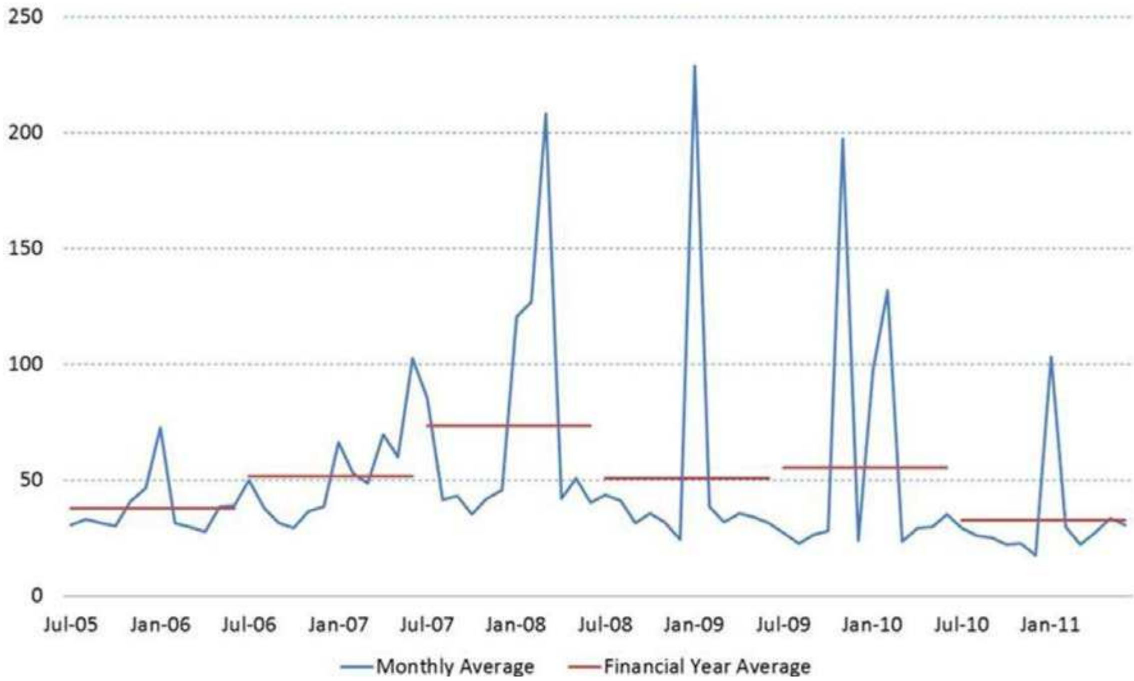
(Source: Bannister & Wallace 2011, p. 15)

Foster et al (2011, p. 3) states that the evolution of efficient storage systems will be critical in solving transient stability problems associated with wind generation. Alternatively, AEMC (2009, p. viii) 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 Open Cycle Gas Turbine (OCGT) and hydro could meet the transient stability problem in a peaking role. Section 6.12 discusses the role of gas in this peaking role as OCGT rather than as a baseload replacement for coal and Section 6.8 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* (VTT 2009, pp. 30-4) discusses how recent innovations in the electronics of wind turbines themselves. 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 (2009, pp. 30-4) notes that modification of legislation or codes in many countries is required to make use of the technology.

Furthermore, Parkinson (2011b) 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 (Pierce 2011) confirms this reduction in the average sport price for electricity in SA, see Figure 6-5.

Figure 6-5 Average Sport Price in South Australia per MWh



(Source: Pierce 2011, p. 7)

However the AMEC chairman also discusses the increase in volatility in spot price in Table 6-3 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 (2011b) claim that the demand for OCGT has fallen.

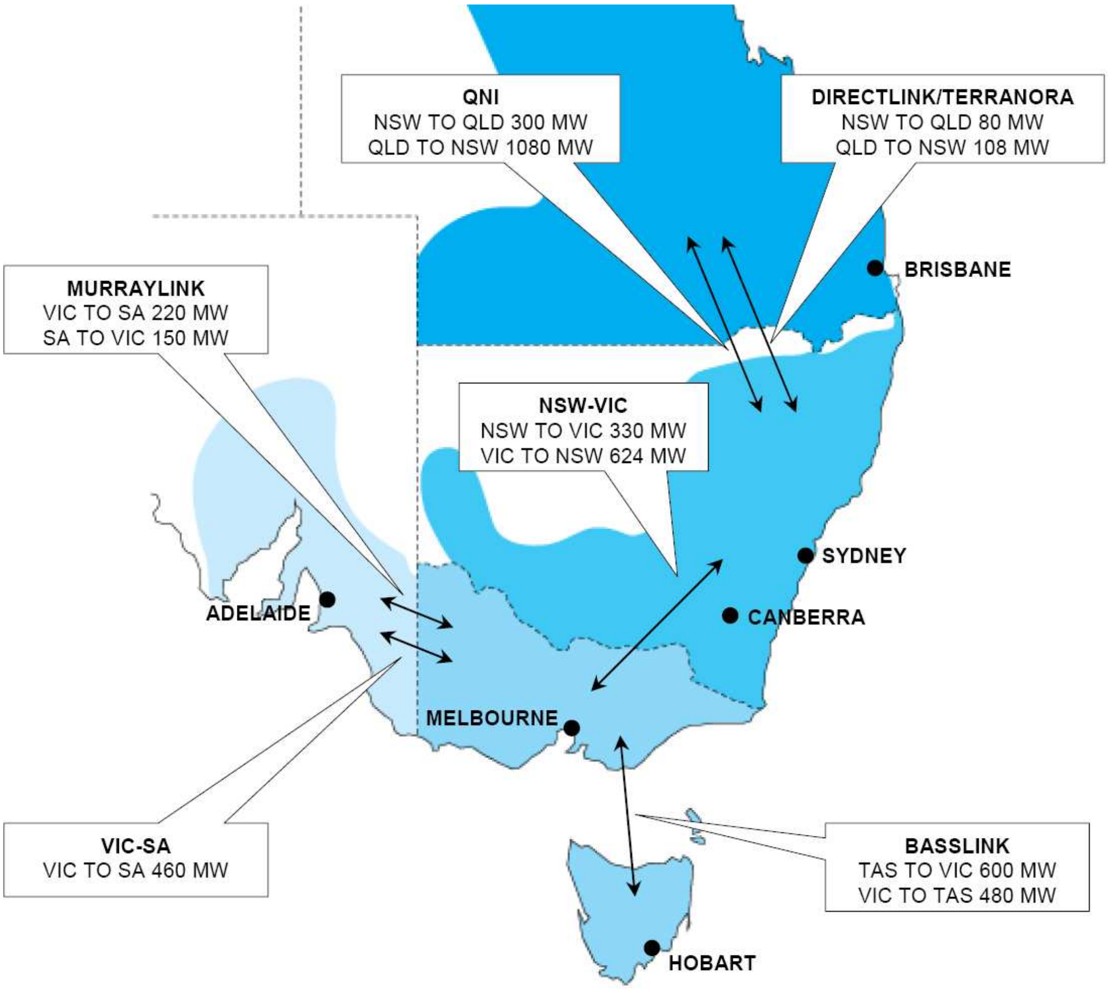
Table 6-3 South Australian wholesale prices

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: Pierce 2011, p. 8)

Parkinson (2011b) claims that there are successful large installations in a number of countries where variability has not posed a major problem. For instance Jones (2011, p. 91) 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 6-6 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 (2011b) notes that there are legislative moves in Victoria to block interconnector expansion from SA to VIC, which is a source of maladaptation to climate change.

Figure 6-6 Interconnectors on the NEM

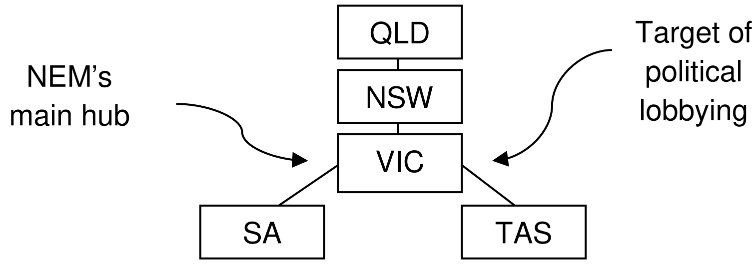


(Source: Tamblyn 2008, p. 7)

Additionally, Parkinson (2011b) notes legislative moves in Victoria to hinder the installation of new wind generation, which is a further source of maladaptation. 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 6-7 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.

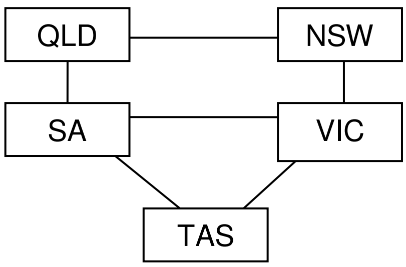
Figure 6-7 NEM's main hub targeted by political lobbying and conflict of interest



However, NEMLink provides a solution to the maladaptation in Victoria exacerbated by Victoria's position as the main hub in the NEM. Figure 6-8 shows the topology of NEMLink. Garnaut (2011, p. 32) discusses NEMLink (AEMO 2010b) as providing a truly national grid by adding interconnectors between SA and QLD and between SA and TAS. The current grid topology in

Figure 6-7 lacks redundancy where breaking the interconnectors between two states isolates parts of the grid. In comparison, the NEMLink topology in Figure 6-8 can lose the interconnectors between any two states and the grid stays connected. This redundancy provides technical advantages (AEMO 2011f) but also provides redundancy against political maladaptation. Section 9.6 further discusses the conflict of interest of state involvement in interconnector management.

Figure 6-8 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 (AEMO 2011f). Section 4.2 further discusses NEMLink in a research question. 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 6.8 further discusses pumped hydro storage.

In a research question, Section 4.2.3 discusses simulations of 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. A complimentary research question discusses relaxing the constraints on interstate transmission to test Garnaut's (2011, p. 2) claim regarding inadequate interconnectors and to test the integration of further onshore wind generation into the NEM.

6.8 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.

The Energy Power Research Institute (EPRI) (2010, p. ix) claims that over 99% of storage capacity worldwide is pumped hydro. EPRI (2010, Figure 2-2) 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 (2010, pp. 4-22) 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 (2010, pp. 5-2) 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.

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. Section 9.5 further discusses grid linked storage that this project uses as an adaption to climate change performance indicator.

There are other energy storage mechanisms to add to the list of electricity storage systems that use different energy mediums to store energy and overcome the intermittency of renewable electricity generation such as thermal storage and 'power to gas' technologies. Not using electricity for heating and cooling but using the waste heat of local electricity generation and/or renewable heat sources where the heat or thermal energy can be easily stored and utilised significantly reduces the need for expensive electricity storage. EPRI (2010, Figure 2-2) fails to present power-to-gas as an energy storage option. Section 6.10 discusses the transmission and generator investment deferring ability of power-to-gas. The next section discusses pumped hydro storage in more detail.

6.9 Hydro

Section 2.9 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 (2008, p. 24) 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 (2008, p. 40) 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 (2010, p. 33) sees no role in expanding hydro and MUREI (2010, p. 23) 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 2.9. Third is a projected increase in wind speed for most of Tasmania other than a slight decrease in summer in northeast Tasmania, as discussed in Section 2.7. These three factors make the combination of expanding onshore wind generation and of introducing pumped hydro storage very attractive for the export of electricity from Tasmania. Section 4.2 proposes a simulation of an expansion of onshore wind generation and introducing pumped hydro storage in Tasmania.

6.10 Geothermal, wave, off-shore wind, power-to-gas and other options

At the time of writing, the previous sections complete a discussion of 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 (2011) 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 (2008). Noting even the coal generators received assistance from the states in an infant industry stage. Chapter 9 discusses maladaptation 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 6.12 discusses the benefits of a broader portfolio of energy sources.

The following technologies developing outside Australia are too attractive to remain undiscussed:

- off-shore wind and wave power;
- solar thermal heating and cooling and power-to-gas.

Serious consideration needs to be given to their implementation in Australia. Power-to-gas is discussed last as it overcomes intermittency and matching supply to demand problems of renewable energy.

6.10.1 Off-shore wind and wave power

Although Australia's onshore wind energy capacity may be a bit patchy in the NEM, Australia has the second largest offshore wind energy resource in the world, second only to the Russian Federation (Makridis 2012). Australia also has considerable wave energy resources. For example, wave energy capacity from Geraldton to Tasmania alone is over 1,300TWh/year, about five times Australia's total energy requirements (CSIRO 2012a). Offshore wind and marine energy resources are generally within 20km of the coast and most energy demands in Australia and would provide greater capacity factors to the electricity infrastructure with the development of an offshore grid similar to the UK.

6.10.2 Solar thermal heating and cooling and power-to-gas

'Power to gas' technologies where surplus renewable electricity from wind and solar is converted into hydrogen or syngas for injection into the gas grid overcomes the issues associated with electricity storage as gas can be easily stored, transported and utilised removing the link between generation and demand. 'Power to gas' project being developed in Germany (E.ON 2012) provides a robust alternative to switching off wind turbines or solar at times when generation exceeds demand. This will become an increasing issue with high penetration of intermittent wind and solar. Additionally the CSIRO (2010b) solar gas project at Newcastle provides a technique using solar power to increase the energy content of gas.

Onshore wind will benefit from power-to-gas technologies to overcome the necessity of switching wind turbines off at times of too much electricity generation. This is a problem that has had to be overcome in Europe due to Europe's high degree of wind energy penetration.

In Germany, it has been found that up to 15% hydrogen gas converted from surplus renewable electricity can be injected into the natural gas grid network at 70% efficiency and above 15% penetration hydrogen can be converted into syngas and then a substitute natural gas via 'methanation' injected into the gas grid at 56% efficiency for surplus renewable electricity that would otherwise be lost. This compares with the 33% efficiency of a typical coal fired power station before grid losses.

The electricity infrastructure needs to be viewed in conjunction with other energy infrastructure such as thermal energy and gas infrastructure. In Europe, particularly in Scandinavia and Germany smart grids are not considered for the electricity grid alone but in conjunction with the thermal energy and gas grids and different forms of energy are switched between grids to provide energy storage and manage over or under generation and peak loads and to mitigate or adapt to the effects of climate change. Section 9.5 discusses further smart grids.

Using thermal energy derived from solar thermal heating and cooling and power-to-gas technologies will also reduce electricity consumption and peak demand impact on the electricity infrastructure as well as overcome the intermittency of renewable electricity generation utilising thermal storage or storage of renewable gas in the gas infrastructure. These techniques have been developed and implemented in Europe, particularly in Germany and Scandinavia increasing the capacity and avoiding costly investment in the electricity infrastructure.

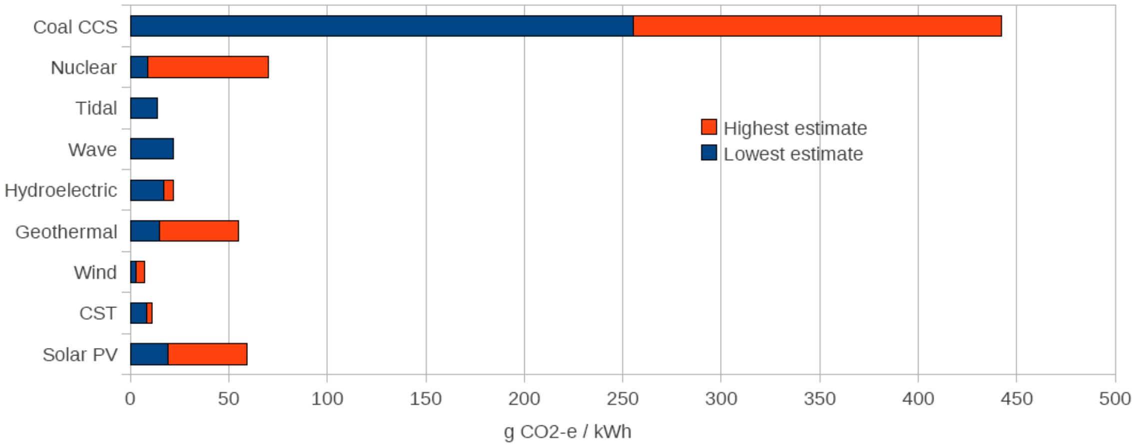
It should also be noted that in Germany and Sweden renewable gas can only be used for decentralised energy (cogeneration/trigeneration), renewable heating and cooling or transport. It cannot be used for electricity generation only power stations by law. Other countries such as Austria, Netherlands and the UK use other incentives such as banded feed-in tariffs.

In the UK, a single company runs both the electricity transmission and gas grids removing vested interest barriers between the two grid infrastructures.

6.11 Lifecycle carbon footprint of generating technologies and transmission

Figure 6-9 shows the expected CO_2 emissions per kilowatt hour averaged over the life cycle of the generating technology. Figure 6-9 could be extended to include OCGT and Combined Cycle Gas Turbine (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.

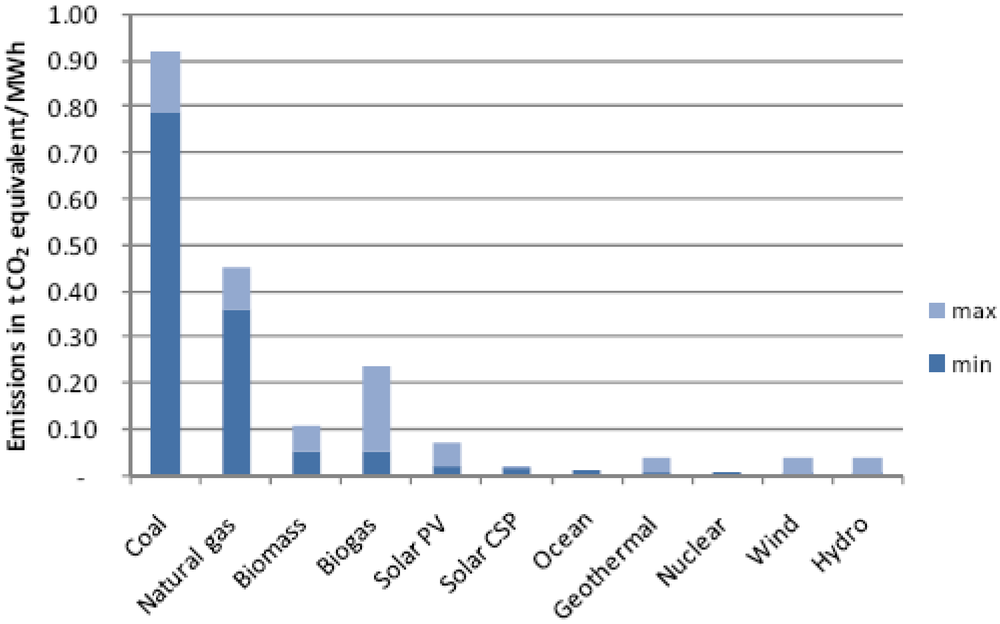
Figure 6-9 MUREI's life-cycle CO_2 emissions of power generating technologies



(Source: MUERI 2010, p. 35)

Like Figure 6-9, Figure 6-10 compares the life-cycle CO_2 emissions of power generating technologies but includes natural gas, biomass and biogas.

Figure 6-10 IEA's life-cycle CO_2 emission of power-generating technologies



(Source: IEA 2011a, p. 18)

Figure 6-10 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 6.5 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.

6.12 Portfolio of energy sources and baseload as a source of maladaptation

Building bigger and longer grids with greater exposure to climate change is not the solution to increases in electricity demand. As has been experienced in Europe, North America and more recently Asia a combination of decentralised and centralised energy infrastructure is required to address this problem, utilising distributed generation technologies in cities and industrial centres supplemented by centralised energy technologies utilising large scale renewable energy resources, back-up and storage. To that end, this section discusses energy as a portfolio, the implications for infant industry targeting and the baseload concept as a source of maladaptation.

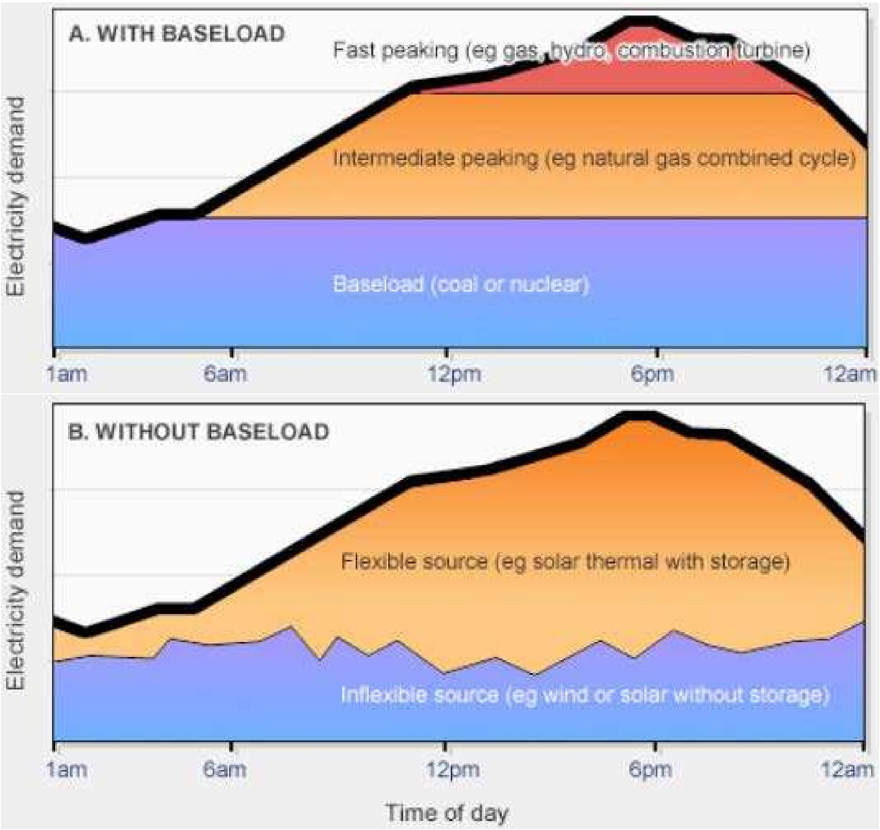
The International Energy Agency (IEA) (2011a, p. 11) finds that having a significant share of renewable energy in a country's energy portfolio can increase energy availability and reduce supply risk. Renewables in an energy portfolio reduce the volatility associated with the price of fossil fuels and 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 (Watt 2011b) without feed-in tariffs. Similarly, onshore wind in New Zealand is being deployed without dedicated support for renewables. However Watt (2011b) concedes that parity is insufficient to induce investment in solar PV as people expect a much quicker payback on capital than calculated by Net Present Value (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.

Australia will need to move towards a much higher penetration of renewable energy. This is infeasible using intermittent large scale onshore wind energy and small scale solar PV with fossil fuel spinning reserve. The first mover advantage of on-shore wind and solar PV is blocking investment in other renewable energy resources, particularly non-intermittent resources and technologies, which Australia will need to reach a non-intermittent renewable energy future. Incentives, such as scaled incentives for non-intermittency, greater capacity factors or diversity, should be structured so that it contributes to a more resilient decentralised and centralised energy infrastructure much more adaptable to climate change. In Europe, this is achieved through banded feed-in tariffs, other incentives or by energy policy such Germany's Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz or EEG). Section 9.1 further discusses feed-in tariffs and financing investment in renewables and Section 9.4 further discusses RET and encouraging diversification by more selectively targeting infant industries.

A further source of maladaptation 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 6-11 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 6-3. 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 6-11 Meeting demand with and without baseload



(Source: Farrell 2011, p. 26)

Farrell (2011, p. 26) discusses how baseload is unnecessary to meet demand. Figure 6-11 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 (Farrell 2011, p. 24). Similarly, MUREI (2010, p. 32) 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 (2011a), the Queensland Premier, discusses the building of two new gas power stations by TRU energy in Gladstone and Ipswich. Bligh (2011a) 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 (2011a) 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.

6.13 Conclusion

This Chapter finds institutional structure as the source to many maladaptations to climate change. However three are singled out as major sources of maladaptation.

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. Chapter 9 further discusses these maladaptations in relation to institutional structure.

Second is the climate change maladaptation induced by fragmentation of the NEM's institutional structure. Chapter 9 discusses fragmentation maladaptation in relation to transmission and distribution, smart grid, RET and feed-in tariffs with a view to developing climate change adaption performance indicators. Section 4.4 discusses how the climate change adaption indicators are used to form a testable proposition about political and market structure.

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. Chapter 9 further discusses the first mover advantage problem for diversified portfolios.