Energy Policy 38 (2010) 3180–3191

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Electricity market design for facilitating the integration of wind energy: Experience and prospects with the Australian National Electricity Market

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ARTICLE INFO

Article history:
Received 28 November 2008
Accepted 23 July 2009
Available online 13 August 2009

Keywords:
Wind integration electricity market

ABSTRACT

Australia has been an early and enthusiastic adopter of both electricity industry restructuring and market-based environmental regulation. The Australian National Electricity Market (NEM) was established in 1999 and Australia also implemented one of the world's first renewable energy target schemes in 2001. With significant recent growth in wind generation, Australia provides an interesting case for assessing different approaches to facilitating wind integration into the electricity industry. Wind project developers in Australia must assess both potential energy market and Tradeable Green Certificate income streams when making investments. Wind-farm energy income depends on the match of its uncertain time varying output with the regional half hourly market price; a price that exhibits daily, weekly and seasonal patterns and considerable uncertainty. Such price signals assist in driving investments that maximize project value to the electricity industry as a whole, including integration costs and benefits for other participants. Recent NEM rule changes will formally integrate wind generation in the market's scheduling processes while a centralized wind forecasting system has also been introduced. This paper outlines experience to date with wind integration in the NEM, describes the evolution of market rules in response and assesses their possible implications for facilitating high future wind penetrations.

1. Introduction

Wind energy is an emerging energy resource that seems poised to make an increasingly valuable contribution towards meeting the pressing greenhouse and energy security challenges facing electricity industries around the world. It has already achieved significant penetrations in a number of countries (LBNL, 2008), is one of the world's fastest growing sources of generation and is widely seen as a key technology for achieving a more sustainable electricity sector (IEA, 2008).

However, it represents the first intermittent energy source to reach significant penetrations in power systems and has significantly different technical and economic characteristics from conventional generating plant. Facilitating the integration of wind energy into the electricity sector is therefore key to its success and these special characteristics can pose important challenges to existing arrangements for power system operation. Meanwhile, many electricity industries worldwide have, themselves, been undergoing restructuring over the last two decades towards more commercially competitive, market-based decision making.

In its broadest sense, the challenge for wind integration within electricity industries is to facilitate wind energy in achieving its maximum energy, environmental and wider societal value. Maximizing energy value is a particular challenge as wind penetrations increase and has to be addressed in the context of the electricity industry as a whole.

Electricity industry operation inevitably involves a mix of centralized and decentralized (generally commercially motivated) decision making. However, the last two decades have seen a concerted effort in many countries to increase the role of competitive markets within their electricity industries. Results to date have been mixed given the challenges of appropriately separating centralized and market-based decision making, assigning costs and benefits and associated risks to participants and supporting wider societal objectives.

Wind energy represents the first highly non-conventional generation to reach significant penetrations in large power systems, and is now testing the adequacy of decision-making arrangements in traditional monopoly and restructured industries alike around the world.

Australia's National Electricity Market (NEM) provides an interesting context for considering the challenges and options of facilitating wind energy integration in restructured industries. The NEM has a large geographical scope, a rather different mix of generation from many other countries, and its own particular

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doi:10.1016/j.enpol.2009.07.047

electricity market and associated renewable energy policy support framework. The last decade has also seen considerable wind energy development, some integration challenges and significant consequent changes to NEM arrangements.

In this paper, we draw upon experiences to date with the NEM to explore issues of policy and market design to facilitate wind energy integration into restructured electricity industries. We first provide a framework for analysing the challenges of wind integration for the electricity industry in Section 2. In Section 3 we then consider the Australian industry context for wind generation including a physical description of the NEM, the Australian wind resource and wind industry development to date. In Section 4 we describe the present decision-making framework for the NEM including its governance, security, commercial (market) and technical regimes. The key policy mechanism to support renewable energy deployment, the Mandatory Renewable Energy Target is described in Section 5. The effectiveness of this decision-making framework for facilitating wind integration into the NEM is then explored in Section 6 with a particular focus on the impacts of NEM design and regulation. This Section also includes discussion of recent developments in the NEM in response to growing wind penetrations. Section 7 concludes with a summary on the strengths and weaknesses of the NEM design on facilitating wind integration, and some emerging challenges.

2. Facilitating wind integration into electricity industries

2.1. The wind integration challenge

In its broadest sense, the challenge for wind integration within electricity industries is to facilitate wind energy in achieving its maximum societal value. This value has energy, environmental and potentially wider social dimensions (MacGill and Outhred, 2008):

- Wind's energy value depends in part on the investment and operational costs of particular wind farms. However, its value is also determined by the impact it has on the benefits and costs of other power system elements. These costs and benefits have significant temporal and locational variability and uncertainty that emerge from the coordinated behaviour of all demands and generation on a shared network.
- The environmental values of wind can include greenhouse emission reductions that have little temporal and locational variation, but also regional air and water benefits as well as possible visual amenity and other environmental costs. Achieved emissions reductions depend, however, on the other generation technologies in the power system and the way wind generation interacts with their coordinated operation.
- The social benefits of wind energy can include investment and job outcomes with industry development.

Maximizing energy value is one of the particular challenges of increasing wind penetrations. As wind energy moves from a niche technology to a significant industry contributor its impact on energy value will also become increasingly significant. Electricity industries, of course, face many challenges other than wind energy integration, which should therefore be considered in a broader context that addresses issues including (Outhred, 2008):

- Delivering economically efficient energy services for end-users
- Maintaining security of supply for the system, and appropriate levels of reliability for end-users
- Appropriately supporting other opportunities for meeting energy security and greenhouse challenges including enhanced end-user participation and energy efficiency, and a range of other emerging renewable and small-scale highly efficient fossil-fuel technologies such as cogeneration.

Some common design requirements underlie this broader context, including the need to:

- efficiently manage temporal uncertainty from the short- (seconds) to long-term (decades or more) and location specific uncertainties due to the electrical network that underpins the industry,
- coordinate the activities of many decision-makers with widely differing roles, incentives, information and understanding, and
- efficiently direct payments from end-users to industry participants in terms of the value they provide to the industry as a whole.

The policy and market design challenge is to maximize the net benefits bought to the electricity industry by its end-users, available supply options and network arrangements. The question addressed in this paper is how wind integration in power systems can be facilitated to maximize its contribution to overall industry benefit.

2.2. Electricity industry decision making

Electricity industry operation inevitably involves a mix of centralized and decentralized decision making. There are very large numbers of very diverse end-users, while maintaining continuous electrical flows through a large interconnected power system requires high levels of coordination. The traditional paradigm for the industry was largely centralized decision making on the supply side and networks through government owned or highly directed monopoly utilities. The last two decades has seen worldwide efforts in restructuring national electricity industries. Generally this has included:

- structural disaggregation from monopoly (typically government owned) utilities to a mix of competing firms in generation and retail markets, yet monopoly network service providers and centralised market and system operators, and
- the introduction of far greater decentralized, commercial (market price based) decision making.

This reflects a shift towards decentralized decision making, but not a complete transfer. Electricity's special characteristics mean that traditional commodity markets are impracticable. Instead, electricity markets are inevitably 'designer' markets with specially tailored interfaces to necessary centralized decision making.

The outcome to date of these restructuring efforts has been mixed—a reflection of some of the challenges involved, as well as the high political interest that such an important industry inevitably entails. While it is too soon to declare restructuring's conceptual success or failure. Some principles of good electricity industry market design appear to be clear (MacGill and Outhred, 2005):

- an appropriate mix of decentralized (commercial) decision making where possible, and centralised decision making where necessary or superior,
- a focus on embracing, and hence better managing, the inherent uncertainties within the electricity industry from the very short- to longer-term-uncertainty drives competition and risk

is generally best allocated to participants on the basis of who is responsible and best placed to manage it,

- allocation, as best possible, of costs and benefits to participants with respect to the costs and benefits they each provide to the industry,
- establishing a level playing field that does not favour incumbent technologies and participants against 'new entrants', and
- support for appropriate innovation to meet emerging challenges and change.

In essence, restructuring comes down to the development of different ways for undertaking the operational and investment decisions that determine electricity industry outcomes. One possible formal decision-making framework for a competitive electricity industry is given in Outhred (2007a) and presented in Table 1. This framework is divided into four regimes that recognise the differing roles of decision-makers, ranging from policy-makers and regulators to system and market operators and regulated and unregulated industry participants.

Electricity industry restructuring almost inevitably occurs in a context of existing technologies and incumbent participants. Wind energy represents the first highly non-conventional generation to reach significant penetrations in large power systems, and such penetrations can add considerable:

- physical (technical) complexity in terms of the shared, non-storable, highly variable and somewhat unpredictable wind energy flux that is used by wind farms and which governs their potential operation. There are also the non-conventional generation interfaces utilized by wind turbines including induction generators and full power converters, as well as the common occurrence of strong wind resources being located in remote areas with weak network connections.

Table 1
Decision-making framework for a competitive electricity industry (Outhred, 2007a).

Regime	Role
Governance regime	The set of formal institutions, legislation and policies that provide the framework in which a competitive electricity industry operates. This includes the formal regulatory arrangements for industry participants as well as the broader social context in which the industry operates. It may involve more than one national jurisdiction.
Security regime	The task, assigned to one or more system operators, of maintaining the integrity of a local or the industry-wide core of an electricity industry in the face of threats posed by plausible large disturbances. The security regime typically has authority to restrict and, if necessary, override the commercial regime in defined circumstances. For example, it may direct participants to operate their components at specified levels and, under defined circumstances, disconnect components.
Commercial regime	The commercial arrangements for the competitive electricity industry. This may include spot and derivative markets for electrical energy as well as ancillary service markets and commercial interfaces for regulated industry participants, such as network service providers.
Technical regime	The set of rules that allow the various components of an electricity industry, when connected together, to function effectively as a single machine, providing a continuous flow of electrical energy of appropriate availability and quality between generation and end-use equipment, tracking decision-maker targets, rejecting disturbances and degrading gracefully if equipment faults occur.

- Commercial and security-related complexity due, in part, to the challenges of selecting suitable sites for wind farms, their related network connection costs and the variable and uncertain energy production they will offer. More important, perhaps, will be wind generation's potentially significant implications for other generation given the time and expense of committing and decommitting large thermal plant and ramping its output up or down. Large and unexpected correlated (regional or system-wide) wind energy changes may also have significant implications for power system security through supply/demand imbalance or rapidly changing network flows.
- Institutional or governance complexity necessary to manage all the shared issues of planning, grid connection, network operation and management of power system security, and the impacts of wind on other market participants. All of this has to be managed within the broader context of energy security, climate change and other policy objectives.

2.3. *The challenge of high wind penetrations for electricity industry restructuring*

High wind energy penetrations will therefore test the adequacy of electricity industry restructuring in all of these decision-making aspects. Can industry arrangements facilitate wind integration by providing appropriate market, regulation and related policy 'signals' so that (Outhred, 2008):

- Developers site their wind farms according not only the wind regime and hence potential production, but also with consideration of network connection, and regional factors varying energy value such as other generating plant and possible network congestion. Furthermore, will such incentives support wind farms to locate themselves in a geographically dispersed manner that will maximize the diversity between wind-farm power outputs?
- developers install wind turbines and related control devices that offer enhanced ride-through, voltage support, appropriate dynamics including inertia and other possible ancillary services including frequency control. Within limits, the dynamic behaviour of wind turbines with power electronic interfaces (those that use a doubly fed induction generator or an alternator) can be tailored according to power system operating requirements.
- Wind-farm operators can coordinate their generation outputs to limit combined power output or rate of increase of output on potentially local, regional or even system-wide basis depending on evolving power system security needs
- Other industry participants can coordinate their response to changing wind-farm outputs including potentially demand-side participation as well as control of flexible conventional plant
- Market investors are encouraged to consider the value of flexible generation plant (and potentially controllable loads) when undertaking their investments.
- Regulated monopoly network service providers considers the needs of wind generation when making decisions on appropriate network operation and investment
- All market participants can access reliable wind energy forecasts (in the sense of dependable and useful characterization of future uncertainty) to assist in their operational and investment decision making.

The critical role of technical, security, commercial and governance decision making for the electricity industry is evident. Furthermore, the issues must be considered in a specific context, because the wind resource, power system characteristics and institutional arrangements differ between countries.

3. The Australian electricity industry context for wind generation

The Australian NEM extends some 4000 km from North to South and approximately half this distance East to West across Eastern Australia. It includes all States and Territories other than Western Australia and the Northern Territory, as shown in Fig. 1. It has over 40 GW of generation and a peak total demand to date of around 33 GW representing over 90% of Australian electricity demand.

The generation mix of the NEM varies by market region (State) but is, in aggregate, dominated by coal-fired plant (around 80% of electricity provision) with contributions from gas-fired generation and hydro power supplying the remainder (AER, 2008). There are significant network constraints between some market regions including NSW and Queensland, Victoria and South Australia, and Victoria and Tasmania. Apart from some State-based retailing and licensing arrangements, the NEM operates under a uniform set of National Electricity Rules as outlined in the following section.

By way of comparison a generalized map of the Australian wind energy resource is shown in Fig. 2. Regions of high wind speeds are particularly concentrated in the South of the NEM including South Australia, Victoria and Tasmania. Both South Australia and Tasmania have relatively low populations and

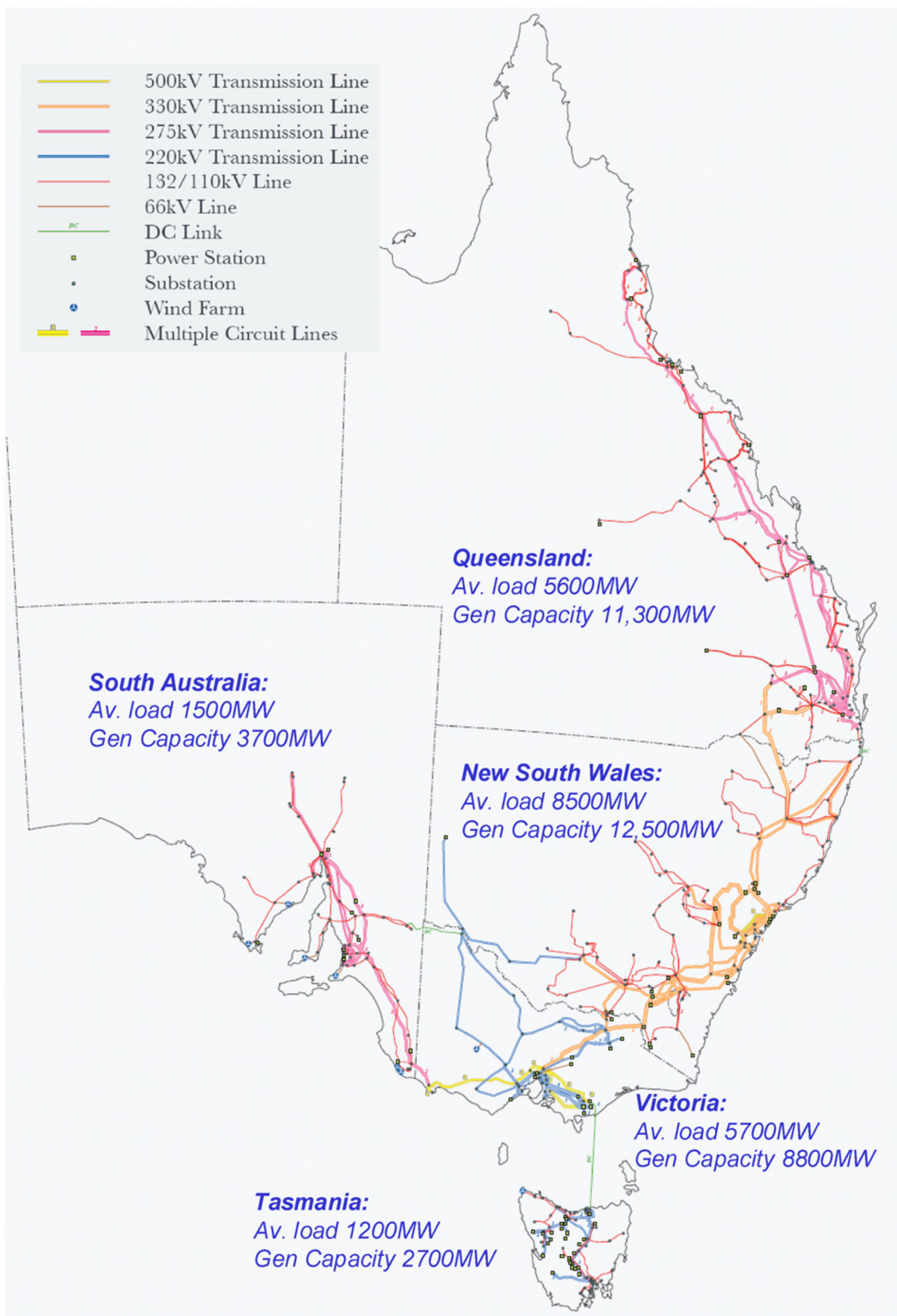

Fig. 1. Australian National Electricity Market generating plant and transmission network, with approximate average load and generation capacity for each of the market regions (States). (Adapted from NEMMCO, 2008b).

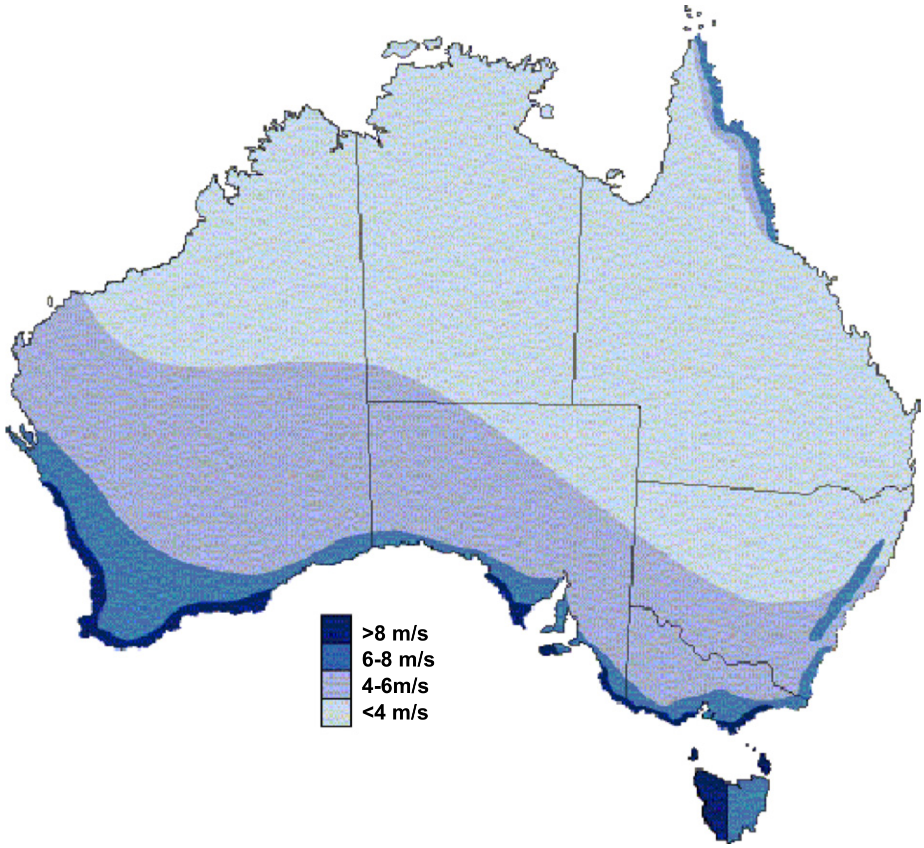

Fig. 2. Estimated Australian wind resource (average m/s) (AGO, 2007).

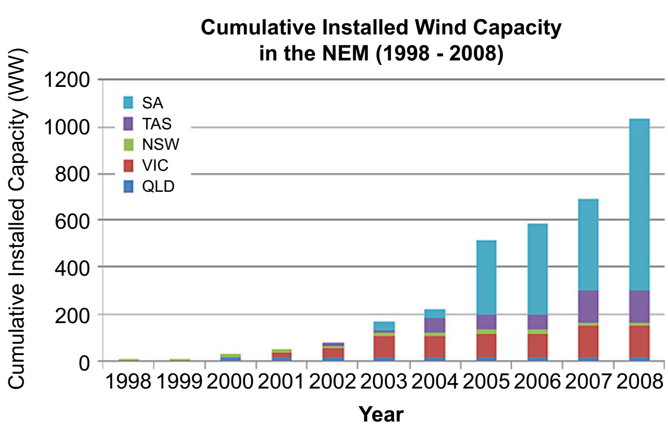

Fig. 3. Current installed wind generation in the NEM (Centenera, 2008).

associated electrical demand, as well as limited interconnections to the rest of the NEM.

Wind energy industry development has expanded significantly since the introduction of the Mandatory Renewable Energy Target (MRET) in 2001. This was the world's first national Renewable Obligation and Green Certificate Trading scheme. Income from selling Renewable Energy Certificates (RECs) to liable parties provides approved renewable energy projects an additional cashflow to that obtained from electricity sales into the NEM wholesale market. Suitable hydro, wind energy, biomass and solar projects are all eligible to participate. Details are provided in Section 5.

Wind energy has proven to be remarkably successful under the scheme in competition against hydro, biomass and solar projects. It is estimated to have delivered more investment than all other technologies combined, and some 40% of annual RECs (ORER, 2008). Along with an excellent wind resource, South Australia also has excellent wind-farm siting opportunities along three peninsulas and has consequently seen most of the wind industry development to date, as shown in Fig. 3. South Australia's wind penetration is already very significant by way of international comparisons, particularly given its interconnection constraints. South Australia currently has over 70% of installed NEM wind capacity yet less than 10% of electricity demand. Wind is now providing well over 10% of South Australian electricity production (ESIPC, 2008) and the State has therefore already presented some interesting integration challenges for wind energy in the NEM.

Wind energy penetration for the NEM as a whole is currently less than 2% by energy. However, the three southern most states – South Australia, Victoria and Tasmania – have over 90% of installed NEM wind capacity yet less than 40% of electricity demand and this region is therefore approaching 5% wind penetrations.

4. Decision-making framework for the Australian NEM

Outhred and Schweppe (1980) and Schweppe et al. (1980) set out the conceptual ideas that underpin the design of the Australian National Electricity Market. The NEM formally commenced operation in 1999. Outhred (2007b) discusses the underlying principles for, and experience to date with, electricity industry restructuring given the experience of the NEM. Key features of the NEM decision-making framework are described below and summarised in Table 2 using the regime roles defined earlier.

Table 2
Decision-making framework for the Australian NEM.

Regime	NEM ArrangementsNEM arrangements
Governance regime	Separate organizations for policy making (MCE), rule making (AEMC) regulation (AER) and market operation (NEMMCO/ AEMO). Rule changes can be triggered by proposals submitted by any stakeholder, or through reviews requested by MCE. Rule-change process intended to not unduly favour incumbent participants or technologies, and to balance the commercial interests of market participants against the need to change rules as circumstances require it.
Security regime	The highest priority of the ISO and Market Operatormarket operator, NEMMCO. NEM design closely integrates security and commercial regimes through potentially extremely high spot prices (A$10,000 MWh) to incentivise supply/demand balance, and partially commercialized Frequency Control Ancillary Services.frequency control ancillary services. NEMMCO also undertakes a range of centralized assessments of future system adequacy to inform market participants and possible investors.
Commercial regime	Gross regional wholesale electricity market with associated Frequency Control Ancillary Servicesfrequency control ancillary services market that resolves security -constrained dispatch every five minutes 5 min (30 min average pricing). Compulsory participation by all generation greater than 30 MW (unless intermittent). No commercially accountable day-ahead energy market or capacity market. Participant rebidding possible up to 5 min from dispatch. A range of derivative markets to support risk management and investment (not formally managed by NEMMCO).
Technical regime	Technical connection standards with specific provisions for some non-conventional generation technologies such as wind power. Network connection governed within minimum allowable and automatic access standards through a negotiation process that involves only shallow connection costs.

4.1. Governance regime

The key bodies that constitute the governance and regulatory regime for the NEM are the Council of Australian Governments, the Ministerial Council on Energy (MCE), the Australian Energy Market Commission (AEMC), the Australian Energy Regulator (AER) and the National Energy Market Management Company (NEMMCO).
These organizations have the following roles:

- The Council of Australian Governments (COAG) brings together Federal and State governments in a forum that has the intent of fostering uniformity and consistency in governance policy.
- The MCE coordinates Federal and State policy for the NEM. It was established by COAG to provide it with advice on energy policy.
- Uniform industry-specific legislation, the National Electricity Law (NEL) defines the decision-making framework for the electricity industry, including commercial, technical, security and regulatory arrangements. The specific details of these arrangements are set out in the National Electricity Rules, The AEMC manages the National Electricity Rules, and the rule change process by which they can be further developed.
- The AER implements a consistent regulatory regime for transmission network service providers and will also assume this role for distribution network service providers over the next few years. It also monitors compliance with the National Electricity Rules by NEMMCO and market participants as well assessing the overall effectiveness of these rules.
- NEMMCO is both the market and system operator and thus has responsibility for implementing and managing both the security regime and the short-term aspects of the commercial regime.

This governance regime applies different degrees of formality and transparency to proposed changes depending on the organization and issues involved. The AEMC, AER and NEMMCO have particularly transparent processes with significant information about current and proposed arrangements available, and significant opportunities for stakeholder input—both proactive and reactive.

A wide range of government decision making has relevance to the NEM. This includes climate and regional development policy development. Federal renewable energy policy is particularly relevant and covered later in the paper. Other relevant governance participants include State governments who having planning and licensing regimes relevant to siting generation units and regulating their environmental performance. They also currently regulate retail electricity market arrangements within their jurisdictions and some have related environmental policy measures such as feed-in tariffs for small generators (MacGill et al., 2006).

4.2. Technical regime

The National Electricity Rules contain rules for connection for generators and loads, which call on national and international standards where appropriate. The general principles are for open access, subject to meeting these technical standards, and an obligation to pay only 'so-called' shallow connection costs. The standards set minimum (essential), and automatic requirements for connection. 'Good faith' access negotiations between parties and NSPs are specified for connection proposals that lie between these minimum and automatic standards (AEMC, 2007).

4.3. Commercial and security regimes

The National Electricity Rules set out the design of a uniform National Electricity Market that closely integrates security-related and commercial decision making. The centre-piece of the NEM is a set of regional gross-pool spot energy and ancillary services markets that solve a security-constrained dispatch every 5 min. NEMMCO is the single spot market and system operator for the whole of this system. Regional boundaries are formally required where major transmission is congested for a significant proportion of the time. In practice, and largely due to the State-based development of the Australian electricity industry, regional boundaries are currently located at every border between States within the NEM. All generating plant of greater than 30MW capacity (except intermittent generation including wind) are required to participate as scheduled generators and submit offers to sell or bids to buy energy (and/or ancillary services) in the NEM dispatch process. The pre-dispatch processes forecasts up to 40 h ahead of real-time and provides public forecasts of energy and ancillary service prices and (privately to each dispatchable participant) dispatch levels based on participant bids and offers, the demand forecasts and the estimated effects of dispatch constraints. Demand is permitted to participate directly in the wholesale market, however, nearly all end-users interface with the market through an electricity retailer (NEMMCO, 2007).

There are eight frequency control ancillary services (FCAS) markets to provide load following (raise and lower) and three contingency responses (raise and lower) of different time periods (6 s, 60 s and 5 min) between the 5 min energy dispatches market dispatch co-optimizes energy and FCAS bids and offers to establish regional prices for energy and all eight FCAS for each 5 min period. These prices incorporate losses and potential congestion on the regional interconnectors. Commercial trading is based on these prices averaged over 30 min. Locational pricing within regions is achieved using average loss factors that are calculated annually. Importantly all generators are permitted to change their offers (rebid) just prior to each 5 min dispatch without penalty. Furthermore, the only commercially significant prices in the NEM are its averaged 30 min regional prices—the pre-dispatch prices are advisory only. Also note that the NEM is an energy-only market and participants are required to manage their own unit commitment and other inter-temporal scheduling challenges (within a range of technical dispatch constraints).

The long-term commercial regime in the NEM is implemented via derivatives for electricity and ancillary service spot markets and is largely left to commercial regime participants to organize in conjunction with financial market providers. There has been some movement towards large generators and retailers joining together to form 'gentailers' who then have a partial physical hedge against price variability and volatility. There are supplementary markets in environmental instruments at both state and federal levels, which have the effect of increasing the commercial returns for renewable energy resources.

The real-time spot markets for energy and frequency-related ancillary services provide a security-constrained dispatch and are interfaced to a strong security regime that reviews and can adjust the technical envelope for the security-constrained dispatch on a 5 min basis. NEMMCO's security management powers extend with decreasing authority from this very strong short-term role, to what is intended to be an information-provision role through centralized projections of system adequacy with horizons of one week (reviewed half hourly), 2-years (reviewed daily) through to a 10-years horizon that is reviewed annually. The intent is to allow competitive processes to manage the investment aspects of resource adequacy, supported by the energy-only spot market design and the associated derivative markets. NEMMCO does however have the power to issue directions to market participants should that be required to ensure power system security, and can also seek capacity reserves up to 6 months out should they be deemed necessary.

In summary, the NEM design is unusual amongst restructured electricity industries around the world, featuring a compulsory gross-pool spot market that solves energy and frequency control ancillary services dispatch for five regional nodes without any formal day-ahead market or capacity market. It appears to have achieved reasonable success to date in matching commercial market signals with the underlying economics of the electricity industry, within an effective security regime. Wholesale prices have been generally low by international standards although a key factor here is the low costs of coal-fired generation in Australia (AER, 2008, p. 92). It has formal objectives of open access, 'causer pays' cost allocations and equal treatment, although these are difficult to deliver in practice within an electricity industry. Still, the general principle is that market participants pay, and/or are paid, according to their contribution to overall industry costs and benefits. For example, FCAS regulation costs are imposed on generators according to their estimated contribution to regional requirements over each 5 min dispatch, whilst contingency raise and lower costs are allocated to generators and retailers respectively according to their regional share of generation and consumption (Thorncraft et al., 2008).

The wholesale spot market prices electricity every 5 min across five regions. FCAS markets determine frequency control ancillary services costs, again at 5 min intervals. The NEM is therefore infused with uncertainty—generators can rebid within 5 min of dispatch and are highly motivated to respond to changing market conditions. Derivative markets provide some opportunities to manage the price risk associated with these markets (Outhred, 2007b).

5. Framework for Australian renewable energy policy support

The Australian Federal Government's Mandatory Renewable Energy Target (MRET) requires Australian electricity consumers to source an increasing amount of their electricity from new renewable generation sources. Eligible sources include hydro, biomass, wind and solar projects. The liable parties within the NEM are electricity retailers and those large consumers who purchase directly from the wholesale market. The 'additional renewable electricity' liability that the liable parties are required to acquit was originally intended to be equivalent to 2% of their electricity purchases by 2010. This 2% target was translated into a fixed national target of 9500 GWh of additional renewable generation in 2010. The annual target ramps up linearly to this 2010 target and was originally intended to remain at this level until 2020 (MacGill et al., 2006).

MRET is not formally incorporated into the NEM governance, security, commercial or technical regimes. Instead, the scheme is intended to provide an additional commercial incentive sufficient for appropriate renewable energy project investments to achieve commercial returns within the NEM sufficient to ensure compliance with the target. Key features of the MRET decision-making framework are as follows, using the regime roles defined earlier.

5.1. Governance regime

The key bodies involved in governance and regulation of MRET are the Federal Government and COAG with regard to policy development and legislation, and the Office of the Renewable Energy Regulator (ORER) to administer the scheme. A review of the scheme performance after 2-years was incorporated into the enabling legislation but there are no formal ongoing public processes for rule changes. Recently, there has been considerable policy development around MRET to significantly expand the target for 2020. This is discussed further in the next section.

5.2. Technical regime

Technical connection to the NEM of projects being driven by MRET is intended to be managed through the standard NEM technical regime. However, as noted in the next section, the significant wind generation being driven by MRET has resulted in considerable changes to this regime.

5.3. Security regime

The potential security implications of MRET for the NEM are intended to be entirely managed by NEM processes. However, again, growing security concerns with increasing wind penetrations have driven considerable change in the NEM rules. The primary security 'setting' for MRET itself is the penalty for retailers and large energy users that do not meet their liabilities under the scheme. This was set at A$40 for each REC of shortfall and hence represents a commercial 'signal' rather than security constraint to MRET participants. This penalty charge was intended to lie modestly above the expected marginal cost of RECs under the scheme and hence limit the potential costs to retailers and hence end-customers should renewable energy project developers be unable to cost-effectively meet REC market demand (MacGill and Passey, 2009).

5.4. Commercial regime

Liable parties demonstrate compliance by annual acquittal of Renewable Energy Certificates (RECs) equivalent to share of the target to the ORER. Approved renewable energy projects representing 'new' renewable generation beyond those levels existing prior to the introduction of MRET are able to generate RECs. Trading of RECs between these projects and liable parties takes place through long-term Power Purchase Agreements (PPAs) or spot and forward broker trading. Long-term PPAs signed between retailers and project developers have played a critical role in driving investment in new projects. These have typically bundled energy and REC projects. However, there have also been a number of 'merchant' projects where developers finance their projects 'off sheet' and then receive spot or derivative energy and REC prices for their output (Kann, 2009).

The underlying intent with MRET is that a competitive market should emerge between REC provision from potential renewable energy technologies and particular projects and REC purchase by liable parties in order to efficiently meet the scheme targets. The outcomes should hinge, of course, not just on the underlying costs of the renewable energy projects for each MWh and hence REC produced, but also the energy value of this generation within the NEM wholesale market any associated costs such as interconnection with the network.

MRET, has now been operating for some 7-years. It has easily met its admittedly modest targets and driven considerable investment—an estimated A$5 billion to 2008 (ORER, 2008). The flexibility of this technology neutral market-based approach has also proved valuable. Some early projections of which renewable technologies would contribute to the target suggested that biomass would make the greatest contribution. In practice, a number of proposed biomass projects have encountered difficulties for reasons including technical challenges with some biomass residues, controversies over the use of residues from 'old growth' forest, and a severe drought over much of Eastern Australia for much of the scheme's life. The market has therefore redirected its attention somewhat to other technologies. Wind technology advanced significantly over the first few years of the scheme, due largely to overseas market developments, and wind projects were therefore well placed to take advantage of the market opportunity.

There appears to be competition between project proposals that has project costs looking highly cost effective by international standards—traded REC prices have varied from around A$40 to as little as A$15 (at a time when there appeared to have already been sufficient investment to meet the original scheme target for 2020) and then back to over A$50 per REC (as both the government and major opposition party introduced policy commitments to expand the 2020 target). Note that while the shortfall penalty is A$40 per REC the purchase of RECs is tax deductable whilst penalty payments are not, meaning the effective penalty rate is above $55 per REC under current corporate taxation arrangements. Wind projects have generally been on the margin of the market and this suggests project requirements in the order of $40–50 per REC; or €25–30—competitive by international standards. Note also that the electricity price received by wind projects is also low by international standards with volume weighted average prices in the NEM typically in the order of A$30–50/MWh over the life of MRET to date. This suggests that wind-farm cashflow from MRET and from energy sales in the NEM are typically fairly similar. In this way, MRET supports renewable project development yet does not remove energy market signals in the way that other possible policy support mechanisms such as feed-in tariffs may.

The Australian experience is very different from that seen in Europe where Green Certificate Schemes are generally believed to have demonstrated poor effectiveness (target achieved) and low efficiency (high profit margins to developers) (European Commission, 2008). Possible reasons for this difference might include the modest nature of the MRET target, a number of design flaws regarding the inclusion of solar hot water and pre-existing hydro plant that has reduced the effective target even further, a sufficiently severe shortfall penalty and a reasonably competitive retail electricity market (MacGill and Passey, 2009). Unfortunately, the significant REC price volatility over the life of the scheme does appear to have had significant adverse impacts on orderly renewable energy industry development and growth (Kann, 2009). The federal government has now drafted legislation to extend the MRET target in order to achieve 20% renewable energy electricity by 2020—an expansion of the current 9500 GWh/year target for 2020 to 45,000 GWh. This raises significant questions of the possible future performance of MRET and these will be explored in the following section.

6. Effectiveness of the NEM decision-making framework for facilitating wind integration

The success of wind generation under MRET suggests that wind generation has not been unduly hampered by NEM arrangements to date. However, the success of wind has driven considerable discussion, review and revision of NEM arrangements, as outlined below.

6.1. Governance regime

Early work in Australia considering the potential challenges of integrating wind energy into the NEM included that undertaken by NEMMCO (2003, 2004), the Ministerial Council on Energy's Wind Energy Policy Working Group (WETAG, 2005), South Australia's Electricity Supply Industry Planning Council (ESIPC, 2005) and the Australian Greenhouse Office (Outhred, 2003, 2004).

In July 2004, the MCE established a Renewable Energy and Distributed Generation (R&DG) Working Group "to provide strategic advice … on policy directions for removing impediments to, and promoting the commercial uptake of renewable and distributed generation technologies and practices in the Australian energy market." The resulting discussion paper (MCE, 2006) identified:

- policy and technical issues including the planning process, network pricing and connection arrangements, network management and development and the treatment of renewable generation as negative load,
- responses underway at that time including a MCE work program underway to address issues for large intermittent generation such as wind, a NEMMCO review of technical standards, initiatives on wind energy forecasting and network pricing and regulation review, and
- possible future MCE responses including network planning and consideration of the future need for system management procedures and technologies necessary to accommodate increasing levels of renewables.

The AEMC has undertaken reviews directly relevant to wind energy including one that is currently underway into *Energy Market Frameworks in the light of Climate Change Policies.* Relatively recent rule changes include *Publication of information for non-scheduled generation, Technical Standards for Wind Generation and Other Generator Connections* and *Central Dispatch and Integration of Wind and Other Intermittent Generation*. These are discussed in the following sub-sections. Given the growing role of wind energy and its particular characteristics many other reviews are also relevant including those investigating a National Transmission Planner, Congestion Management and Demand-Side Participation in the National Electricity Market (AEMC, 2008a).

It is well appreciated that the process for rule changes within the NEM requires high transparency and consultation of all stakeholders due to the significant commercial implications that may be involved. One difficulty is that such processes can be resource intensive for participants, a particular challenge for new entrants, and take considerable time to be finalised. As an example, the rule change on central dispatch of wind was proposed in mid-2007 and the resulting changes went 'live' in early 2009. Wind turbine manufacturers, wind-farm developers and relevant industry associations have all been very active in these rule making processes and would seem to have had significant impacts on the outcomes.

Another key nationally directed governance process for wind energy has been that for MRET, and here governance has been far less assured. The original MRET legislation specified a formal review after 2-years operation in 2003. This review identified a range of problems including a boom-bust cycle in investment. However, it was argued that the need for market-based environmental regulation to ensure investment certainty constrained possible rule changes (MacGill et al., 2006). This has proven problematic in ensuring the effectiveness and efficiency of the measure. In 2007, a new Australian Government announced its commitment to ensuring that 20% of Australia's electricity supply comes from renewable sources. This includes increasing the existing 9500 GWh target to 45,000 GWh (AEMC, 2008b). The current draft legislation does not address any of the glaring design flaws identified during the initial 2003 review or the scheme's subsequent performance. The outcome will be a significantly less effective and efficient scheme that may have been possible with better governance (MacGill and Passey, 2009).

The Electricity Supply Industry Council of South Australia has also taken a particular interest in the integration of wind energy into the National Electricity Market (ESIPC, 2005, 2008). This is not surprising given the rapid development of wind energy in that State under the original MRET. In the absence of what ESIPC termed a 'timely' response from the formal NEM governance processes, the State Government imposed a requirement that new wind farms in South Australia would have to register as scheduled generation in the NEM in order to meet State licensing requirements. The impacts of this requirement are discussed later in this section.

The overall governance process for and around the NEM continues to evolve due to emerging changes and challenges of which wind energy integration is only one. COAG has decided to establish the Australian Energy Market Operator (AEMO), which will take over the role of implementing and managing electricity and gas markets in the near future (AEMC, 2008a).

6.2. Commercial and security regimes

At present, wind farms within the NEM are generally classified as "intermittent" generation and have not been required to participate within the market's scheduling, ancillary services and security projection regimes. Within the dispatch process, such non-scheduled wind farms are effectively treated as negative load. They operate as price takers (although high penetrations can certainly impact on these prices) and dispatch all of their available wind generation unless constrained down for security reasons.

The NEM would appear to have some advantageous arrangements for effectively and efficiently facilitating the integration of significant levels of wind energy:

- Supply/demand balance for regulation, contingencies and energy is managed through a gross pool rather than primarily bilaterally. This may be advantageous for variable and somewhat unpredictable generation which can find it difficult to contract bilaterally forward on fixed volumes without finding itself having significant exposure to net balancing market outcomes (Bathurst et al., 2002). In the NEM, the spot market solves supply/demand balance for all generation and load every 5 min.
- The NEM provides transparent regional prices for all market participants that reflect a considerable aspect of the underlying locational, temporal and uncertainty value of electricity as it evolves over time. These price signals have significant implications for wind-farm investment as energy value represents a significant proportion of project revenue. In particular, the additional cashflow delivered to wind farms through MRET does not shield wind farms from these signals in the way that feed-in tariff support arrangements may. Wind farms are therefore located with consideration of expected regional pool prices (that reflect potential inter-regional transmission constraints) and intraregional loss factors, and the predicted match between their generation and periods of generally higher pool prices. This is of potentially significant value for wind integration (Green, 2008).
- The NEM FCAS arrangements provide a highly transparent approach for pricing regulation and contingency ancillary services which wind farms may have particular needs to call upon. There is considerable value in co-optimising energy and FCAS dispatch for intermittent generation (Thorncraft et al., 2008).
- The freedom of scheduled participants to rebid to the 5 min dispatch boundary lets them revise offers with improving forecasting information down to near real-time and provides strong incentives for them to enhance their short-term operational flexibility. The use of shorter 'gate closures' also supports wind energy integration (Green, 2008).

  The last 5-years has seen a number of changes to NEM arrangements and rules to better facilitate higher wind penetrations including:
- greater transparency through a rule change to require public reporting on historical generation output of large wind farms and other non-scheduled generation (AEMC, 2005).
- Development of a centralized Australian Wind Energy Forecasting System (AWEFS) to support security-driven and commercial decision making. AWEFS is designed to produce wind forecasts that can be integrated into NEMMCO's forecasting processes, from the 5 min dispatch process to the 2-year medium term projected assessment of system adequacy. It provides wind energy forecasts at individual wind farm, regional and system-wide aggregations including some measures of expected uncertainties. NEMMCO procured the system with Australian Government funding and it was officially launched in October 2008 (NEMMCO, 2008). This supports NEMMCO's obligations to ensure the security of the NEM and will also provide all market participants with some information on possible future wind energy production. This information may well have relevance to their decision making.
- A rule change to require wind generation to participate more formally in scheduling and security processes through a new semi-scheduled category of market participant.

This latest development reflects the growing challenges of having significant intermittent generation within the NEM remaining outside some of the market's important scheduling and security processes. NEMMCO then has limited opportunities to direct their behaviour while remaining accountable for maintaining system security. Similar concerns have been raised for a number of other electricity industries including those of

Europe (Hiroux and Saguan, 2009). The NEM rule change which took affect in March 2009 requires significant intermittent generators (such as wind farms) to participate in the central dispatch and PASA processes through submitting dispatch offers as seen with for scheduled units, and limiting their output at times when that output would otherwise violate secure network limits.

The intent is for NEMMCO to be able to efficiently manage network constraints when they arise by being able to constrain the maximum output of semi-scheduled generating units in the same way as scheduled generating units at those times.

Interestingly, intermittent generating units can choose to be classified as scheduled generating units and South Australia currently requires new wind farms in the state of significant size to register as scheduled generation in order to obtain a generation license. Three wind farms are currently operating as scheduled generators within that State without apparent difficulty and more are under construction. One approach these wind farms have taken is to rebid their current output every 5 min into the dispatch at a negative price reflecting the value of Renewable Energy Certificates they would receive if dispatched (Centenera, 2008).

The evolving status of wind generation within formal market processes in the NEM is summarised in Fig. 4. Overall, the NEM appears to be managing the present levels of wind generation. These are, admittedly, relatively low by some international comparisons. However, the South Australian region of the NEM now has an installed wind-farm capacity equivalent to around half of the State's minimum load and only limited interconnection to other regions of the market. Wind generation now appears to be having a significant impact on market prices in the State as shown in Table 3. It highlights that wind farms are earning less than other generators from electricity sales and that the fraction has declined as wind penetration has increased.

This trend seems likely to continue as there are plans to build further wind farms in South Australia. These price outcomes are, however, now providing an increasing incentive for wind-farm developers to look for project opportunities in other States that may not feature as attractive wind resource or site availability, but which have a lower wind penetration. This is, of course, a better industry outcome as well in terms of integration costs and other challenges.

The potential impact of wind farms having to participate in ancillary service markets if they are registered as scheduled or semi-scheduled generation has been considered by Thorncraft et al. (2008). At present, turnover in the FCAS markets in the NEM is typically less than 0.5% of spot market turnover, reflecting at least in part the short time period (5 min) over which these ancillary service markets operate given 5 min spot market operation. 'Causer pays' principles for ancillary services in the NEM can be hard to implement in practice due to the shared nature of ongoing net supply and demand imbalances within the industry. Nevertheless, it seems that even significant wind energy penetrations may not have major impacts on FCAS markets, or individual wind-farm costs.

The participation of wind energy in the NEM's associated derivative markets is made more challenging by the volume uncertainty associated with their operation. Wind farms might choose not to participate in these markets. However, there is also anecdotal evidence of volume firming derivatives being offered by some participants with flexible gas-fired plant for wind farms participating in the derivative markets (Dimery, 2008).

6.3. Technical regime

The general technical access regime within the NEM is based around open access and 'shallow' connection cost obligations on those seeking connection. This has been relatively supportive of wind-farm connections although the necessary negotiation process could vary significantly with different NSPs. For example, some network connection agreements imposed by network service providers on wind farms have included the right to constrain wind-farm output down under particular circumstances.

The arrival of significant wind energy in the NEM highlighted some limitations of the technical connection standards, and these have been recently revised through a rule change on 'Technical standards for wind generation and other generator connections' (AEMC, 2007). Wind generators were exempted from aspects of the original standards because they specifically referred to scheduled, synchronous or transmission connected generating units. By comparison, wind generators have been classified as non-scheduled, generally use asynchronous generators and may be connected to distribution networks (AEMC, 2007). Other aspects of the standards were potentially problematic because the imposed on requirements on each individual generating

- Non-scheduled
  - *Existing category for intermittent gen– wind treated as negative demand*
  - Can only be curtailed for system security or key network issues
  - Don't pay for FCAS
  - *Recent changes:* technical connection standards relevant to wind generators

    Historical windfarm outputs published

    Centralised wind forecasting system (AWEFS)
- Scheduled
  - *South Australia currently requires new wind farms to register as scheduled*
  - Submission of dispatch offers
  - Compliance with targets
  - Causer-pay for ancillary services
  - Ability to offer ancillary services
  - Publication of individual outputs:- forecast, offered & actual
- Semi-Scheduled
  - *Specifically intended for intermittent gen >30MW + compulsory from March 2009*
  - Submission of dispatch offers
  - Causer-pay for ancillary services
  - Ability to offer ancillary services
  - Are treated as positive supply
- If involved in a constraint
  - Compliance with targets if less than forecast

Fig. 4. Summary of the present non-scheduled, scheduled (recent wind farms within South Australia) and semi-scheduled status of wind generation in the NEM (adapted from Outhred et al., 2007c).

Table 3
Volume weighted average electricity prices for wind farms and other generators in South Australia (Outhred, 2008).

Year	Volume-weighted average price for SA wind farms ($/MWh)		Volume-weighted average price for other SA generators ($/MWh)	
	Full year	Summer	Full year	Summer
2004–2005	NA	NA	39.25	32.62
2005–2006	32.57	39.59	43.91	67.50
2006–2007	49.69	51.55	58.71	67.21
YTD 2007–2008	66.99	63.94	108.25	149.92

unit—potentially very expensive for wind farms that comprise numerous relatively small capacity turbines in comparison with large thermal plant. The eventual rule change has, in the words of the AEMC, "balanced the need to remove unnecessary hurdles for new generator entry, in particular new generation technologies including wind, while ensuring that NEMMCO and the network service providers (NSPs) are able to maintain ongoing power system security and power quality. The rule (is more technologically neutral, applicable to both scheduled and non-scheduled generation; allows for flexibility in the negotiation of the performance standards and how they can be met, depending on individual circumstances of the connection location and the technology used; and clarifies the provision of information requirements on connection applicants to ensure NEMMCO and the NSPs have sufficient modelling information to maintain system security while preserving the intellectual property of the generator proponents and manufacturers."

The expanded MRET target, however, seems likely to pose additional challenges. Issues include the bilateral negotiation process which hampers coordinated NSP responses to numerous connection applications and equal treatment on the management of 'deep' congestion problems. These can have significant commercial implications for generators including wind farms which are often located in weak parts of the network.

7. Conclusions

Australia's National Electricity Market and renewable policy support arrangements both incorporate significant roles for commercial, competitively driven, decision making. The NEM has, to date, provided what appear to be relatively efficient temporal and locational price signals for electricity generation. MRET also seems to have created a relatively efficient market in delivering sufficient cashflows beyond those available from the energy market to get renewable energy projects including significant wind generation financed and built. Wind project developers in Australia must make investment decisions on the basis of possible future renewable energy market and energy market income streams arising from their proposed projects within these competitive arrangements. Energy market income depends on the market region within which the wind farm is located, its specific location within that region and the match of its time varying output with the half hourly market price that exhibits daily, weekly and seasonal patterns and considerable uncertainty.

However, wind energy generally participates as unscheduled generation and therefore lies outside of some important NEM processes. NEMMCO has limited opportunities to direct their behaviour yet remains accountable for maintaining system security. Formal market rule changes are underway to better incorporate wind farms into the NEM's ongoing operational decision making by requiring greater participation in the market's data provision, scheduling, ancillary services and security projection arrangements.

While these may seem onerous for wind-farm developers and operators they can be argued to represent a necessary price for wind to become a major electricity industry participant. Another key development is the availability of centralized wind forecasts for each region and time periods from 5 min to 2-years. Together, these market developments should facilitate the integration of significantly greater wind generation under the expanded MRET target for 2020, and for future low carbon electricity industries into the future.

As always, however, restructuring is an ongoing process and there are a range of potential challenges and opportunities likely to emerge over the coming decade. The introduction of a national emissions trading scheme in Australia in 2010 and growing attention on the need to enhance demand-side participation will also both impact on this integration challenge—potentially in useful ways through greater use of flexible gas-fired generation and greater opportunities to manage supply demand balance through demand-side as well as supply-side responses. The key decision-making regime for effectively responding to these challenges will be the market governance arrangements.

The new expanded Renewable Energy Target of 45,000 GWh in 2020 represents a four fold increase in the existing MRET and seems likely to pose a very significant challenge for wind integration in the NEM. This target is being implemented within an increasingly stressed electricity industry infrastructure, including transmission, and a rapidly evolving industry structure with less government ownership and growingly powerful vertically integrated 'gentailers'. The risks of poor outcomes with the proposed RET may not have been fully appreciated in the exposure draft legislation and regulations (MacGill and Passey, 2009). It will be interesting to see how well the current arrangements are able to manage the high levels of wind penetration that seem likely over the coming decade, and appropriately support the other forms of renewable energy generation that will almost certainly need to be developed and then integrated in order to achieve significant emission reductions from the NEM.

Acknowledgement

This work was supported in part by the Australian Greenhouse Office as part of the Federal Government's Wind Energy Forecasting Capability initiative.

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