CSIRO Future Grid – Cluster Project 4

Robust Energy Policy Frameworks for Investment in the Future Grid

Milestone Report 6

by

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CEEM Milestone Report

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1 INTRODUCTION

1.1 CSIRO CLUSTER PROJECT BACKGROUND

The broad objectives of the UNSW CSIRO Cluster project are:

- The development and application of an interdisciplinary policy assessment framework to better understand and assess existing and proposed policy options for driving appropriate investment in the electricity industry given its unique technical (e.g. system security), economic (e.g. network investment) and wider social (e.g. affordability imperatives) characteristics. A key focus is on the interactions between these policies.
- Development of a high level (ie. focused on broader policy relevant perspectives rather than just detailed technical and economic modelling) quantitative policy analysis tool for exploring the potential impact of different policies on the most economic future electricity generation portfolios.
- Application of this policy assessment framework and quantitative policy analysis tool to develop high level insights on coherent and comprehensive climate and energy policy frameworks to drive appropriate investment in the future grid. A particular focus is on maximising the synergies and minimising possible conflicts between multiple policy instruments such as might be seen with renewable energy targets and network investment drivers.

1.2 SCOPE OF THIS ANALYSIS

This analysis is the sixth and final deliverable Milestone analysis for the CSIRO Future Grid project from the University of New South Wales. It is intended to cover the progress on the following topics:

- Quantitative modelling tool
- Policy design and assessment framework
- Policy scenario assessment across the cluster, and lessons from Australian and International experience

This report summarises the work completed by CEEM since our previous Milestone Report (March 2015). A separate report will summarise the work over the whole Future Grid project, from the cluster. Much of CEEM's work throughout the project has also been summarised in a recent CEEM working paper, and its executive summary is also provided here[1].

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[1] J. Riesz, B. Elliston, P. Vithayasrichareon, I. MacGill (2016), "100% Renewable Energy for Australia: A Research Summary". CEEM Working Paper, March 2016. Available at: http://ceem.unsw.edu.au/sites/default/files/documents/100pc%20RE%20-%20Research%20Summary-2016-03-02a.pdf

2 QUANTITATIVE MODELLING TOOL

Previous Milestone reports have presented a range of extensions to the quantitative modelling tool previously developed by Dr Peerapat Vithayasrichareon, MC-ELECT, and applied in this project.

Milestone Report	MC-ELECT Extensions
2	Incorporating additional network investment costs with different technologies Consideration of a wider range of low-carbon generation technologies Application to scenarios with high PV penetrations
3	Extension to energy constrained hydro generation. Application to scenarios comparing the merits and risks of high renewable versus high gas-fired generation for major emission reductions. Model outcomes highlighted the risk exposure of a gas generation led response to climate change given gas and carbon price exposure compared to high renewable scenarios Initial consideration of demand-side participation
4	Extensions to consider energy policy aspects beyond carbon pricing including emission targets; also to analyse long-term energy security through fuel diversity assessments
5	Incorporating wholesale market price and revenue modelling. Outcomes highlight the adverse impact of the merit order on the revenues of both renewable and fossil-fuel generation. Further analysis of high gas generation NEM scenarios and their particular gas-price and carbon risk assessment Impact of operational constraints on portfolio planning with high renewables. Outcomes highlighted the generally modest impacts of some operational constraints such as ramp rates, but the significant potential impact of minimum synchronous generation requirements. Impact of electric vehicles and solar PV on efficient frontier generation portfolios for the NEM

Additional work has been undertaken with another modelling tool, NEM Optimiser (NEMO) developed by Dr Ben Elliston, which has particular capabilities in modelling very high renewable penetrations.

The recent focus for extensions to the quantitative modelling tool has been on exploring market pricing and revenue outcomes in the electricity market, with a particular focus on scenarios with high renewable generation. The tool now calculates hourly spot market prices, allowing analysis of the potential market dynamics of different generation portfolios, with explicit consideration of uncertainty and risk. This has been applied to the analysis described below.

Background

An observed decline in average spot market prices as renewable penetrations grow (commonly termed the "Merit Order Effect") raises a concern that energy-only market frameworks may prove ineffective for very high renewable portfolios. This analysis aimed to test whether an energy-only spot market could operate successfully with a very high renewable system.

Approach

This study applies Monte Carlo dispatch modelling to a case study in the Australian National Electricity Market (NEM), a significant energy-only market, to explore probabilistic spot pricing dynamics in portfolios ranging from 15% to 85% renewable energy (RE), with and without carbon pricing.

Results and Discussion

The modelling outcomes indicated that increasing RE does not detrimentally affect the operating profits of peaking plant (such as open cycle gas turbines), since they only operate during scarcity pricing events. These events still occur in a high RE system, but occur at different times since they are driven by the coincidence of low wind and PV generation with high demand, instead of high demand alone.

An increase in the Market Price Cap (MPC) at any RE level was found to significantly increase operating profits for almost all generator types (except photovoltaics, if this technology is over-represented in the market). The profitability of firm capacity (coal, combined cycle gas turbines and open cycle gas turbines) is found to be especially sensitive to the level of the MPC. This suggests that adjustments to the MPC may be effective for adjusting investment incentives for firm capacity, and may be sufficient to offset the declining operating profits related to increasing RE proportions.

This suggests that an energy-only market may remain viable with a high RE portfolio, as long as the MPC can be increased sufficiently, and the risks associated with this can be appropriately managed by market participants exposed to the MPC. The modelling indicates that the precise level of the MPC required to target the desired investment incentives will change depending upon the level of the carbon price, but indicates that operating profits are sensitive to the level of the MPC regardless of the carbon price.

Publication

Early versions of this work were presented at the following conferences, with details available in conference papers as follows:

- P. Vithayasrichareon, J. Riesz, I. MacGill, (2015) "***Market Pricing and Revenue Outcomes in an Electricity Market with High Renewables – An Australian Case Study***", IAEE International Conference, Antalya 2015. Available at: http://ceem.unsw.edu.au/sites/default/files/documents/IAEE15%20abstract%20-%20final.pdf
- P. Vithayasrichareon, J. Riesz, I. MacGill, (2015) "***Impact of High Variable Renewable Generation on Future Market Prices and Generator Revenue***", IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC) 2015, Brisbane. Available at: http://ceem.unsw.edu.au/sites/default/files/documents/PES%20APPEEC%202015%20-%20Revenue_withoutdiffMPC.pdf

The work is now being finalised for journal submission, with anticipated details as follows:

- P. Vithayasrichareon, J. Riesz, I. MacGill, (2016) "***Electricity market operation with high levels of variable renewable generation***".

3 POLICY ASSESSMENT AND DESIGN FRAMEWORKS

Previous Milestone reports have outlined development of policy design and assessment frameworks:

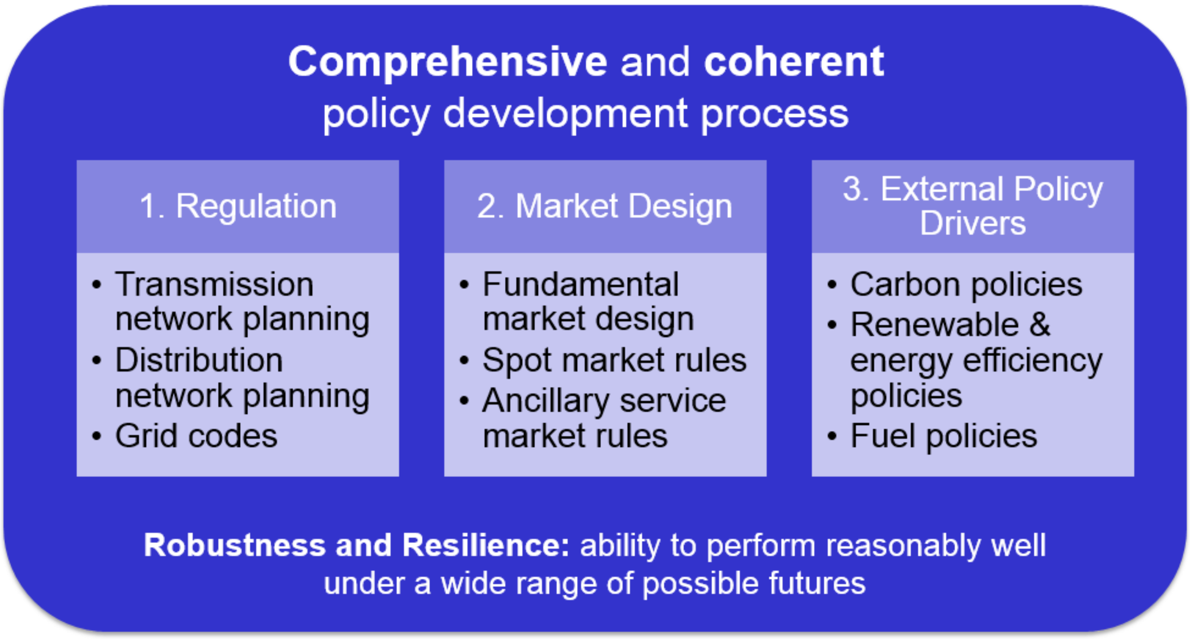
Milestone Report	Policy assessment and design frameworks
1a	Review of policy assessment frameworks including socio-technical system, regulatory cycle, regulation impact assessment regulation review Review of electricity sector transformation frameworks including Australia, EU (Denmark, Germany, UK) and US (California and New York) case studies Regulatory impact assessment guidelines
2	Interdisciplinary assessment framework development
3	Case studies of policy design frameworks with a focus on the Australian Energy White paper process, repeal of the Australian carbon price, the development of the Emission Reduction Fund, the Renewable Energy Target Review and the Optional Firm Access development process. A key outcome is the importance of transition within major policy change processes.
4	Detailed case study of the OFA design process including stakeholder interests, potential interactions with carbon pricing and renewable energy support policy frameworks. Comparison of proposed and final rule outcomes for Scale Efficient Network Extensions
5	Insights into policy design frameworks arising from the Energy White paper process highlighting its failiure to reconcile market orientation with the market inefficiencies of unpriced externalities, limited market competition and the broader frameworks under which private generation investment must be undertaken Potential impact of electric vehicles on future grids

CEEM has developed a "three pillar" approach to policy development, as illustrated in Figure 1. Energy policy is affected by a wide range of areas, broadly falling into three categories:

1. Regulation (including transmission network planning, distribution network planning and grid codes),
2. Market Design (including spot market rules, ancillary service market rules and so on), and
3. External policy drivers (such as carbon policies, renewable energy policies, fuel policies, etc.).

All three are relevant to energy industry outcomes. Any policy under consideration must be assessed in the context of these three pillars, with the focus on ensuring the resulting policy framework is comprehensive and coherent. Robustness and resilience should also be assessed, ensuring the identified policy has the ability to perform reasonably well under a wide range of possible futures, given the considerable uncertainty in the policy environment at present.

Figure 1 - Three Policy Pillars policy assessment framework



This framework has been applied to the policy design and assessment analysis outlined in case studies described in the following section.

4 POLICY SCENARIOS AND FINDINGS

Previous Milestone reports have outlined a range of scenarios developed across the cluster and presented assessments of Australian and International experience with particularly key issues.

Milestone Report	Policy scenario findings
1b A	Frameworks for transmission locational and sizing positions Review of current Australian arrangements including regulation as well as rule change processes, reliability standards and the Optional Firm Access
1b B	Review of Australian arrangements and proposals for the connection of remote renewables. International comparisons including Texas, California and Ireland. Summary of key learnings including risk management, planning, stakeholder engagement, clear targets
2	Survey of Australian and International options and experience in transmission (and, to a lesser extent, distribution) network planning processes, electricity market design (including wholesale spot and ancillary service arrangements) and external policy drivers (carbon policy), renewable and energy efficiency support, fuel policies and optimal future of coal-fired generation in the future grid Proposed priority research areas including transmission planning and Optional Firm Access, connection of remote renewables, energy only market design under high renewables, NEM design options for renewable energy integration and future flexibility mechanisms, and for external policy drivers Emission Reduction Fund design, renewable financing, risk weighted investment portfolios and supply-side climate mitigation policies Cluster scenario guidelines and principles – stretch scenarios for conceivably plausible futures, internal coherence and consistency within scenarios, design with the purpose in mind, and avoiding implying a 'central' scenario
3	Detailed assessment of Optional Firm Access with a focus on the risks around transition from current arrangements and potential advantages to incumbents

4	Detailed proposals regarding Optional Firm Access transition access arrangements and for facilitating significant network expansion for connecting remote renewables Case study on capacity renumeration mechanism including product definition and requirement, procurement processes and important design features Decision to use the CSIRO future forum scenarios to guide policy assessment for the cluster with a focus on high centralised renewables, and highly distributed energy scenarios
5	Comparison of different jurisdictional transmission frameworks – final CIGRE case study outcomes. Capacity market design for the electricity industry

4.1 AUSTRALIAN POLICY – DISTRIBUTED ENERGY

4.1.1 Network tariffs and retail markets for distributed energy

Background

More cost reflective tariffs for electricity are generally accepted to be a more economically efficient approach to pricing network services. However, they are highly non-trivial to implement in practice. Furthermore, it can be unclear whether the intention is to provide price signals to consumers that drive appropriate investment, or to achieve what is effectively recovery of past costs. There would seem to currently be insufficient guidance from the AEMC on which costs should be considered and prioritised (future, current or past costs) and some apparent no-go areas including more regionally diverse tariffs reflecting the costs of network service to remote and regional customers, or those in areas where load growth is likely to drive augmentation expenditure. For this analysis, we have focused on achieving appropriate investment signals – the key to longer-term economically efficient outcomes.

Approach

Existing and proposed retail network tariff structures were modelled using half-hourly demand data from 2012-13, for 2,200 households, sourced from the Ausgrid Smart Grid, Smart City Trial.

Results and Discussion

It was found that applying different tariff structures changed the impact of photovoltaics, energy efficiency and other customer interventions on the network service provider revenues. For example, if time of use tariffs were applied, the dollars collected per household was found to decline as the proportion of photovoltaics installed increased. In contrast, demand tariffs maintain a relative constant dollars collected per household, as photovoltaics penetration increases. A key issue here is how household peak demand is defined – in particular, is it a measure of household contribution to periods of network demand or, as seen in a number of the proposed CRF tariffs put forward by DNSPs, a measure of household peak demand within a fairly broad time window. Our findings highlight the value of better testing of the structure of demand tariffs including modelling a range of potential emerging technologies prior to their introduction, in order to understand the potential impact upon household decisions as well as network service provider revenues.

The analysis suggests that many of the new tariffs being introduced don't necessarily better align household network costs with their contributions to peak demand than existing tariff structures. For example, the demand tariffs offered by SA Power Networks (for Distribution Use of System charges) do not provide a strong correlation between household total annual cost and household demand at time of network peak; the correlation is found to be similar to flat tariffs. This is because this tariff (and many like it) uses the customers' demand peak over a broad period each day, over the full year. This doesn't reflect very closely the likely customer use at the actual time of network peak. A better approach would be to apply the demand tariff based upon the customers' demand at the actual time of the annual network peak (or even better, over some select group of peak demands in order to reduce random tariff outcomes due to the stochastic behaviour of households driven by factors such as periods of occupancy), and to provide customers with as useful information as possible about the period in which that is likely to occur. Ideally, this would be complemented by programs and mechanisms to help households 'automate' their response to such tariff arrangements.

While our analysis is still preliminary, initial outcomes certainly highlight the inadequacies of a number of the so-called more "cost-reflective tariffs" intended to be used by DNSPs. There are a range of opportunities to do better, and provide tariff options that are more coherent, and fairer across a range of distributed energy options that have a potentially valuable role in the future grid.

Publications

This work has been published in:

- S. Young, A. Bruce, I. MacGill (2016), "***Australian Electricity Network Customer Revenue by Tariff Type in a Variety of Scenarios***", submitted to IEEE PES GM.
- R. Passey (2015), "***Cost reflective pricing and its impact on storage***", APVI Storage Workshop, Solar, Storage, and New Energy Business Models, Sydney, June 2015

4.1.2 Shadow pricing against storage

Background

The potential for a dramatic transformation away from centralized grid electricity supply as a growing proportion of customers choose to disconnect from the network and self-supply raises important questions for the future of network utilities. Indeed, such an outcome likely represents a far more significant challenge to the current supply industry than that of increased renewable and distributed generation since it raises the question of what future role it might have at all.

Approach

This study explored potential future business models for network service providers under circumstances where grid disconnection may become feasible for a significant proportion of retail customers.

Results and Discussion

This analysis argued that in the case where grid disconnection is less expensive than continuing centralized supply under existing regulated network tariffs, Network Service Providers (NSPs) will need to shift towards more competitively-oriented pricing in what could be an increasingly competitive market (in competition with self-supply alternatives). This implies a move away from "cost-recovery" pricing, towards competitive pricing approaches, such as "shadow-pricing" just below the competition (self-supply alternatives, such as the combination of home storage and photovoltaics). Regulatory frameworks will need to adjust to allow such innovative pricing structures, and eventually might even become unnecessary, with consumers no longer requiring regulation beyond that applied in other competitive industries.

Publication

This work was presented at the Asia-Pacific Power and Energy Engineering Conference in 2015, and published as a conference paper:

- J. Riesz, J. Gilmore, "***Rethinking Business Models for Network Service Providers – Shadow Pricing against Storage***", IEEE Power and Energy Society (PES) Asia-Pacific Power and Energy Engineering Conference (APPEEC), Brisbane, 15-18 Nov 2015. Available at: http://ceem.unsw.edu.au/sites/default/files/documents/Riesz-IEEE-PES-AsiaPacific-2015%20-%202015-07-15a.pdf

4.2 AUSTRALIAN POLICY – CENTRALISED ENERGY

4.2.1 Quantifying key uncertainties in the costs of nuclear power

Background

In power system portfolio decisions, cost risk (uncertainty over cost) should be an important consideration, in addition to central estimates of cost. Explicit quantification of cost risk can be used as an input to sophisticated portfolio optimisation modelling tools that take cost risk into account.

Consideration of cost risk is particularly important when comparing technologies such as nuclear generation (which are generally accepted to have a high capital cost risk), and many renewable technologies (which can often be constructed in a relatively short duration, and are not exposed to fossil fuel price fluctuations, minimising their associated cost risk).

Approach
This study quantifies the uncertainty in each of the cost components for nuclear power, and combines them using a Monte Carlo analysis, allowing a direct assessment of cost risk for this technology. Levelised cost of energy (LCOE) estimates are also provided to allow an indicative comparison of the scale of cost risk, compared with other technologies.

Results and Discussion
The most important contributors to cost risk for nuclear power generation are identified to be overnight capital cost (OCC) estimates, the degree of cost escalation over the construction and pre-construction periods, and the duration of those periods.

In the absence of cost escalation, the mean LCOE of nuclear power is found to be AU$145/MWh in jurisdictions excluding Asia (or AU$130/MWh if Asian plant costs are included in the distributions), with a standard deviation of $62/MWh. However, when cost escalation over construction and pre-construction periods is included at rates observed during nuclear build programs in France and the USA, the mean LCOE increases to AU$515/MWh, with a standard deviation of AU$2,646/MWh. These results indicate that nuclear power costs have an 80% probability of exceeding $170/MWh, and a 50% probability of exceeding AU$278/MWh, based upon Monte Carlo analysis.

This suggests that for jurisdictions such as Australia, nuclear power is likely to be considerably more expensive than other low emissions alternatives, such as wind and photovoltaics, and may be comparable in cost or more expensive than "dispatchable" renewable options such as concentrating solar thermal. Furthermore, the considerable cost risk associated with nuclear power is a significant disadvantage.

Publication
This analysis has been submitted to the International Journal of Energy Research for consideration, with details as follows:

- J. Riesz, C. Sotiriadis, P. Vithayasrichareon, J. Gilmore (2016) "***Quantifying key uncertainties in the costs of nuclear power***". Submitted to the International Journal of Energy Research.

The draft manuscript is available upon request.

4.2.2 Research and deployment priorities for renewable technologies

Background
This study aimed to identify the most important research and deployment priorities, to enable low cost, high renewable power systems.

Approach
An evolutionary program was applied to optimise the mix of generating technologies in scenarios of 100% renewable energy (RE). Various technologies were omitted or

reduced in availability to determine their relative importance for achieving low cost RE portfolios. The Australian National Electricity Market (NEM) was used as a case study, with results likely to be of relevance for any international jurisdiction considering a transition to a high proportion of renewables.

Results and Discussion

A wide range of portfolios with 100% RE were found to be potentially feasible, with generation costs in the range of AU$65 to AU$87/MWh in 2030.

The single most important factor for achieving low cost RE is found to be the integration of large quantities of wind generation (supplying around 70% of energy in all the lowest cost scenarios); therefore wind integration and removal of barriers to wind deployment is identified as a significant research priority for achieving high RE portfolios in the NEM.

In contrast, photovoltaics were found to saturate at less than 10% of total energy supplied in all the lowest cost portfolios (based upon present NEM demand profiles) indicating that policy measures to enable utility-scale photovoltaics should be implemented with caution, and possibly considered in partnership with measures to promote demand side participation and storage (which would be likely to mitigate this saturation effect, and were not modelled in this study).

Biofuelled gas turbines were found to be important, being the only "peaking" renewable technology in the NEM with significant deployment potential (featuring characteristics of high operating costs, but low capital costs, such that it operates with a low capacity factor of less than 10%). A complete absence of bioenergy increases costs by AU$20-30 /MWh, and even having only 0.1TWh per year of bioenergy available reduces average costs by AU$3-4 /MWh. This suggests that enabling some amount of peaking technology should be a significant priority if the goal is to achieve 100% RE, although a small amount of natural gas peaking generation may be a suitable substitute that contributes minimal greenhouse gas emissions.

Limits on the non-synchronous penetration (NSP) driven by short-term frequency control concerns and other power system technical limitations are found to be relatively expensive, suggesting a significant research priority around finding alternatives to NSP limits, low cost means of providing inertia, or ways to relax NSP limits while maintaining system stability.

Pursuing the commercialisation of cost effective geothermal and CST technologies may be important if stringent NSP limits persist, and if the deployment of these technologies remains the only satisfactory way to meet that limit in high renewable systems. However, these technologies do not appear to be essential for achieving efficient high renewable systems for Australia as long as sufficient wind and peaking bioenergy generation is available.

Publication

This work was presented at a conference as follows, with an extended abstract available:

- J. Riesz, B. Elliston (2015), "***The Impact of Technology Availability on the Costs of 100% Renewable Electricity Generation Scenarios for Australia***", 38th IAEE

International Conference, Antalya, Turkey. Available at: http://ceem.unsw.edu.au/sites/default/files/documents/IAEE2015-Riesz-Elliston-Factorsaffectingcosts-2014-12-17a.pdf

An extended discussion has been recently submitted to the journal Energy Policy for consideration, with details as follows:

- J. Riesz, B. Elliston (2016), "***Research and Deployment Priorities for Renewable Technologies: Quantifying the importance of various renewable technologies for low cost, high renewable electricity systems in an Australian case study***", Submitted to Energy Policy.

The draft manuscript is available upon request.

4.2.3 The incremental cost of renewable generation

Background

When developing policies to promote renewable energy, it is important to understand how the average cost of electricity might increase to achieve a particular renewable energy target. It might be reasonable to expect that there could be diminishing returns from the higher levels of investment. For example, 90% renewable electricity may be significantly less expensive to achieve than 100%. This study explores that hypothesis.

Approach

This study evaluates the incremental costs of higher levels of renewable energy (RE) supply using an evolutionary optimisation tool to find least cost electricity generation portfolios. The Australian National Electricity Market (NEM) in 2030 is used as a case study for exploring various generation portfolios from low to high shares of RE, low to high greenhouse gas emissions caps, and low to high carbon prices.

Results and Discussion

Incremental electricity system costs are found to increase approximately linearly as the RE share grows from zero to 80%, and then demonstrate a small degree of non-linear escalation, related to the inclusion of more costly renewable technologies such as solar thermal electricity.

Similarly, electricity system costs increase approximately linearly as a greenhouse gas emissions cap is lowered from 150 megatonnes (Mt) to 30 Mt, and then demonstrate a small degree of non-linear escalation for caps below 30 Mt.

However, in both cases this escalation is moderate, and does not appear to provide a strong argument for long-term policies that aim for RE shares lower than 100%, or electricity sector emissions caps higher than zero as options for rapid decarbonisation.

Publication

This work has been submitted to the journal Renewable Energy for consideration, with details as follows:

- B. Elliston, J. Riesz, I. MacGill (2016), "What cost for more renewables? The incremental cost of renewable generation – An Australian National Electricity Market Case Study". Submitted to Renewable Energy. Preprint available at: http://ceem.unsw.edu.au/sites/default/files/documents/WhatCostMoreRenewables-preprint.pdf

4.3 FORMAL SUBMISSIONS

CEEM aims to continue to provide useful contributions to the ongoing development of Australia's energy policy frameworks, on the basis of our research in this area. Two recent submissions are summarised below.

4.3.1 Submission on the Climate Change Authority's Report

This submission responded to the Climate Change Authority's (CCA) Special Review Second Draft Report.

Key contributions and insights

This submission highlighted the inevitability of policy flotillas, and identified the need for broader policy, given the scale and scope of climate change, and the range of options for addressing it. This means there is a need for frameworks that can address the coherence and comprehensiveness of many interacting policies, and the assessment of individual policies must be undertaken in this broader context. This submission provided some key insights on how this might be achieved.

Effective climate policy design has proven challenging for jurisdictions around the world over the past two decades, and particularly challenging in Australia. The lack of bipartisan consensus on the importance of addressing climate change was clearly a major factor. This was in large part an outcome of the role that carbon intensive exports, primarily coal, with large and influential stakeholders representing them, play in Australian industry policy. Europe and increasingly other countries such as China, see the opportunity for climate policy to also address energy security concerns arising from their heavy dependence on fossil fuel imports. On energy security, however, Australia is somewhat schizophrenic, recognising energy security issues in terms of liquid fuel imports, but effectively promoting greater dependence on fossil fuel imports for its current and prospective coal and gas customers.

The approach of successive governments towards climate change policy development has, however, almost certainly been an additional factor in Australia's limited progress. In particular, there has never been close integration between energy and environmental, particularly climate, policy despite the reality that all energy policies are also de facto climate policies – for good or bad – whilst most climate policies are invariably energy policies given the energy sector's predominant role in global greenhouse gas emissions. A particularly relevant example at present is that of US and Chinese energy policy efforts to reduce the air pollution impacts of coal-fired generation – efforts that are also providing valuable greenhouse gas emission mitigation outcomes.

There was an opportunity to integrate energy and environmental policy efforts through the parallel Ecologically Sustainable Development (ESD) and energy micro-economic reform agendas of the early 1990s – an opportunity that was squandered (MacGill and Healy, 2013). Ideally, the CCA would have the opportunity to revisit this broader context for the development of climate policy. If not, it would still be worth better highlighting the implications of undertaking climate policy development largely separately, and certainly incoherently, of energy policy development.

Publication

This work was submitted to the Climate Change Authority's Special Review Second Draft Report:

- N. Raffan, A. Bruce, I. MacGill (2016), "***Australia's Climate Policy Options: Submissions in response to the Climate Change Authority's Special Review Second Draft Report***", CEEM, February 2016. Available at: http://ceem.unsw.edu.au/sites/default/files/documents/201602%20CCA%20Climate%20Policy%20Options%20Submission%20CEEM%20UNSW.pdf

4.3.2 Submission on the Review of Governance Arrangements

CEEM contributed a formal submission on the Review of Governance Arrangements for Australian Energy Markets, in direct response to the Panel's draft report.

Key contributions and insights

CEEM's submission highlighted that it would be appropriate for a review of this nature to be outcomes-focussed, with reference to objectives against which the success (or failure) of governance arrangements could be assessed. However, there was no assessment against any objectives in terms of desired outcomes included in this review. The National Electricity Objective (NEO) could provide one possible point of reference. The Australian Energy Market Agreement (AEMA) would also appear suitable, as a key foundation document that defines the mandate for the Energy Council, defining six objectives for reform.

CEEM's submission also outlined the need for integrated planning and decision-making. The Energy White Paper process was not addressed, despite the fact that it should clearly be considered within the scope of a review of Australian energy markets governance.

The review also placed climate change mitigation outside of energy governance arrangements, despite the fact that virtually all energy policy has climate implications, and most climate policies target the energy sector. One of AEMA's six objectives is environmental: "*address greenhouse emissions from the energy sector, in light of the concerns about climate change and the need for a stable long-term framework for investment in energy supplies*". Thus, the failure to effective address climate change in the energy sector to date indicates that significant governance changes are required.

Overall, the review's finding that there is an unprecedented pace of change (relating to information technology, renewables, climate policy, and so on), combined with a "strategic policy deficit", which was "identified across market institutions as a whole" suggests that significant governance changes could be warranted. However, the review recommends only relatively modest "tweaks" to governance arrangements. This appears unlikely to be appropriate and sufficient.

Further reading

This work was submitted to the Review of Governance Arrangements:

- N. Raffan, I. MacGill (2015), "***"Review of Governance arrangements for Australian Energy markets – Submission in response to the Panel's Draft Report",*** CEEM Submission. Available at: http://ceem.unsw.edu.au/sites/default/files/documents/20150824%20Governance%20Review%20Draft%20Report%20Submission%20CEEM%20UNSW.pdf

4.4 INTERNATIONAL POLICY

4.4.1 Experimental Economics

Background

Experimental methods are now playing a central role in economics, in testing and refining theories concerned with individual behaviour or market performance. In fact, these methods have been very influential in studying and designing electricity markets, and other markets such as spectrum auctions, where it has been demonstrated that small design details can have efficiency and revenue implications in the order of billions of dollars. For example, economics Nobel Laureate Vernon Smith was involved in designing the Australian electricity market through the use of such experiments. Experimental economics methods make it possible to implement variations of available information with a high degree of control, allowing isolation of their effects to unravel a causal rather than a purely correlative relationship.

Approach

The aim of this study was to use laboratory experiments to investigate the possible effects of increasing or decreasing transparency in a wholesale electricity market with high levels of variable generation. Specifically, we examined to what extent information uncertainty on the supply or the demand side will affect the suppliers to exert market power and drive prices up. Our benchmark was a full transparency setting, where all electricity traders are perfectly informed about the overall demand as well as the currently available capacities of all other market participants. The first treatment corresponds to the situation where each trader is limited to only information on their own generation capacity, whereas information about other producers consists of only their potential capacities and the associated probabilities. The second treatment varies the demand level among a set of options and their corresponding probabilities, which reflects a stochastic feature of the demand side.

The experimental design involved groups of three players. Each represents an electricity trader in a wholesale electricity market, selling electricity by offering supply quantities at various prices. Market prices resulted from the bidding of the groups, and groups remained unchanged throughout the entire experiment. Each player had two generation sites of different technologies. The generation sites featured different unit costs (one is low cost, and the other expensive) and different capacities. The lower cost site had a higher capacity and reflects the operating characteristics of variable renewables, for which availability depends upon weather conditions. The expensive operating cost technology was always available but has a lower capacity. The electricity demand varies between three levels and is randomly determined. The benchmark treatment revealed all information on demand and supply to all players in the group.

Information levels were reduced in the other two treatments, which allow attribution of any observed change in behaviour to the corresponding information variation. The experiment lasted for 24 rounds and the profit of one of the 24 rounds was randomly selected and paid as an incentive. The experiment was conducted in the experimental economics laboratories at UNSW Australia and ZHAW.

Results and Discussion

By experimentally modifying the degree of information, we showed that available information and strategic behaviour are intimately related. Our experimental results indicated that in monopoly cases (where one player has abundant, cheap generation available while the two others only have limited expensive generation available) prices are significantly lower under supply uncertainty than full information. In the duopoly cases (where one has only expensive generation while the two others have the cheap technology available) we do not find a difference. In the competitive case (all have low cost technologies) we find higher prices under supply uncertainty than full information. With regard to the demand uncertainty we do not find any significant differences.

These results suggest that while "local" or "temporal" market power due to randomness associated with variable renewables may be a substantial problem in a highly certain market, it is likely less so with a sufficient degree of uncertainty around the availability of those technologies. This suggests that the generation uncertainty inherent in variable renewable technologies (such as wind and photovoltaics) may actually provide an advantage to customers and market regulators by limiting the exercise of transient market power.

Publication

This work has been accepted for presentation at the following conference:

- R.Betz, A. Hefti, J. Riesz, I. MacGill, P. Shen (2016), ***"Wholesale electricity markets with high shares of renewable energies: Effects of uncertainty on prices***", IAEE International Conference, Bergen, Norway, June 19-22.

An extended abstract summarising the work is available upon request.

4.4.2 Energy and climate policy frameworks: Possible international insights

Approach

The major differences and similarities between the Kyoto Protocol and the new Paris Agreement were analysed, and new elements were identified.

Results and Discussion

The Kyoto Protocol was found to employ a *top-down* approach, with the list of Annex B countries (developed countries) taking on quantified emissions limitations or reduction commitments. In contrast, the new Paris Agreement applies a mainly *bottom-up* approach, with an agreement upon an overall target of keeping global average temperature within 1.5 - 2°C, and achieving global peaking as soon as possible, with a balance between emissions and removals by the second half of the century. It also applies National Determined Contributions (NDCs) for *all* countries (not only Annex B countries), although these are not binding, since they do not form part of the Agreement.

There are also significant similarities between the Kyoto Protocol and the Paris Agreement. Both allow withdrawal three years after the agreement has entered into force, with one year notice. Both employ emissions trading (or internationally transferred mitigation outcomes), and both dedicate a share of the proceeds to finance administrative expenses and support adaptation.

The new elements included in the Paris Agreement include an emphasis on a balance between mitigation and adaptation, a focus on loss and damage, the application of non-market approaches, a new focus on transparency on action and support (with flexibility for developing countries), and the inclusion of a global stocktake every five years (starting in 2023).

Collaboration

This work was presented by Dr Regina Betz at the 60th Annual Conference of the Australian Agricultural and Resource Economics Society (AARES):

- R. Betz (2016) "***Kyoto to Paris: Same, same but different***", 60th Annual Conference of the Australian Agricultural and Resource Economics Society (AARES), Canberra, 5th February. Available at: http://ceem.unsw.edu.au/sites/default/files/event/documents/AARES_presentation.pdf

5 FINAL END OF CLUSTER REPORT

The CSIRO Future Grid cluster is in the process of developing a final end of cluster report, which will summarise the key messages of the research from across the cluster into an accessible document. CEEM has also developed a summary of much of our research conducted throughout the project, as it relates to the topic of 100% renewable energy scenarios for Australia. This work is summarised below.

5.1.1 100% renewable energy for Australia: A research summary

This paper summarises the latest research on the challenges and opportunities of a future 100% renewable Australian National Electricity Market (NEM). It focuses on work undertaken at the Centre for Energy and Environmental Markets (CEEM) at UNSW Australia, but also discusses other relevant Australian studies undertaken by groups including Beyond Zero Emissions (BZE), the University of Sydney, and the Australian Energy Market Operator (AEMO).

The summary finds that scenarios with 100% renewables in Australia are technically feasible, as long as the generating portfolio includes a mix of technologies including a sufficient amount of renewable types that are firm and synchronous (such as hydro, biogas, concentrating solar thermal and geothermal). A significant expansion of transmission infrastructure is likely to be required, although modelling studies to date have found that the costs of transmission are around 10% of the total scenario costs, which suggests transmission costs are important, but not dominating.

The costs of 100% renewable scenarios from a range of modelling studies are found to be in the range of $71/MWh and $200/MWh, weighted in the middle of this range at around $100-$140/MWh. This translates to an increase in retail customer bills of around 6-8c/kWh, or an increase of around 20-30% from present. Importantly, a cost increase in this range is very similar to that forecast by organisations such as the CSIRO for other possible future NEM scenarios, including those involving continued significant reliance on fossil-fuels, depending on future fuel and potential carbon emission costs. This means that a transition to a 100% renewable NEM may represent a very modest cost compared to likely alternatives.

Publication

This summary report was published on the CEEM website, as a resource for non-government organisations, policy makers, and the general public:

- J. Riesz, B. Elliston, P. Vithayasrichareon, I. MacGill (2016), "***100% Renewable Energy for Australia: A Research Summary***". CEEM Working Paper, March 2016. Available at: http://ceem.unsw.edu.au/sites/default/files/documents/100pc%20RE%20-%20Research%20Summary-2016-03-02a.pdf

CEEM working Paper – Executive Summary

About this paper

This paper summarises the latest research on the challenges and opportunities of a future 100% renewable Australian National Electricity Market (NEM). It focuses on work undertaken at the Centre for Energy and Environmental Markets (CEEM) at UNSW Australia, but also discusses other relevant Australian studies undertaken by groups including Beyond Zero Emissions (BZE), the University of Sydney, and the Australian Energy Market Operator (AEMO).

Background

Australia has one of the most emissions-intensive electricity systems in the world, relying heavily on coal-fired generation. This means that a transition to a 100% renewable power system represents a near fundamental transition from the present system. Given the challenges experienced over the past decade by alternative low carbon options including Carbon Capture and Storage (CCS) and nuclear, and the rapid progress of key renewable technologies, a clean energy future for Australia may well hinge on whether 100% renewables is whether this is possible and, if yes, how might it best be achieved.

Is 100% renewables technically feasible?

Australia has extraordinary renewable energy potential, particularly in wind and solar. Wind and solar photovoltaics (PV) technologies are commercially available and well proven, and provide some of the most cost competitive generation options in Australia. However, wind and solar PV bring new challenges to power systems. Notably, they are:

1. ***Variable*** – The availability of wind and PV is highly variable and only somewhat predictable (particularly for PV).
2. ***Non-synchronous*** – Wind and PV are non-synchronous, meaning that they interact very differently with the power system, and do not inherently provide many of the types of grid services that we have come to rely upon from large coal and gas-fired generators.

However, wind and PV are not the only renewable technology types available for potential deployment in Australia. As shown in Table 1, there are a range of other renewable options, all of which are 'firm' (non-variable and fully dispatchable), and synchronous (they integrate with the grid in a very similar way to conventional coal and gas-fired technologies, and provide the same kinds of grid services). Indeed, globally, there are already a number of nations with near 100% renewable electricity, including Brazil, New Zealand and Iceland. All of these systems rely heavily upon the firm, synchronous renewables, such as hydro, geothermal and biomass.

Table 1 – Renewable technology options for deployment in Australia

Variable, non-synchronous	Firm, synchronous
Wind	Hydro
Photovoltaics (PV)	Concentrating solar thermal (CST) with storage
Wave	Biogas turbines (and other bioenergy)
Tidal	Geothermal

These technologies have different challenges; for example the potential to expand hydro generation in Australia is likely to be limited, bioenergy can compete with other land and resources uses, geothermal is at an early pilot stage in Australia, and concentrating solar thermal (CST) remains very expensive compared to wind and PV.

However, by creating a generating portfolio including some *mix* of all of these types of renewables, the research suggests that these challenges can be managed to create a technically viable 100% renewable power system for Australia that is reliable and secure. The challenge for Australia will be that in order to create a *cost effective* 100% renewable grid, we will likely need to integrate much larger quantities of wind and PV, at levels beyond the experience of any grid in the world to date. Much international research is focused in this area.

Research on 100% renewables in Australia

The research into 100% renewable electricity systems in Australia has focused to date on exploring the temporal and geographical variability of renewable resources over hourly time periods, investigated under a range of assumptions regarding available renewable energy options, their costs, and future electricity demand. The non-synchronous nature of wind and PV has been minimally explored to date, but is typically managed in the models by requiring a minimum amount of synchronous generation (such as hydro, CST, biogas turbines or geothermal) to be operating at any time. There is reasonable confidence that this would address the issue, although the level of synchronous generation required is unknown at present.

Work to date by UNSW and others including the Australian Energy Market Operator (AEMO) suggests that a 100% renewable NEM can deliver the same level of reliability as the present electricity system, provided that there is sufficient:

1. ***Firm, synchronous generation*** – The modelling indicates a need for at least some firm, synchronous capacity included in the portfolio (potentially including hydro, CST with storage, biogas turbines, or geothermal). These technologies provide 'dispatchable' power at times of insufficient solar and wind, as well as other grid services.
2. ***Transmission*** – A large increase in transmission capacity is likely to be required, linking spatially diverse renewable generation and loads across the NEM. This allows wind and solar generation to be geographically dispersed and hence less variable; there are few periods when there is no sun or wind across the whole NEM.

Whilst there are a range of technical challenges for electricity industry operation that require further investigation, no insurmountable technical barriers to a 100% renewable NEM have been identified.

How much will 100% renewables cost?

There are many limitations in the modelling of future power systems, most particularly applying to estimates of cost. Given the many years that will be required to transition from Australia's present, fossil-fuel dominated system, we require forward looking estimates for the costs of renewable energy technologies. Although it is reasonable to predict that ongoing learning and innovation will mean that the costs of many of these technologies will reduce over time (based upon past experience, such as the reductions in the cost of PV over the past decade), the degree to which costs might fall for each technology is highly uncertain.

We use formal Australian government cost projections provided by the Australian Energy Technology Assessment (AETA) for 2030 and 2050 and current NEM demand in our work. Our findings highlight that the future costs of a 100% renewable NEM will depend upon many factors, including the technologies available and possible constraints on their widespread deployment, their realised future costs, and the costs of necessary additional network investment. Our lowest cost scenarios include large amounts of wind and PV (for cheap bulk energy), combined with around 40 GW of firm, synchronous renewable technologies, including hydro, concentrating solar thermal with storage, and biogas turbines. These firm renewables provide dispatchable power on demand, sufficient to reliably meet the system peak demand of 35 GW, with an additional margin, even if there are some periods with absolutely no wind and photovoltaic power available. Work by others with different assumptions has come up with broadly similar generation mixes depending on assumptions around particular technologies such as CST (BZE) and geothermal (AEMO).

Future wholesale electricity costs for 100% renewables portfolios have been estimated by UNSW and others (BZE, AEMO and the University of Sydney) to be between $71/MWh and $200/MWh (including transmission), weighted in the middle of this range at around **$100-$140/MWh**. The various cost estimates are illustrated in Figure 2, including the components attributed to transmission.

Figure 2 – Projected costs of 100% renewables for the NEM[2]. Sources: [1, 2, 3, 4, 5][3]

[2] DR refers to the discount rate applied.

[3] [3] and [4] remain under peer review, and are not yet formally published.

To provide a basis for comparison, average annual wholesale NEM generation prices have varied in the range $30-60/MWh (or 3-6c/kWh) over the past fifteen years. This does not include transmission and distribution network costs or retail margins. The average household cost, including all these components, is currently around 29c/kWh or $290/MWh. Projections by AEMO based upon their modelling indicate that retail customer bills would need to increase by around **6-8c/kWh**, an increase of **20-30%**, to an electricity rate of around 35 - 37c/kWh, to achieve 100% renewables.

Based upon a total annual electricity cost of $1,499 for an average household [6], a 20-30% increase would equate to around $300 to $400 per year.

Importantly, a cost increase in this range is very similar to that forecast by organisations such as the CSIRO for other possible future NEM scenarios, including those involving continued significant reliance on fossil-fuels, depending on future fuel and potential carbon emission costs. This means that a transition to a 100% renewable NEM may represent a very modest cost compared to likely alternatives.

How can we achieve lower cost 100% renewable systems?

UNSW's modelling suggests that achieving 100% renewable portfolios at the lower end of the projected cost range will likely require the following measures:

- ***Enable significant wind generation*** – The lowest cost portfolios consistently include significant quantities of wind generation (supplying up to 80% of energy). Portfolios with lower proportions of wind are feasible, but generally more expensive. Enabling wind deployment in this range may require measures to establish and maintain a broader societal consensus around the benefits associated with this technology.
- ***Address wind and PV integration challenges*** – Achieving such high proportions of wind and PV generation brings many technical integration challenges which will need to be addressed, including in adjustments to the NEM Rules, and in AEMO's operational procedures. UNSW's modelling suggests particular importance in maximising the amount of energy that can come from non-synchronous sources, by minimising the application of unnecessarily conservative constraints[4].
- ***Some bioenergy*** – The availability of at least a small amount of flexible bioenergy (or other peaking capacity, such as demand side participation) is important to assist with periods of low wind and solar generation, at a reasonable cost. Portfolios without any bioenergy are feasible (as long as other firm synchronous technologies such as CST can be deployed), but are generally more expensive.

[4] In the Irish system, they have implemented an "NSP" limit, which defines the maximum amount of "non-synchronous penetration" that can be managed by the system in any dispatch interval. If the NSP is limited to 50%, for example, then half of the energy generated in any period must come from synchronous sources, such as CST, geothermal or (bio)gas turbines. If the NSP is increased to 90%, then only 10% of energy in any period needs to come from synchronous sources (and up to 90% can come from wind and PV). Relaxing the NSP limit is found to reduce system costs considerably. Research is required to determine the appropriate level for this limit, and how to minimise it.

- ***Minimise uncertainty*** – The cost of capital is very important for renewables, and financiers will adjust this rate depending upon their judgement of the risks associated with investing in a project. Policy frameworks and stable market environments that minimise uncertainty over project returns will minimise the cost of capital, and can reduce the costs of renewable generation considerably.

It is also clear that new policies, market rules and regulatory frameworks will be required to facilitate the major renewable investment involved, with suitable regard to appropriate patterns of technology, location and timing. More generally, Australia will need to establish and maintain a broader societal consensus around this profound electricity industry transformation.

Transmission requirements and costs

Many of the best solar and wind sites in Australia are in remote locations that will require significant transmission investment. Furthermore, balancing wind and PV generation around the NEM requires strong interconnections to take advantage of geographical diversity.

Some preliminary and high level estimates suggest transmission costs in the range of **$6 – 20/MWh** (from studies by UNSW and AEMO), to enable 100% renewable scenarios. This equates to around 10% of the total cost of a 100% renewable system, suggesting that transmission expenditure is important, but not a dominating contributor to costs.

These costings only include a high level representation of the major interconnections; further investment is likely to be required intra-regionally. For comparison, current transmission expenditure in the NEM is around $2.7b/year or around $14/MWh. Much of this investment is "sunk", so a proportion of the transmission investment required to enable 100% renewable scenarios is likely to be additional to these costs. For this analysis, all new transmission investment has been considered as additional to present (included in the total system costs quoted).

The impact of a 100% renewable NEM on distribution network costs will depend on many factors including, critically, the role that distributed renewables such as residential, commercial and industrial PV plays. There has been very little Australian work to date on the overall costs of distributed scenarios of this nature.

Is 90% renewables likely to be significantly less expensive?

UNSW's analysis suggests that there is not a significant escalation in costs to go from 80-90% renewables to 100% renewables. This is largely due to the availability of a range of firm, synchronous renewable technologies (such as biogas turbines and concentrating solar thermal with storage) that can cost effectively and reliably meet the last 10-20% of energy that would otherwise be supplied by fossil fuels. Biogas turbines, in particular, have a low capital cost, and therefore are cost effective for operating rarely but providing the required level of reliability.

Mitigation of cost risk

UNSW's modelling also highlights explicit co-benefits in moving to high renewable scenarios, through the mitigation of cost risk associated with uncertain gas and carbon prices in future. Renewables are shown to be very effective at mitigating this cost risk, which consumers are exposed to in high fossil fuel scenarios (particularly high gas scenarios). For this reason, a "gas transition" to renewables has been shown to be high cost, and high risk, compared with a direct transition to renewables.

Nuclear and Carbon Capture and Storage

UNSW's modelling highlights that nuclear energy and carbon capture and storage are both likely to be higher cost than renewables (in some cases, significantly higher cost). These technologies also carry a significantly higher cost risk profile than renewables.

What next?

The technical feasibility and quite likely relatively attractive economics for a 100% renewable NEM, naturally gives rise to possible next steps.

Given Australia's pressing clean energy challenges, there are excellent reasons to set higher and more ambitious renewable generation targets than those established at present. While there are significant opportunities to reduce the costs of renewable options through judicious R&D and demonstration, major deployment has proven a key driver of reducing cost and improved expertise.

As renewable penetrations climb, we should not underestimate the challenges in effectively and efficiently integrating these technologies into the NEM. Current NEM arrangements have proven remarkably resilient to regionally significant wind and PV penetrations to date (by comparison with some other electricity industries around the world). However, a 100% renewable NEM will inevitably operate very differently to the present, and significant resources will be required for all electricity industry stakeholders to understand, drive and adapt to these changes.

Such profound electricity industry transition will also require societal consensus on the importance of addressing our clean energy challenges and renewable energy's role in addressing them. Beyond these challenges lie the opportunity for Australian leadership and innovation in creating a clean energy future for Australia and others around the world.

6 SELECTED PUBLICATIONS, PRESENTATIONS SINCE MILESTONE REPORT 5

CEEM Working papers:

- J. Riesz, B. Elliston, P. Vithayasrichareon, I. MacGill (2016), "100% Renewable Energy for Australia: A Research Summary". CEEM Working Paper, March 2016. Available at: http://ceem.unsw.edu.au/sites/default/files/documents /100pc%20RE%20-%20Research%20Summary-2016-03-02a.pdf

Book chapters:

- Smith, R and MacGill, I.F. (2016) "The future of utility customers and utility customers of the future," in *Future of Utilities - Utilities of the Future How technological innovations in distributed generation will reshape the electric power sector*, ed. F.P. Sioshansi, Academic Press
- MacGill, I. F. and Watt, M.E. (2015) "Economics of Solar PV Systems with Storage in Main Grid and Mini-grid Settings," in *Solar Energy Storage*, ed. B. Sorensen, Academic Press.

Journal papers:

- Elliston, B., J. Riesz and I.F. MacGill (2016) What cost for more renewables? The incremental cost of renewable generation – An Australian National Electricity Market case study, *Renewable Energy,* 95: 127-139, September.
- Oliva, S., MacGill, I. F. and Passey, R. (2016). Assessing the Short-Term Revenue Impacts of Residential PV Systems on Electricity Customers, Retailers and Network Service Providers. *Renewable & Sustainable Energy Reviews*, 54: 1494-1505.
- Vithayasrichareon, P. and MacGill, I. F., (2016). Valuing large-scale solar photovoltaics in future electricity generation portfolios and its implications for energy and climate policies. IET Renewable Power Generation, 10(1):79-87.
- J. Riesz, J. Gilmore, I. F. MacGill (2015) "Assessing the viability of Energy-Only Markets with 100% Renewables – An Australian National Electricity Market Case Study", *Economics of Energy and Environmental Policy (EEEP),* in press, accepted 09/15 .
- J. Riesz, J. Gilmore, I. MacGill, (2015) "Frequency Control Ancillary Service Market Design – Insights from the Australian National Electricity Market" *The Electricity Journal, 28 (3): 86-99*. [link]
- J. Riesz, P. Vithayasrichareon, I. MacGill, (2015) "Assessing "Gas Transition" pathways to low carbon electricity – An Australian case study", *Applied Energy, 154: 794-804*. [pdf]
- P. Vithayasrichareon, G. Mills, I. MacGill, (2015) "Impact of Electric Vehicles and Solar PV on Future Generation Portfolio Investment", IEEE Transactions for Sustainable Energy, 6 (3), 899-908. [link]
- I. MacGill, A. Bruce (2015) "Photovoltaics in Australia: Time for a Rethink", IEEE Power and Energy Magazine, March/April issue. [pdf]

Reviewed conference papers:

- Agranat, O., Bruce, A. and MacGill, I. F. (2015). Short-term frequency Management in the Australian NEM. in *Proc. Asia-Pacific Solar Research Conference (APSRC)*, Brisbane, December.
- Wilkie, O., MacGill, I. F. and Bruce, A. (2015). Revenue Sufficiency in the National Electricity Market with High Penetrations of Renewable Energy. in *Proc. Asia-Pacific Solar Research Conference (APSRC)*, Brisbane, December.
- Easton, S., Bruce, A. and MacGill, I. F. (2015). Generator exit from the Australian National Electricity Market with increasing penetrations of renewable energy. in *Proc. Asia-Pacific Solar Research Conference (APSRC)*, Brisbane, December.
- Young, S., MacGill, I. F. and Bruce, A. (2015). Impact of Electric Vehicles on NEM and Household Expenditure for a Variety of Charging Regimes. in *Proc. Asia-Pacific Solar Research Conference (APSRC)*, Brisbane, December.
- Kelly, D., Passey, R., MacGill, I. F. and Bruce, A. (2015). Assessment of Cost-Reflectiveness of Proposed Network Tariffs in Australia. in *Proc. Asia-Pacific Solar Research Conference (APSRC)*, Brisbane, December.
- Selbie, R., Bruce, A. and MacGill, I. F. (2015). Assessing the Value of Utility-Scale Energy Storage Arbitrage in the Australian NEM. in *Proc. Asia-Pacific Solar Research Conference (APSRC)*, Brisbane, December.
- Hungerford, Z., Bruce, A., and MacGill, I. F. (2015). Review of demand side management modelling for application to renewables integration in Australian power market. *2015 IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC)*, Brisbane, Australia.
- Raffan, N., Bruce, A. and MacGill, I. F. (2015). Planning in the Australian National Electricity Market - Challenges and Opportunities. *2015 IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC)*, Brisbane, Australia.
- Vithayasrichareon, P., Riesz, J. and MacGill, I. F. (2015). Impact of High Variable Renewable Generation on Future Market Prices and Generator Revenue", *2015 IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC)*, Brisbane, Australia
- Discussion papers: Riesz J., Vithayasrichareon, P. and I.F. MacGill (2016) 100% Renewables in Australia: A Research Summary' CEEM Discussion paper, March 2016, available at www.ceem.unsw.edu.au
- F. Regairaz, M.R. Hesamzadeh, A. Di Caprio, A. Balkwill, F-P. Hansen, J. Riesz, (2015) "Market price signals and regulated frameworks for coordination of transmission investments", *CIGRE Symposium*, Lund, Sweden.
- P. Vithayasrichareon, J. Riesz, I. MacGill, (2015) "Impacts of Operational Constraints on Generation Portfolio Planning with Renewables", *2015 IEEE Power and Energy Society General Meeting*, Denver, CO, USA. *[Best conference papers on Integration of Renewable & Intermittent Resources]* [pdf]

– J. Riesz, B. Elliston (2015) "The impact of technology availability on the costs of 100% renewable electricity generation scenarios for Australia", *38th IAEE International Conference*, Antalya, Turkey. [pdf]

– J. Riesz, G. Thorpe, Regina Betz, Johanna Cludius (2015) "A framework for designing and categorising Capacity Markets – Insights from an Application to Europe", *38th IAEE International Conference*, Antalya, Turkey. [pdf]

– P. Vithayasrichareon, J. Riesz, I. MacGill (2015) "Market pricing and revenue outcomes in an electricity market with high renewables – An Australian case study", *38th IAEE International Conference*, Antalya, Turkey. [pdf]

Submissions:

– Bruce, A., MacGill, I.F., Passey, R. and Stringer, N. (2016), *CEEM Submission to the AEMC Consultation Paper: National Electricity Amendment (Local Generation Network Credits) Rule*, available at www.aemc.gov.au.

– Neil Raffan, Anna Bruce and Iain MacGill (2016), *Australia's climate policy options: CEEM Submission in response to the Climate Change Authority's Special Review Second Draft Report*' available at www.cca.gov.au.

– Neil Raffan and Iain MacGill (2015) *CEEM Submission to the COAG Energy Council's 'Review of Governance Arrangements for Australian Energy Market – Draft Report(July 2015),* Available at www.ceem.unsw.edu.au.

Presentations:

– Jenny Riesz (2016) Renewable Technologies in the Future NEM: 100% Renewables for Australia? Australian Power Institute (API) Summer School, Sunshine Coast, February 24, 2016

– Iain MacGill (2016) "Examining the impact of energy storage systems on demand-side participation" Electricity Storage Future Forum 2016, Powerhouse February 23, 2016

– Iain MacGill (2016) "Assessing the Economic Value and Market Implications of PV in the Australian National Electric Market," 'Value of Solar PV for Singapore' Energy Studies Institute Workshop, National University of Singapore, Singapore, February 18, 2016

– Regina Betz (2016) "Kyoto to Paris: Same, same but different" Australian Agricultural & Resource Economics Society (AARES) Conference, Canberra, February 5, 2016

– Peerapat Vithayasrichareon (2015) "The Role of Renewables in Hedging against Future Uncertainties and Enhancing Energy Security, Energy Studies Institute, National University of Singapore, December 8, 2015

– I. MacGill (2015) "Opportunities and challenges facing network businesses in the Australian NEM: some CEEM research perspectives", Visiting delegation seminar UNSW, 16 June. [pdf]

– Rob Passey (2015) "Cost-Reflective Pricing and its Impact on Storage", Australian Solar Conference, Australia Technology Park, Sydney, June 4, 2015

– J. Riesz (2015) "Energy-only Markets with High Renewables - Can they work? Models for Resource Adequacy", Workshop on electricity markets with a high share of renewables, Zurich University of Applied Sciences, Zurich, Switzerland, 29 May. [pdf]

– R. Betz, J. Riesz, P. Shen (2015) "Workshop II: Economic Methods, Experimental Economics", Workshop on electricity markets with a high share of renewables, Zurich University of Applied Sciences, Zurich, Switzerland, 29 May. [pdf]

– I. MacGill (2015) "High renewable penetrations in the Australian National Electricity Market (NEM): Challenges and opportunities", Workshop on electricity markets with a high share of renewables, Zurich University of Applied Sciences, Zurich, Switzerland, 29 May [pdf]

– R. Betz (2015) "Workshop on Electricity Market Design: Capacity Remuneration Mechanism", Workshop on electricity markets with a high share of renewables, Zurich University of Applied Sciences, Zurich, Switzerland, 29 May [pdf]

– I. MacGill (2015) "Renewable energy policy support in the Australian National Electricity Market: key challenges and opportunities", Workshop on electricity markets with a high share of renewables, Zurich University of Applied Sciences, Zurich, Switzerland, 29 May [pdf]

– P. Vithayasrichareon (2015) "Modelling future generation portfolios under electricity industry uncertainties and multiple objectives", Workshop on electricity markets with a high share of renewables, Zurich University of Applied Sciences, Zurich, Switzerland, 29 May [pdf]