Centre for Energy and Environmental Markets

Submission on 100 percent Renewables Study – Draft Modelling Outcomes Report

by

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Submission to AEMO and Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education (DIISRTE)

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About CEEM

The UNSW Centre for Energy and Environmental Markets (CEEM) undertakes interdisciplinary research in the design, analysis and performance monitoring of energy and environmental markets and their associated policy frameworks. CEEM brings together UNSW researchers from the Australian School of Business, the Faculty of Engineering, the Institute of Environmental Studies, and the Faculty of Arts and Social Sciences and the Faculty of Law, working alongside a growing number of international partners. Its research areas include the design of spot, ancillary and forward electricity markets, market-based environmental regulation, the integration of stochastic renewable energy technologies into the electricity network, and the broader policy context in which all these markets operate.

CEEM has a particular interest in AEMO's modelling of 100 percent renewable energy, since the Centre has been conducting similar modelling of scenarios of 100 percent renewable energy for the National Electricity Market for the past several years (Elliston et al, 2012, Elliston et al, 2013).

We would welcome comments and suggestions on this, and all CEEM publications. The corresponding author for this submission is Dr Jenny Riesz (j.riesz@unsw.edu.au.)

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Executive Summary

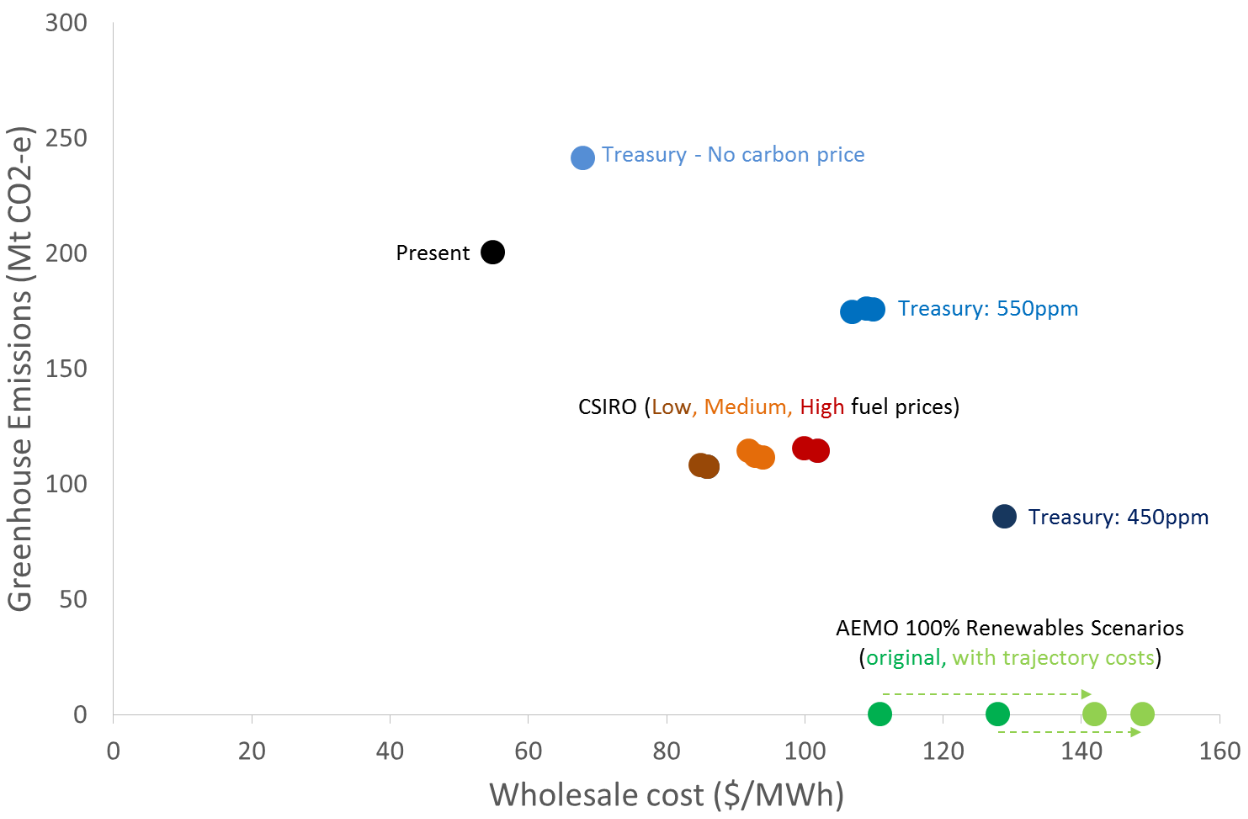
In April 2013, the Australian Energy Market Operator (AEMO) released a draft report outlining the findings of a comprehensive and detailed modelling process exploring several scenarios for 100 percent renewable energy in the National Electricity Market (NEM). This document provides a formal response to the draft report from the Centre for Energy and Environmental Markets (CEEM), at the University of NSW.

This submission first acknowledges the high value of the modelling undertaken. This AEMO study provides the first steps towards understanding and articulating the details of 100 percent renewable options within the diverse range of future electricity industry arrangements that may be feasible options for Australia. Detailed articulation of power system options that are very different from the one operating today are particularly important to ensure that decision making is not limited by institutional barriers and familiarity bias. We therefore applaud AEMO, the Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education (DIISTRE), the Department of Resources, Energy and Tourism (DRET) and all other parties and stakeholders involved for the vision and thought leadership in completing this study.

This submission also includes a selection of recommendations to constructively build upon and add value to what is already an excellent study. These recommendations are:

1. Provide appropriate reference points to aid the reader in accurately interpreting the costs provided. Although there is no 'exact' reference scenario available, a range of previous modelling studies provide helpful reference points that are a valuable aid for readers who are not immersed in the electricity sector. Given the high relevance of this work to a wide range of stakeholders (including policy makers and the general public) it is appropriate to strive for ways to provide helpful framing. An example is proposed in Figure 2.

Figure 1 – 2030 comparison of scenarios



Source: Based upon "medium" scenarios from CSIRO efuture modelling (available at http://efuture.csiro.au/), and the Treasury "Strong Growth Low Pollution Future" modelling (2011).

2. Provide guidance on the relative significance and magnitude of the many uncertainties and limitations listed. An approach for estimating indicative 'trajectory costs', which AEMO has already suggested may be the most significant, is proposed. This is also illustrated in Figure 2.
3. The transparency of this modelling process to date has been excellent. We particularly applaud the release of the extensive modelling input data sets, which provides a superb resource for improving the quality of later research. We suggest that AEMO continue in this vein with the release of modelling results in an easily accessible spreadsheet form with any necessary documentation.
4. As discussed above, this modelling process has been of extremely high value in articulating and detailing power system options that are very different from today's conventional power system. This is extremely important in ensuring that all options are considered on an equal footing without a bias towards familiar options. Although it is recognised that this modelling is not without cost, it is considered very important that this modelling be repeated annually on an ongoing process. Ideally scenarios of 100% renewable energy would be included in the annual National Transmission Network Development Plan (NTNDP).

5. AEMO's ongoing annual modelling processes (such as the NTNDP) should also include a selection of very low emissions scenarios, in line with climate science and the full range of possible emissions reduction targets (including Australia's 'fair share' towards limiting warming to 2°C above pre-industrial levels). This should include scenarios in the range of 80-95% renewables and technology mixes restricted to commercially available technologies.
6. The high degree of public interest in this modelling suggests an opportunity for facilitating and informing a broader discussion about Australia's energy future. This opportunity could be embraced by conducting a broader and more inclusive stakeholder consultation process.
7. The inclusion of a summary of input assumptions in the body of the report is applauded as a useful guide for the reader. Some minor suggestions are provided on some areas where further clarity around input assumptions in the text of the report would be helpful.
8. The opening commentary in the report (in the Introduction and Key Observations sections) could benefit from some more nuanced wording. Suggestions are provided in the body of this report.

CEEM commends AEMO and DIISTRE on the completion of an immensely valuable study that helps to inform and guide Australia on the critical decisions regarding our energy infrastructure.

Contents

Background

The federal government announced its Clean Energy Future Plan in July 2011, which foreshadowed that the government would ask the Australian Energy Market Operator (AEMO) to expand its planning scenarios to include further consideration of energy market and transmission planning implications of moving towards 100 per cent renewable energy in the Australian National Electricity Market (NEM).

In July 2012, the Department of Climate Change and Energy Efficiency (DCCEE) published the scope of the 100 per cent renewables study. From that date, AEMO developed new models and techniques necessary for optimising the generation mix in a 100 percent renewables scenario, and worked with consultants (ROAM Consulting and the CSIRO) to develop the required data inputs.

A draft report outlining modelling results was released on 26 April 2013, and was presented by AEMO and DIISRTE at a stakeholder forum held in Melbourne on 2 May 2013. Submissions on the draft report from stakeholders were invited, hence this prepared CEEM submission.

According to the original scope of work, the final report is to be published by 31 May 2013. At this time, there does not appear to be a formal process in place to continue and expand upon this study.

1 Purpose of this submission

This submission provides a formal response by the Centre for Energy and Environmental Markets (CEEM) to the draft report on the 100 percent renewables modelling study. It includes a range of recommendations for making this study more useful and valuable as a tool and point of reference for the electricity industry and the public in Australia.

CEEM has a particular interest in AEMO's modelling of 100 percent renewable energy, since CEEM has been conducting similar modelling of scenarios of 100 percent renewable energy for the National Electricity Market for the past several years (Elliston et al, 2012, Elliston et al, 2013) and is undertaking a joint ARENA funded project with the Melbourne Energy Institute at the University of Melbourne on low carbon transition of the NEM.

2 Commendation

CEEM would like to formally congratulate AEMO and DIISRTE on the release of this landmark report. The modelling contained is of high quality, and can serve as a valuable reference for decision making and future analysis. In our view it represents a world-leading effort by an electricity system and market operator to consider the potential technical and economic implications of very high renewable energy penetrations.

Australia has challenging decisions ahead on the future of our electricity sector, and more broadly on the future of our economy. Affordability, energy security and climate change concerns have all been heightened in recent years. Policy makers and other stakeholders need the tools to navigate and manage our many ongoing uncertainties, and fully understand the diverse range of options available that can assist in addressing these challenges. In the electricity sector, many of these options are very different to the conventional electricity system in operation today, which creates a particular challenge in their consideration on an equal footing with more familiar, conventional, alternatives. Highly variable and somewhat unpredictable solar and wind generation technologies are likely to be the most challenging in this regard, and therefore require the most effort to fully understand. The AEMO report provides an essential foundation to underpin and further progress that understanding.

The electricity industry, policy makers, and the Australia public will find ongoing value in the AEMO report. It helps to clarify some of the costs, benefits and issues related to the option of a 100 percent renewable electricity system. Although the need for further work is clearly recognised, this report provides an important first step.

The operational considerations review (included in Appendix 6) is of particular value, providing a nuanced and insightful assessment of the many issues that may need to be addressed, and suggesting directions for further exploration in this space. We congratulate AEMO in finding ways to add value to the tightly defined scope of work, utilising the deep expertise of AEMO's employees.

CEEM also congratulates AEMO and DIISRTE on the transparency of the modelling process. In particular, the release of the extensive input data sets developed as a part of the process makes a valuable contribution to increasing the sophistication and accuracy of further modelling by industry and the public sector.

3 Recommendations

A range of recommendations are outlined in the following sections. These are aimed at ensuring that the maximum value is extracted from the comprehensive and high quality modelling process that has been undertaken.

3.1 Recommendation 1: Provide appropriate points of reference

It is understood that due to time constraints and other factors, the modelling scope did not include a reference scenario to allow comparison of the 100 percent renewable scenarios with 'business as usual' investment in the electricity sector.

Furthermore, it is appreciated that there would be considerable challenge in defining the most appropriate assumptions that should apply to such a business as usual reference scenario. For example, should the impact of policies to reduce greenhouse emissions (such as a carbon price) be included? And if so, what level of ambition should be assumed around greenhouse reduction targets? Thus there are a wide range of possible alternative scenarios that could be considered 'reasonable' reference points for comparison.

While these challenges are recognised, the AEMO study estimates the economic costs of a major transformation of the NEM over a period of two to four decades that would have major energy security and greenhouse implications, and wider implications. Given this, the lack of provision of appropriate reference points in the report risks misinterpretation and misrepresentation of the results. This modelling is of high interest to a diverse range of stakeholders, including the general public and policy makers, who may not have a nuanced understanding of the sector, its present costs or an appreciation of what is "typical", and the current challenges that the industry has to address. All stakeholder would greatly benefit from a range of reference points that provide a basis for comparison with this study, and assist in understanding the results, and placing them within an appropriate context.

Although the scope of work did not explicitly include the modelling of a comparable reference case, a wide range of credible long term modelling studies have been completed in recent years. A combination of these could be easily used to provide a helpful reference and aid understanding. For example, a range of existing scenarios have been selected and represented in Figure 2 and Figure 3 below. The reference scenarios illustrated include a range of carbon trajectories and a range of fuel prices and technology costs.

It is accepted that such comparisons are not entirely 'apples with apples', since the 100 percent renewables study employed a different type of modelling methodology to the other studies. Furthermore, the Treasury modelling was based upon different cost assumptions since it was conducted prior to the release of the Australian Energy Technology Assessment (AETA). Regardless, these alternative scenarios do provide a valuable reference point to consider when placing the findings of the AEMO study into context.

The largest source of error in comparison with these reference scenarios is likely to be in the fact that the 100 percent renewable modelling was conducted entirely in a single year, and did not include consideration of the trajectory to reach that point. This means that the capital costs were calculated entirely at the 2030 or 2050 technology capital costs respectively, rather than at the costs that would have occurred at the time when the technology was actually built, progressively over the preceding decades.

CEEM agrees with AEMO that the cost of the trajectory is likely to be an important factor influencing the cost of the 100 percent renewable scenarios. Since it significantly impacts results, the best approach is to attempt to quantify this factor. While it is appreciated that a detailed modelling of optimal trajectories is out of the scope of this analysis, a simple calculation can provide an approximate estimate that helpfully provides an order of magnitude indication of the scale of additional cost that may be incurred.

CEEM undertook to perform some simple calculations to estimate the additional cost uplift caused by installation over a trajectory, based upon the results data provided in AEMO's draft report. The shape of the technology cost reduction curves over time for each technology was sourced from the AETA study, and 'stretched' as necessary to reach the values used for technology costs in the AEMO study. AEMO could repeat this analysis using the original GALLM technology cost trajectories applying to each scenario (which have not been made publicly available at this time). Renewable capacity for each technology was assumed to be installed linearly over time from the present to the relevant year (2030 or 2050). It is appreciated that more mature technologies (such as wind and photovoltaics) are likely to be installed more rapidly in the earlier years and less mature technologies (such as wave and geothermal) are more likely to be installed in the later years. However, in the absence of an optimised modelling process to determine the least cost trajectory, a linear installation approach that is technology agnostic was deemed to provide a reasonable approximation.

CEEM's modelling suggests that the cost of constructing generation capacity over a trajectory in this manner would increase the total capital cost estimate by the order of 10-20% over estimates using only the 2030 or 2050 technology costs.

Wholesale cost impacts were more challenging to calculate because AEMO's report does not include exact numbers for energy produced by each technology in each scenario. However, proportions were estimated from the pie charts provided to estimate the contribution of variable operations and maintenance and fuel costs, as an input to calculation of wholesale costs.

Based upon the described approach, wholesale costs were found to increase by the order of 20-30% over the estimate in the study when trajectory costs were included.

Although these estimates are not equivalent to a fully optimised trajectory assessment, they do provide a helpful frame of reference to aid stakeholders in understanding the magnitude of additional cost that may be relevant. As such, it offers useful insights for policy makers, industry and the general public in accurately understanding the implications of this study.

These results have been complied in Figure 2 and Figure 3 to provide an illustration of the relative cost and carbon intensity of the 100 percent renewable scenarios, compared with a range of reference cases from previous modelling exercises. The estimated indicative impact of adding the trajectory costs is also shown.

Figure 2 – 2030 comparison of scenarios

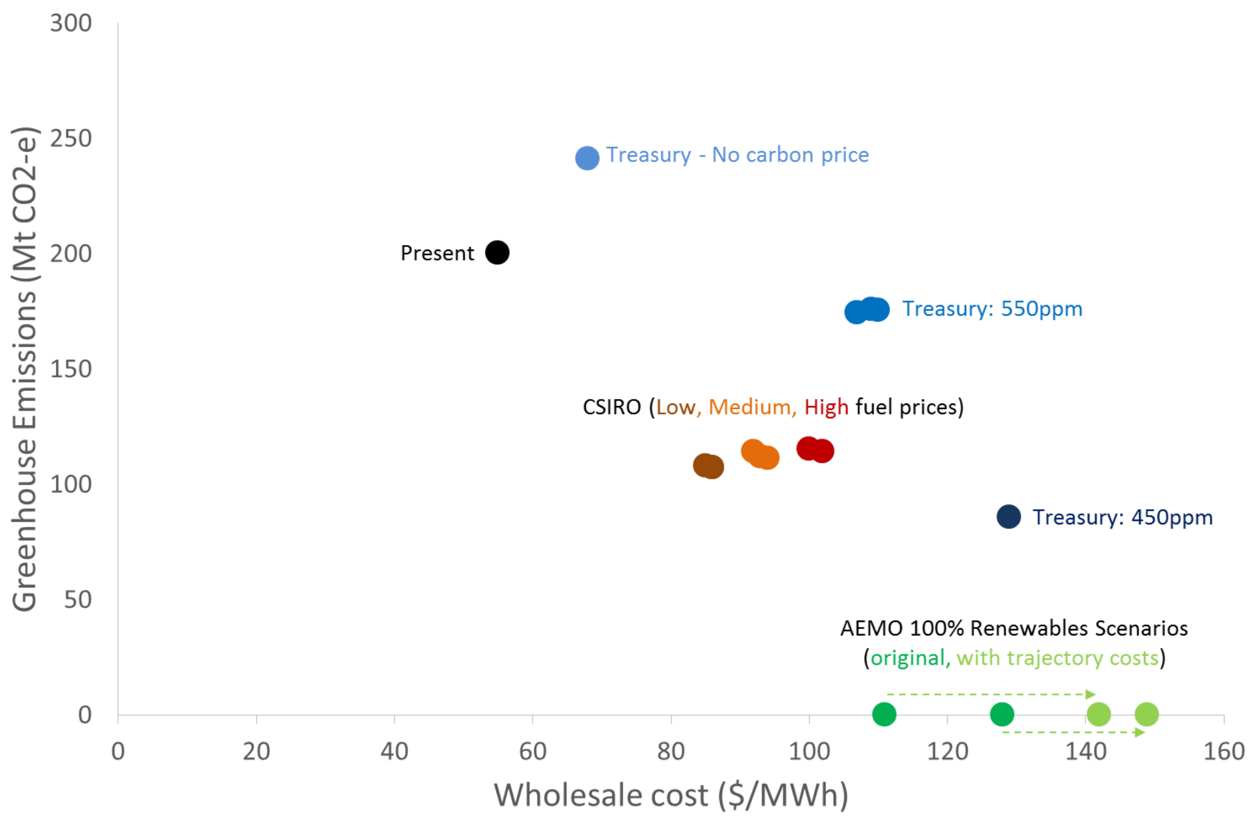
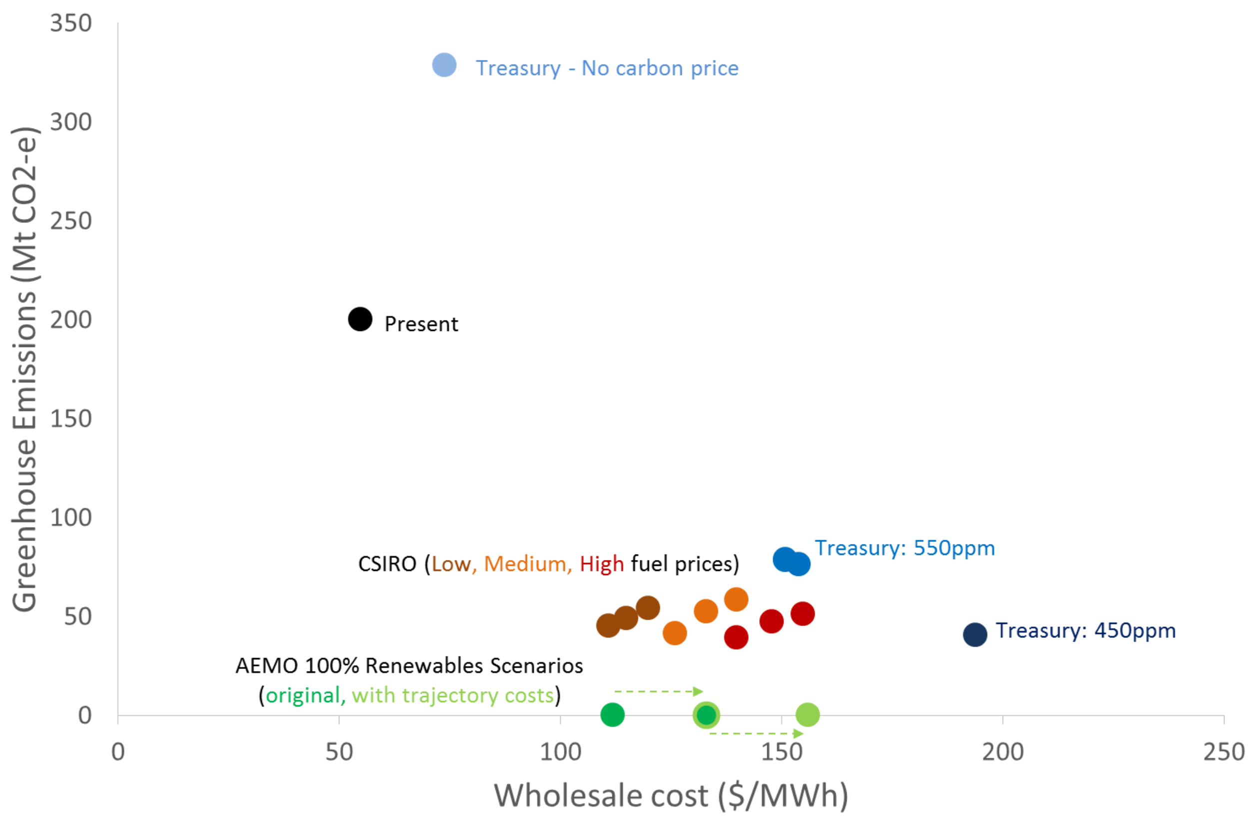


Figure 3 – 2050 comparison of scenarios



Source: Based upon "medium" scenarios from CSIRO efuture modelling (available at http://efuture.csiro.au/), and the Treasury "Strong Growth Low Pollution Future" modelling (2011).

When conducting comparisons to reference cases, a focus on total annual costs (through wholesale costs) is considered preferable to a focus on total capital costs only. This is because the capital cost estimate does not include fuel costs, carbon costs, and other ongoing costs, which may be significant in a fossil-fuel system. This means that a comparison based upon capital costs only will not provide a meaningful comparison between scenarios that include differing proportions of renewable and fossil fuel technologies.

It is recommended that AEMO provide appropriate points of reference with all the cost estimates listed in the final report. This should include reference points to compare total capital costs with an appropriate selection of reference cases (CSIRO may be able to assist with provision of these calculations based upon their *efuture* results). It should also include reference points to compare wholesale costs, and retail costs if possible, in the relevant sections of the report.

To make the comparison with reference cases as meaningful as possible, it is suggested that AEMO undertake a simple trajectory cost calculation using the full data available, and include an order of magnitude estimate of impact of the trajectory cost in the final report.

3.2 Recommendation 2: Guidance on uncertainties and relative impact

In any study of this nature that involves very significant uncertainties and modelling limitations, it is appropriate to explicitly recognise and list these prominently in the report, as AEMO has done.

To provide additional value, it would be helpful to provide guidance to the reader (where possible) on the relative significance and priority order of these uncertainties and limitations. An approach to this has been demonstrated in the previous section with regards to trajectory costs (which AEMO indicated at the forum to be the likely most significant contributor to increased costs). It would be valuable to explore whether similar order of magnitude estimates may be possible to prioritise these remaining uncertainties. This would assist the reader in understanding their relative importance, and guide further research towards issues of greatest significance.

3.3 Recommendation 3: Release modelling results data

As noted earlier, the transparency of the modelling process, and in particular on the release of the comprehensive input data sets used to conduct the modelling is commendable. The opportunity is open to continue and expand on this welcome transparency in the release of the modelling results. After all, this modelling has been conducted at public expense and it is therefore reasonable that the public have access to a detailed set of modelling results in a workable format. On this basis, it is recommended that spreadsheets of the modelling results be made available for download with the final report. These should include, at a minimum, the data represented in tables and figures in the final report (similar to the spreadsheets provided with the Treasury's Strong Growth Low Pollution Future study). Further detail beyond this level would provide even more value, allowing deeper analysis and a broader range of other studies to use this work as a foundation.

This will increase the transparency around the modelling, allowing others to verify the calculations and fully understand the wide range of assumptions that have been made. It will also allow others to use the valuable results obtained for further analysis and comparison more accurately and easily.

More generally, it would establish a long overdue precedent on the presentation of publicly funded energy modelling.

3.4 Recommendation 4: Ongoing modelling of low emissions scenarios

As described above, this modelling process has been extremely valuable. Whilst recognising the substantial uncertainty involved in any modelling exercise of this nature, it serves to clarify some of the costs, benefits and issues associated with the option of a 100 percent renewable power system.

Renewable technology costs are changing rapidly over time, and this is reflected in the rapid evolution of forward estimates of technology costs year to year. These individual technology cost trajectories strongly influence the total cost estimate for a 100 percent renewable power system. Therefore, this 100 percent renewable study is likely to date rapidly, as new technology cost estimates are made.

AEMO has invested substantial time and effort in developing the modelling tools and methodologies to make this study possible. This means that there is an opportunity to continue to utilise these tools to repeat the analysis as new technology costs are released. The Bureau of Resources and Energy Economics (BREE) has indicated that they intend to develop and release an updated set of technology costs in the Australian Energy Technology Assessment (AETA) in 2013, and ongoing annually. This would allow an update of the AEMO 100 percent modelling process, using the software tools already developed.

It is recognised that the AEMO modelling process does involve substantial iteration and manual manipulation, particularly in the development of the associated transmission plan. However, repeating this modelling for an updated set of technology costs should be substantially less work than in the first instance. The initial transmission plan can be iterated upon, which is likely to substantially reduce the time taken to reach an "optimal" resulting plan. Furthermore, many of the input assumptions developed will be able to be used as-is.

As described in published literature, organisations and institutions are often strongly linked to existing technologies, and due to institutional barriers are typically unlikely to produce and promote proposals and alternatives based upon radical changes in technology (Lund, 2010; Unruh, 2000; Künneke, 2008; Hughes, 1987). Lund and others find that the description of concrete technological alternatives and the detailing of alternative energy plans plays an important role in ensuring that the diverse range of alternatives are fully considered on an equal footing with more conventional solutions (Lund, 2010; Foxton et al. 2008; Sovacool, 2009).

It is vitally important that Australia continues to have a relevant and, as best possible, accurate representation of the full range of energy options available for our future. The range of renewable technologies now available in the market represent a radical change in technology, which makes it particularly important that their potential role in the NEM is clearly elucidated. It is vital that accurate understanding of renewable options is actively pursued (alongside other options), ensuring that they are explored as fully as options that are closer to our present power system.

Furthermore, it is important to recognise that the existing system has established problem solving strategies (i.e. heuristics) which can constrain the range of possible solutions to a given problem. It is, therefore, critical to approach scenario development with a degree of flexibility in an attempt to move beyond these established paradigms (Verbong et al. 2002).

This modelling process highlights the long term and highly uncertain nature of the assessments being undertaken at present when making decisions about long lived electricity assets. Most would acknowledge that there remains high uncertainty over the possible power system that may be in operation in 2030 or 2050. It is important that this wide diversity in possible outcomes is clearly demonstrated to market participants in AEMO's modelling studies, such as the Electricity Statement of Opportunities (ESOO) and the National Transmission Network Development Plan (NTNDP). These important documents are used by market participants to underpin large investment decisions.

Most importantly, the range of scenarios considered by AEMO should include scenarios that are in line with Australia's international commitments to do our "fair share" of limiting global warming to 2°C. This would involve rapid reductions in Australia's greenhouse emissions. The electricity sector offers abatement opportunities that are cost competitive and easier to access than in other sectors, and therefore might reasonably be expected to accelerate more quickly than other parts of the economy. This suggests that extremely rapid trajectories for emissions reduction from the NEM should be considered and planned for, amongst the range of futures that may eventuate.

CEEM recommends that the modelling of 100 percent renewable scenarios is repeated annually, as a part of AEMO's usual planning processes. The NTNDP, or some extension of it, is an obvious candidate for inclusion of these scenarios.

3.5 Recommendation 5: Broader range of scenarios

In order to understand the full spectrum of alternatives available it is also important to consider scenarios that include 80-95% renewables. These may prove substantially more cost competitive than a 100% renewable power system, whilst delivering the majority of the benefits. This could be highly instructive for policy makers seeking to understand the options available.

It seems likely that the models constructed by AEMO for this modelling process could incorporate scenarios of this nature without the need for significant modifications.

It would also be highly valuable for AEMO to consider scenarios that involve a subset of technologies (in particular, assuming that the development of geothermal and/or wave technologies stalls, and only the technologies that are demonstrated at utility scale today are available).

CEEM recommends that future studies include modelling of a broad range of scenarios, including scenarios with 80-95% renewables and varying technology mixes, including those restricted to commercially available technologies. The NTNDP should include a suite of very low emissions scenarios in accordance with the climate science on the emissions reduction trajectories that are likely to be required to provide a reasonable assurance of warming less than 2°C above preindustrial temperatures.

3.6 Recommendation 6: Broader formal consultation process

CEEM appreciates that this comprehensive and challenging modelling was conducted in a short timeframe which restricted the potential for a lengthy formal consultation process. No doubt other factors also played a role in the decision not to hold public forums regarding the work..

However, CEEM proposes that a broader and more inclusive formal consultation process with a more diverse range of stakeholders would improve the communication and presentation of results, ensuring that maximum value is extracted.

The questions around Australia's energy future are challenging and complex, and involve a diverse range of stakeholders. A more inclusive and comprehensive formal consultation process around modelling of this nature would provide a valuable opportunity for a broader discussion on Australia's energy future. The strong public and industry interest in the modelling of 100 percent renewable energy should be embraced as a pathway to more sophisticated and better informed discussion on these complex issues.

CEEM recommends that a broader and more inclusive formal consultation process is employed in any future studies of this nature.

3.7 Recommendation 7: Further detail on input assumptions

As highlighted above, CEEM commends AEMO on the high transparency offered by publication of the input data sets as spreadsheets, and by the valuable repetition of key modelling inputs in the draft report. This provides a helpful and easily digestible summary of the input assumptions that are driving modelling outcomes.

CEEM offers the following suggestions for improving the transparency around the statement of input assumptions in the report:

- The report partially uses costs from the Australia Energy Technology Assessment (AETA), but does deviate from these technology costs in some ways. It would be helpful to explicitly summarise and indicate more clearly where cost assumptions have deviated from AETA costs. In particular, it would be helpful to highlight differences assumed in operations and maintenance costs. This could assist in directing attention to data that may warrant amendment in future editions of the AETA.
- It would be helpful to explicitly include the assumptions around the Weighted Average Cost of Capital (WACC) and asset lifetimes applied for generation, transmission and connection assets. This should be included with the section discussing wholesale costs, to make it clear that financing costs have been included in that calculation, and clearly outline the relevant assumptions and approach applied.

3.8 Recommendation 8: More nuanced discussion on key findings

Presenting a balanced view of the complex issues associated with the modelling of a 100 percent renewable power system is challenging, especially given the strong views of many in the industry, from a range of angles. Some aspects of the commentary in the report appeared to be biased towards overemphasis of challenges, while not recognising benefits (particularly in the "key observations" section and early introductory material).

CEEM agrees that it is highly appropriate to emphasise the many uncertain modelling assumptions that have been used and the limitations of the modelling process. However, this opening discussion in the report may be able to be drafted in a more balanced fashion, particularly with regards to the points listed as "key observations" and as key points in the Introduction.

3.8.1 Necessity versus optimisation

The report states that:

"*A wide range of technologies and locations are likely to be needed*".

CEEM proposes that this could be better phrased as:

"*The modelling finds that costs are minimised by the use of a wide range of technologies and locations*"

This study has not analysed whether a diverse range of technologies and locations are actually a *requirement* of developing and operating a 100 percent renewable system. Rather, the modelling shows that the least cost solution involves substantial diversity.

3.8.2 Reserve capacity

The report states that:

"The results indicate that a 100 percent renewable system is likely to require much higher capacity reserves than a conventional power system"

CEEM proposes that this emphasis on reserve capacity is not a meaningful way of understanding or discussing a high renewables power system. Firstly, the higher capacity reserve is not a *requirement* of a 100 percent renewable power system; instead the modelling indicates that the least cost solution includes a substantial proportion of low capacity factor plant. If desired, the modelling could be constrained to solutions that provide exactly the same reserve capacity as the present power system (and the model would select a much higher proportion of geothermal, solar thermal and biomass technologies, increasing scenario costs).

Secondly, a 100 percent renewable power system is not appropriately discussed in terms of "reserve capacity". In this power system, reliability would not be assessed by the calculation and application of a Minimum Reserve Level (MRL), in conjunction with a 10% probability of exceedence maximum demand. This modelling clearly demonstrates that in a high renewable system the periods of constraint that drive the installation of further capacity occur during overnight periods, which does not coincide with peak demand. This means that adding an MRL to the projected peak demand to determine the capacity required for system adequacy becomes completely meaningless. Thus, the concept of a "reserve capacity" is poorly suited to describing 100 percent renewable systems.

To appropriately assess reliability in a 100 percent renewable system, a much more sophisticated assessment of system reliability would need to be applied. This would probably involve explicit Monte Carlo modelling approaches similar to AEMO's Energy Adequacy Assessment Projection (EAAP).

The total installed capacity of the system is of little relevance, so long as it reliably supplies power at a quantified cost, and can be achieved within all land use and other relevant constraints. However, if AEMO wishes to communicate the idea that a larger amount of capacity will need to be installed, some alternative wording might be:

"The modelling indicates that the lowest cost renewable system includes significant quantities of variable renewable technologies (such as wind and solar photovoltaics). These technologies are limited by resource availability and therefore typically operate at relatively low capacity factors (30-40%). Furthermore, the variable nature of these technologies means that they contribute only a proportion of their capacity as a 'firm' contribution to system reliability. This means that the total installed capacity of the system is higher than it would otherwise be."

3.8.3 Bioenergy requirements

The report states:

"The modelling suggests that considerable bioenergy could be required in all four cases modelled, however this may present some challenges."

Similar to the discussion above, in our understanding this modelling has not explored whether bioenergy is *required* in a 100 percent renewable power system, but rather indicates that it plays a significant role in the least cost system (based upon the constraints applied). Again, alternative wording might be:

"All four modelled cases include considerable bioenergy in the least cost generation mix. This modelling has included resource limitations and constraints assessed by the CSIRO to be feasible, to prevent unreasonable consumption of bioenergy that has competing uses. However, if these limitations were deemed to be too generous they could be tightened (for example, restricting the use of bioenergy to a peaking role only, rather than providing baseload energy). This would cause the model to use larger quantities of alternative technologies, increasing scenario costs."

3.8.4 Land-use requirements

The report states:

"Overall required to support a 100 percent renewable power system may be between 2,400 and 5,000 square kilometres".

As discussed above, this land use is not a requirement but rather an outcome of the modelled least cost system. Furthermore, it is appropriate to clarify with this statement that much of this land could also serve alternative purposes (such as the land around wind turbines remaining useful for agriculture). The following alternative wording might be clearer:

"The modelling indicates that the least cost 100 percent renewable system would involve between 2,400 and 5,000 square kilometres. Much of this land would remain available for its present use (for example, the majority of land around wind turbines and along transmission easements would remain available for farming). Constraints were observed in the modelling to prevent installation of land-intensive generators in areas that are highly populated or environmentally sensitive."

3.8.5 System benefits

Since the report lists many of the challenges associated with a 100 percent renewable power system in detail, it could be considered appropriate to also elaborate on the benefits of a 100 percent renewable power system. These would include:

- Significantly reduced greenhouse emissions
- Reduced water consumption, especially if thermal plant are designed to be dry cooled
- Reduced air pollution and the associated health benefits
- Smaller unit sizes may allow reduction of contingency reserves (assuming transmission contingencies remain similar to present)

If it is deemed too challenging to agree on the form of a 'balanced' discussion it may be more suitable to remove superfluous commentary from the report altogether, and simply provide a basic reporting of modelling results.

4 Conclusions

To conclude, we reiterate our congratulations to AEMO and DIISTRE for the completion of a high quality and valuable piece of work. We trust that these comments and suggestions constructively add value to what is already a significant achievement.

5 References

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