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Review of MMA Report, "Greenhouse Gas Abatement from Wind and Solar in the Victorian Region of the NEM"

for

Sustainability Victoria

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1. Introduction

The purpose of this assignment was to review the MMA report, "Greenhouse Gas Abatement from Wind and Solar in the Victorian Region of the NEM", Version 3, 15/7/10 and Version 4, 15/9/10, prepared for Sustainability Victoria. In turn, the purpose of the MMA project was to undertake modelling to "determine the emissions abatement impact of wind farms and solar PV systems located in Victoria". The modelling undertaken by MMA considered seven scenarios for the 2010 – 2020 decade with additional wind capacity in Victoria of 0 MW, 1000 MW, 2000 MW, 3000 MW and 4000 MW as well as combined wind and solar PV additions in Victoria consisting of 2000 MW wind and either 250 or 500 MW solar PV.

A key objective of this assignment was to assess the appropriateness of the underlying assumptions and methodology used by MMA and the validity of the conclusions reached in the MMA report.

2. Wind energy and Greenhouse Gas Abatement in the National Electricity Market

According to the IEA, wind energy was responsible for about 1.5% of global electricity generation in 2009 and "has the potential to provide 12% of global electricity production in 2050"[1]. Australia has good wind resources and wind energy in the National Electricity Market (NEM) has the potential to grow at or above the global average rate.

Wind energy flux is a non-storable primary energy resource, and hence must be exploited when available or it will be lost. Thus wind generation when available will displace other electricity generation resources in the NEM except when the output of wind farms is deliberated restricted due to:

- Wind turbine design limits – wind speed below start-up speed, above rated speed when conversion efficiency is deliberately reduced, or above shutdown speed when the wind turbine is deliberately shut down.
- Wind farm equipment full or partial outages (scheduled or forced outages for turbines or other key plant such as cables, transformers or switchgear)
- Network equipment outages
- Power system operating constraints – either network component ratings or security constraints (voltage, frequency, stability)
- The price received for the electricity generated becoming too low to be profitable – NEM prices can become negative due to "de-commit" auctions when generators are competing to stay on line at times of excess on-line generating capacity (note that a wind farm can

[1] IEA Energy Technology Perspectives 2010 Presentation, Seoul, 16 July 2010, Slide 12

offer to generate at a negative price if earning sufficient income from the sale of RECs to remain profitable). The generators competing with wind farms to stay online may be thermal generators that do not wish to shut down due to the start-up costs they will later incur, or hydro generators that would otherwise "spill".

- An ancillary service bill that a wind farm may expect to receive for a future period of fluctuating output that would reduce its expected profitability to zero (this is feasible in the NEM design but I am not aware of it happening to date).

The above factors may reduce the amount of wind energy produced by a given set of wind farms under given wind conditions. If so, such factors would also reduce the total emission savings that a given installed capacity of wind farms would achieve. However, they do not affect assessment of the effective emission coefficient of wind energy – that is the amount that climate change emissions are reduced per unit of wind energy actually produced (typically expressed as Tonnes CO_2 per MWh) – provided that we have either a direct measurement of wind farm production or a reasonable estimate of the energy sent out from the wind farms that takes such factors into account.

Wind farms do not produce climate change emissions in normal operation. Instead, they displace other forms of electricity generation that may have produced emissions if the wind generation had not occurred. Unfortunately, that means that there is no factual basis in measurement for assessing the effectiveness of wind farms as an emission reduction strategy. All we can do is to model the "counter-factual" that would have occurred in the absence of the wind farms as well as model what occurs in the presence of wind farms and thus estimate the emissions savings attributable to the wind farms from the difference in emissions between the two scenarios. Also, we should note that climate emissions may well occur during manufacture, transport, installation, maintenance and decommissioning of wind farms, which should be taken into account in a lifecycle assessment. The MMA report recognised the need for lifecycle assessment and pointed out the emissions associated with wind farm construction are generally small compared to the potential emissions savings from the displacement by wind energy generation of electricity generated using fossil fuels.

The key ways in which wind farms might displace other forms of generation in the NEM are as follows[2]:

- Considering the next dispatch interval (5 minutes in the NEM), wind generation during that interval would displace other generation in a manner determined by the NEM dispatch engine, which given generator offers, jointly solves for energy and frequency control ancillary service (FCAS) requirements across the NEM and sets dispatch levels for all scheduled generators. The actual displacement would depend on generator offers and

[2] See the National Electricity Rules for definitions – available for download from www.aemc.gov.au

network loss factors, any binding constraint equations (e.g. inter-regional flow constraints) and the implications of the FCAS markets and actual FCAS deployment. Five-minute forecasts by the Australian Wind Energy Forecasting System (AWEFS) set the anticipated dispatch levels for scheduled wind farms, as well as for semi-scheduled wind farms when they are required to participate in the dispatch process.

- During the pre-dispatch timescale (roughly 40 hours look-ahead), predicted wind generation (as forecast by AWEFS and then incorporated in aggregate information sent to market participants by AEMO, or as predicted by other forecasting services) may influence the offer strategies of scheduled generators, including wind farms in scheduled or semi-scheduled categories, as well as unit commitment decisions for slow-start generators (steam boiler plant using black or brown coal or natural gas including some combined cycle plant) and near-term security management decisions by AEMO, including whether to invoke semi-scheduled category obligations for particular wind farms to participate in the dispatch process.
- During the Short Term Projected Assessment of System Adequacy timescale (STPASA, one week look ahead), predicted wind generation by AWEFS or otherwise may influence participant decision-making regarding unit commitment, hydro scheduling, fuel purchasing or maintenance scheduling.
- During the Medium Term Projected Assessment of System Adequacy timescale (MTPASA, two years look ahead), predicted wind generation by AWEFS or otherwise may influence participant decision-making regarding hydro scheduling, fuel purchasing, maintenance scheduling or short-lead time investment decisions.
- During the Statement of Opportunities (SOO) timescale (ten years look ahead), views about likely future wind farm investment and ensuing wind farm electricity generation (as well as views about future government policy, fuel prices, etc.) may influence investment decisions in all types of electricity industry resource (generation, storage, end-use and network). That is because the expected presence of significant amounts of wind generation in a future NEM generation portfolio would influence (for better or worse) the expected profitability (and public benefit) of all other resource investment options.

From the above discussion, we can see that except for small amounts of wind farm capacity, the presence or absence of wind farms in the NEM would influence many NEM decision-makers in complex ways, which in turn creates complexity in developing a plausible “counter-factual” and thus estimating the climate change benefits from installing wind farms. One important point is that forecasts of future wind generation would influence the decisions of NEM participants as well as the actual wind generation when it occurs.

Thus, we can characterise the plausible influence of wind farms on emissions reduction in the following ways:

- From one 5-minute dispatch interval to the next, the relatively high accuracy of AWEFS forecasts[3] in that timeframe means that an efficient dispatch should be achieved in most dispatch intervals. In those circumstances, wind generation would displace the marginal offer(s) in the dispatch solution. Hence the dispatch period counterfactual could be estimated from relevant historical data or (looking forward), using a model that accurately simulated the NEM dispatch engine and scheduled generator decisions about unit commitment and offer strategies. If we further assume that generator offers reflect the underlying incremental operating cost of each generator (with or without a carbon price), we could identify the likely units that would be displaced. Expect in extreme conditions (e.g. Tasmania with high wind, prolonged heavy rain and prolonged Basslink outage), wind would not displace hydro. Rather, it would displace generation based on natural gas, black coal or brown coal and thus reduce climate change emissions by an amount that depended on the emission coefficient(s) of the affected generator(s). Prices in short-term gas markets might influence which generators were displaced. There would also be a small impact on network losses that would modify this outcome in a minor way.
- During the pre-dispatch and STPASA timescales, projected wind farm generation may affect unit commitment decisions of generators that use boiler plant with coal or gas firing. In circumstances favourable to emission reduction, one or more large coal-fired generators using black or brown coal might choose to de-commit, due to minimum operating level constraints, for periods when wind penetration was predicted to be high (these would be most likely to occur overnight and at weekends). De-commit decisions would shift anticipated energy generation from the generator(s) that decided to de-commit to a mix of coal, gas and wind generators. The effect on emissions reduction of such de-commit decisions would also depend on the actual wind generation that occurred during the period in question. If we assume that it was the forecast of wind generation alone that caused the coal-fired generator(s) to de-commit, the emission reductions attributable to wind could be greater than the direct emission reductions due to the actual wind generation during the period in question. In fact, the reductions due to actual wind generation might be lower than if the de-commit decision had not been taken, because wind might then have displaced generation with a higher emission coefficient.
- Circumstances less favourable to emission reduction could also arise. For example a forecast of wind generation that (in hindsight) turned out to be significantly low, could lead to the commitment of more slow-start, high emission-coefficient generators than would have been desirable, thus increasing overall emissions. Thus the accuracy of wind

[3] See the AWEFS project page on AEMO website: http://www.aemo.com.au/electricityops/awefs.html.

forecasts might influence emissions reductions attributable to wind generation as well as the actual energy produced by wind farms.

- During the MTPASA timescale, forecasts for wind farm generation might influence maintenance scheduling, hydro scheduling and fuel purchasing decisions in ways that could either amplify or reduce the emission reductions attributable to the presence of wind farms. Again, forecasts matter as well as actual wind farm production.
- During the SOO timescale, forecasts for wind farm investment and ensuing wind generation might influence investment and retirement decisions for other types of resource (generation, storage, flexible demand, network) – possibly changing the resource mix to be more appropriate to the anticipated wind investment. Ironically, such decisions might reduce the actual emission reduction benefit that could be attributed to wind farms once they were commissioned. Thus unless we consider anticipatory responses to plausible future wind farm investment, we may underestimate the emission reductions that could (in some interpretations) be attributed to a policy that promoted wind farms. For example, expectations of future wind farm investment might deter investment in coal-fired power stations.
- The implementation of policies that facilitated wind farm development, such as forward-looking network investment in a wind-rich region, might also influence investment decisions for all generator types and thus the eventual emission reductions attributable to wind generation.

Key steps in using a simulation model to estimate the future effectiveness of wind farms in reducing climate change emissions in the NEM are as follows:

1. Develop a base case model for the evolution of the NEM over the study period (eg 2010 – 2020) in the absence of the wind farms that are to be studied. This is required to establish a “counter-factual” – that is, what would have happened in the absence of the wind farms – so that we can then estimate the reductions in emissions that would result from including the wind farms.
2. Specify the set of wind farms to be considered, including location and wind power curves for the nominal wind turbines.
3. Estimate the wind regime to which each wind farm would be exposed and its potential wind power production as a function of time (I understand that the MMA simulations used an hourly time step).
4. Estimate the energy sent out for each wind farm as a function of time, taking into account plausible constraints on wind farm output (technical and, if possible, commercial).
5. Subtract the estimated effect of network losses to obtain an estimate of the wind farm energy available to displace production from other generators.

6. Model the effect of wind forecasts on decision-making for other generators to determine one or more plausible scenarios for unit commitment, fuel purchasing and maintenance scheduling. Estimate the differences in unit commitment in the presence or absence of wind farms.
7. Simulate the dispatch process for plausible sets of committed slow-start generators and estimate how the reduction in production due to wind generation would be allocated amongst the other on-line generators.
8. Estimate the implied savings in climate change emissions due to commitment decisions and the dispatch process, noting that incremental efficiency (and thus incremental emissions coefficient) may be a function of thermal plant operating level.
9. Estimate any additional ancillary service activity that would be required due to the energy production from wind farms and the additional climate change emissions associated from that additional activity.
10. For a multi-year project, consider how the evolution of the NEM resource mix might be influenced by the anticipated future presence of wind farms (including the type, size and location of new generating capacity and fuel purchasing decisions).

The size of the wind capacity additions considered by MMA (1000 to 4000 MW) is sufficiently large, particularly at the high end, to influence decision-making concerning other NEM resources. Thus all the above steps are relevant to the MMA project.

3. Solar PV and Greenhouse Gas Emissions in the National Electricity Market

Like wind energy flux, solar energy flux is a fluctuating (mainly due to cloud cover), non-storable primary energy resource. However, unlike wind energy flux, solar energy flux always has a dominant diurnal pattern. Also, changes in solar energy flux can be extremely rapid as they result immediately from interruptions to, or restorations of, the stream of photons that is carrying energy from the sun to the PV panels. This is particularly true for concentrating systems that can only access photons coming directly from a small region in the sky surrounding the sun.

Solar PV generation shares many characteristics with wind generation with respect to displacing other forms of electricity generation. However, there is one important difference. Because there will never be high solar PV penetration in the early morning hours before sunrise when load is normally at a minimum, solar PV is less likely than wind energy to cause de-commitment decisions by coal-fired generators due to low overnight load. Thus on weekdays, solar PV alone would be more likely to displace intermediate generators than base load generators and thus more likely to displace gas fired generation than coal-fired generation unless high coal prices or a sufficiently high carbon price drove the effective incremental operating cost of coal generators above that of gas-fired generators. At weekends, when daytime load is lower than on weekdays, anticipated high solar PV penetration during daylight hours could cause large coal fired generators to de-commit.

In the investment timescale, solar PV would compete more with investment in intermediate duty generators than base load generators, whereas for wind generators, the reverse could be the case depending on the temporal characteristics of the wind resource.

A combination of wind and solar PV would have an increased likelihood than either resource alone of causing de-commit decisions by slow-start generators, discouraging investment in base-load plant and encouraging investment in flexible generation, flexible demand-side resources and cost-effective reversible storage.

4. Summary of assumptions and methodology used in the MMA report

MMA used their PLEXOS model of the NEM and their associated database of NEM resources and demand forecasts to undertake this study. Both the PLEXOS model and the associated MMA database have been demonstrated to provide faithful simulations of the NEM in many prior studies. Seven scenarios were prepared for this study – a baseline case with no new wind or large scale solar PV, four additional wind generation scenarios (1,000 MW, 2,000 MW, 3,000 MW and 4,000 MW additional wind generation respectively) and two combined wind plus solar PV scenarios 250 MW and 500 MW PV respectively with 2,000 MW of additional wind in each case.

5. Comments on the Assumptions and Methodology used in the MMA Report

In my opinion, the MMA assumptions and methodology with respect to evaluating NEM operating behaviour are satisfactory (given the inevitable modelling limitations). One matter that deserves additional consideration is whether varying gas utilisation (due to complementing wind generation) might affect the short-term price and/or availability of gas to gas-fired generators and hence the ability of gas-fired generators to act as complementary resources to wind generation. MMA's assumptions about investment and retirement behaviour also appear sound. However, there is considerable underlying uncertainty about such matters.

6. Summary of the Conclusions in the MMA Report

The MMA Report concludes that wind farms in Victoria would, prior to the introduction of a carbon price, primarily displace NSW black coal generation and Victorian brown coal in off-peak periods with abatement intensity between 0.9 and 1.2 t $CO_{2\text{-}e}$/MWh. In the longer term, it concludes that the abatement intensity would rise with the introduction of a carbon price as Victorian brown coal generators became marginal more often, rising to 1.1 to 1.4 t $CO_{2\text{-}e}$/MWh and then falling later as the brown coal generators were decommissioned. The report also concludes that there is sufficient flexible generation capacity to manage variability in wind generation.

7. Comments on the Conclusions in the MMA Report

In my opinion, the key conclusions of the MMA report, summarised in Section 6, are sound:

- Wind generation in Victoria will reduce climate change emissions by displacing fossil fuel combustion in power stations, primarily a mix of black and brown coal.
- There is sufficient flexible generation to manage variability in wind farm output.

However, it is important to note that some displacement of gas-fired generation will occur and the proportion of displaced gas-fired generation may increase in later years.

Managing the variability of wind generation is unlikely to result in an increase in emissions of any consequence. This is partly due to the need to hold reserves for other reasons (in particular to cover load forecast uncertainty and forced generator outages) and partly due to the prediction capability of the Australian Wind Energy Forecasting System (AWEFS).

Apart from direct displacement of fossil-fuel generation, wind farms may also reduce emissions from the electricity industry through indirect effects:

- Influencing coal-fired generators to de-commit when high wind penetration is anticipated, particularly overnight or at weekends,
- Inducing earlier retirement of brown coal generators than would have otherwise been the case due to reducing profitability as wind penetration increases[4], and
- Discouraging investment in inflexible coal-fired power stations as wind penetration increases.

8. Conclusions and Recommendations

The MMA report provides strong justification for considering the LRET scheme to be an effective climate mitigation strategy; although this does not prove that it is the most economically efficient emission reduction strategy. Policy makers at Federal and State level may wish to consider complementary measures that might enhance the efficiency of the LRET scheme. These could include:

- The removal of inefficient barriers to cost-effective complementary resources (flexible generation, flexible demand, reversible storage)
- Promotion of efficient short-term gas trading arrangements to reduce the cost of complementary resource activity based on gas
- Ongoing refinement of AWEFS to further improve its wind energy forecasting capabilities and to include solar energy forecasting capability.
- Investing in network capacity in resource-rich areas for wind and solar energy.

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[4] See the following paper for an analysis of wind impacts on the NEM: Cutler NJ, Boerema N, MacGill IF, Outhred HR. Wind generation impacts on the South Australian region of the Australian National Electricity Market. Energy Journal, International Association of Energy Economics (submitted September 2010)