The Impact of Large Scale Deployment of Distributed Electricity Generation on Water Resources in Australia

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EXTENDED ABSTRACT

The occurrence of the worst drought conditions in eastern Australia since Federation has heightened debate about the efficient allocation of scarce water resources among competing end-users. This has manifested in the widespread use of water restrictions, debate over desalination and stormwater harvesting in major cities, and conflict between the States and Commonwealth over control of the Murray-Darling Basin.

Only recently has this debate spilled over into the energy domain. The proposed expansion of coal mining in certain areas has focused attention on the allocation of water resources in urban catchment areas. The worsening drought situation in south-east Queensland has forced the State Government to cut the water usage of Tarong North and Swanbank coal-fired power stations by 40 and 20 percent, respectively. Given that electricity supply in Australia is currently dominated by coal-fired generation (approximately 85 percent) this has raised the possibility of reduced water supply to power stations in other jurisdictions.

This paper seeks to assess the impact of large scale deployment of distributed electricity generation on reducing water use in power generation in Australia. We employ a bottom-up partial equilibrium model of the electricity sector, the Energy Sector Model (ESM), and a physical simulation of the economy, the Australian Stocks and Flows Framework (ASFF), to gauge the effects of significant uptake of distributed generation on water consumption for electricity generation. The interaction of these simulations is a significant advance to integrated assessment of economic and environmental impacts. The results of this assessment may inform, and be informed by, social analysis.

1. INTRODUCTION

The level of interest in distributed generation (DG) around the world has increased in recent years (IEA, 2002; CBO, 2003). High profile blackouts in certain markets have highlighted the flexibility of a more decentralised electricity system while the ratification of the Kyoto Protocol has been suggested as a policy driver to harness DG in the pursuit of lower carbon emissions in signatory countries (WADE, 2006).

However, the argument for greater DG deployment in Australia is slow to gain support. Australia’s electricity supply is currently dominated by centralised coal-fired generation. If DG is classified as *electricity generation located close to load and rated at less than 30MW*, DG currently accounts for approximately 4 per cent of installed capacity and 2 per cent of total electricity generation (Reedman and Mtwa, 2006). Uptake thus far has been mainly limited to stand-by generators, deployment of natural gas combined heat and power (CHP) systems in commercial and industrial locations, diesel engines in remote off-grid locations, or other niche applications (e.g., emergency power, deferral of grid upgrades at specific locations, “high nines” energy security).

While increased deployment of DG is currently stifled by economic barriers (e.g., high initial capital costs and the low cost of electricity delivered by centralised coal-fired plants), less recognised are the environmental benefits of DG in terms of reduced water consumption, resource extraction and pollutant emissions. The aim of this paper is to quantify the impacts on water use in electricity generation based on the projected uptake of various DG technologies in meeting future electricity demand in Australia under two alternative scenarios.

This paper proceeds as follows. Section 2 provides a brief overview of the Intelligent Grid Project. Section 3 follows with an outline of the two scenarios of interest. This is followed by a discussion of the modelling approach in Section 4. Section 5 presents the modelling results, which are then discussed in Section 6. Section 7 concludes.

2. OVERVIEW OF “INTELLIGENT GRID” PROJECT

The “Intelligent Grid” (IG) project was initiated in July 2006 within the Energy Transformed Flagship. Its primary goal is to discover, measure and simulate the full value chain for distributed energy (DE) solutions by researching the social, environmental and economic considerations in the choices made when tackling rising electricity demand.

It is intended that these three research components will form an integrated analysis to encompass social attitudes, environmental impacts and cost competitiveness, consistent with “triple bottom line”. The simulation research program is tasked with communicating results to relevant stakeholders.

3. SCENARIO DEFINITION

Within the IG project, there are two baseline scenarios:

Reference case (BAU): in this scenario, projected electricity demand growth assumes moderate improvements in energy efficiency and the continuation of current policy settings without significant policy changes (e.g., no carbon penalty). The current policy settings incorporated in the BAU modelling run are: the Mandatory Renewable Energy Target (MRET); the Queensland 13 per cent gas target; the NSW Greenhouse Gas Abatement Scheme (NGACS); and the Victorian Renewable Energy Target (VRET).

Emission management scenario (EMS): in this scenario, it is assumed that the electricity sector faces a greenhouse gas (GHG) emission reduction target of 60% below 1990 levels by 2050. Emission trading is assumed to commence in 2012; one-year prior to the expiration of the first commitment period under the Kyoto Protocol. Although the Federal Government has not committed to an emission target, the EMS scenario is similar to recent analysis by the Business Roundtable on Climate Change which adopted 60 per cent below 2000 levels by 2050 (Allen Consulting, 2006) and other studies that have adopted 60 per cent below “current” levels by 2050 (e.g., Australian Climate Group, 2004; Turton *et al.*, 2002).

4. MODELLING APPROACH

Paragraph highlighting integration of models prior to brief description of each model

4.1. Energy Sector Model (ESM)

We employ an economic model that seeks to optimise the portfolio of centralised and DG technologies over time that would minimise the total cost of the electricity system.

The Energy Sector Model (ESM) is an Australian energy sector model that was co-developed with the Australian Bureau of Agriculture and Resource Economics (ABARE) and as part of the research commissioned by the Energy Futures Forum that reported last year (Energy Futures Forum, 2006).

A bottom-up modelling approach is justified by our need to discriminate between and explore characteristics of energy technologies and the special features of the market they are employed in.

The model utilises linear programming techniques to mirror real world plant investment decisions by simultaneously taking into account:

- The requirement to earn a reasonable return on investment over the life of a plant;
- That the actions of one plant effects the profitability of all other plants simultaneously and dynamically;
- That the consumption of energy resources by one plant effects the price and availability of that resource for other plants and the overall cost of electricity generated; and
- Electricity market policies and regulations.

The model only evaluates uptake on the basis of cost effectiveness but at the same time takes into account the key constraints with regard to the operation of electricity markets such as requirements for peak plant, current renewable energy and gas legislation, greenhouse gas emission limits, existing plant in each State and lead times in construction of new plant. It does not take into account:

- Community acceptance;
- Environmental impacts of solvents, water usage and non-greenhouse related emissions;
- Plant siting issues other than cost;
- Location of plant within a State; and
- Specific location of CO_2 sequestration sites.

Figure 1 provides an overview of data inputs into and estimated outputs of ESM.

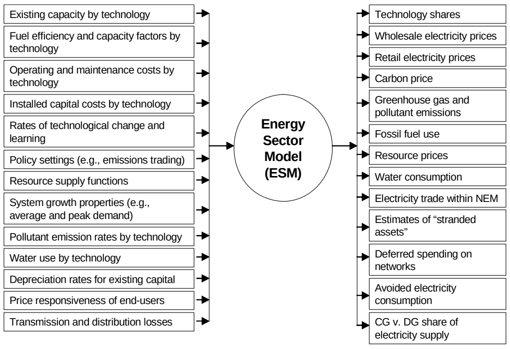


Figure 1. Overview of ESM inputs and outputs

The main features of the ESM used in this paper include:

- Coverage of all States and territories, including electricity trade between States in the National Electricity Market (NEM);
- Fifteen centralised electricity generation technologies including various fossil fuel options with and without carbon capture and storage, nuclear, and renewables (hydro, wind, solar thermal, biomass and hot fractured rocks);
- Eleven distributed generation (DG) electricity plant types including natural gas and biomass plants with and without cogeneration, diesel and natural gas engines, fuel cells and solar photovoltaics;
- For the purposes of assessing the uptake of distributed generation, end users were considered to be one of four groups: industrial, commercial and services, rural and residential; and
- Time is represented in annual frequency (2005, 2006, …, 2050).

Further description of ESM is contained in CSIRO and ABARE (2006) and Reedman (2007).

4.2. Australian Stocks and Flows Framework (ASFF)

ASFF is an accounting framework that represents the interactions between sectors of the physical economy. Sectoral calculators within the ASFF model the dynamics and transactions of physical stocks (e.g., vehicles, building stock and individuals) and flows (e.g., fuel consumption, resource extraction, effluent and emissions). Although the design of these calculators and their interconnecting structures permit sophisticated future scenarios, the accounting architecture of the ASFF imposes a uni-directional information flow. That is, many drivers may influence outputs in numerous ways, but "complex" feedbacks are not modelled in this approach. This allows the outputs of the framework to be explicit and tractable, and allows input from other models (e.g., ESM), analyses and expert knowledge.

In addition to the holistic scope, the ASFF is built on extensive historical data enabling calibration of the framework prior to simulation for future time periods. For example, the ASFF has detailed data on the age structure of capital stocks such as centralised electricity generation plant. Such information enables the estimation of investment in replacement *and* new capital stock in the simulations.

In ASFF, the scenarios defined in Section 3 are modelled in the context of energy demand growth, changing urban structures and population changes.

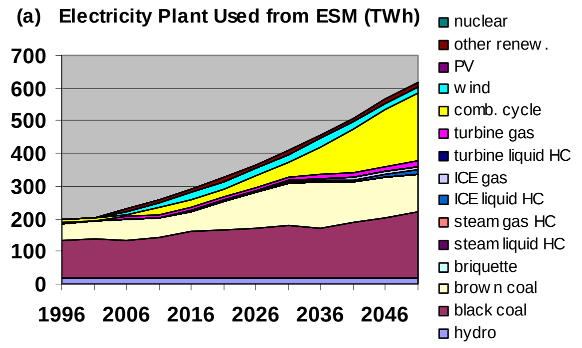
These drivers are coupled with information about other material and energy transformations in an input/output table to calculate the total material, energy and water demands of basic industries such as electricity generation. The details of these calculations can be found in Lennox *et al*. (2005).

4.3. Interaction of ESM and ASFF

Among the variables that influence the environmental outputs, there are several exogenous (input) variables connected directly with the ESM. To reproduce the characteristics of the two baseline scenarios from ESM, the following ASFF variables were used:

- New energy plant share: this is the fraction of new electricity generation plant required that is satisfied by a particular technology type at a given time;
- Load factor: the actual output of a given plant in a given year;
- Energy plant water intensity: the litres of water needed to produce electricity by generation technology over time (see ABS, 2006); and
- Secondary energy use per unit of electricity produced: the joules of energy needed in raw fuel to produce one joule of electricity, by fuel and generation type, over time.

ESM estimates the uptake of a variety of DG technologies based on a simulated future emissions target (no emissions target is assumed in BAU). ASFF does not replicate this calculation, but reproduces the physical aspects of these scenarios (i.e., what technologies are used, to what extent and when). This is a non-trivial modelling exercise because ASFF has to replicate the uptake of new centralised and distributed generation while being consistent with the decommissioning of existing generation plant. Comparison of the technology profile (see Figure 2) shows good agreement between the two models on the timing of uptake and supply of electricity generation by technology type.



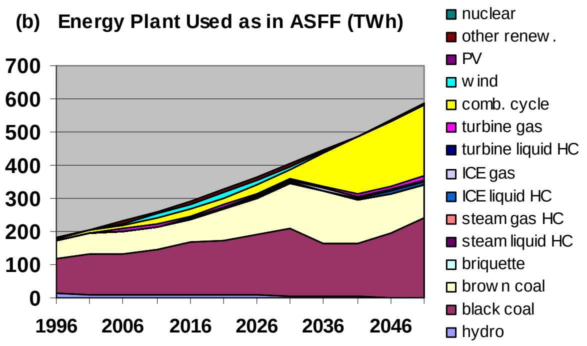


Figure 2. The mix of Electricity plant used in the BAU reference case as in (a) ESM and (b) ASFF

Current outputs from ASFF include the CO_2 produced and total water used for electricity generation.

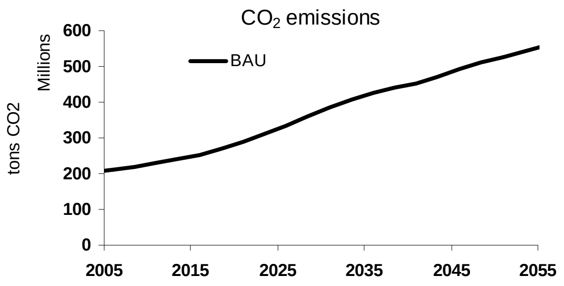


Figure 3. CO_2 emissions for the BAU baseline scenario

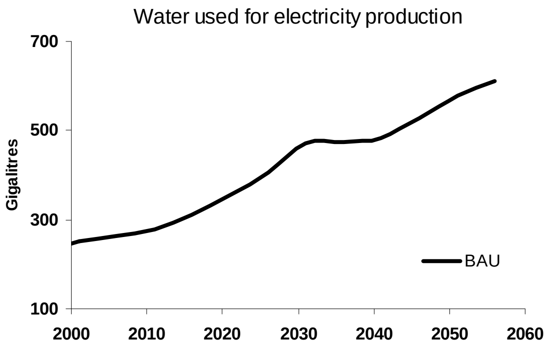


Figure 4. Water consumed during electricity production for the BAU

Note that these environmental results from ASFF may present important new information back to the ESM model. For example, the results concerning water could be important in a situation where there is a significant price for water. Consequently there is certainly the potential for the refinement of both models through another iteration of calculation and simulation.

5. RESULTS

What follows are some results from the first interactions between the ASFF and ESM models comparing the two scenarios of electricity generation corresponding to BAU and EMS applied across all of Australia.

5.1. BAU

The main feature of the BAU scenario is the dominance of coal-fired pf plant in the short- to medium-term that is somewhat displaced by more advanced coal gasification technologies (IGCC) towards the end of the projection period. Increased peak demand over the period is principally met by the deployment of gas peaking plant due to the lack of suitable hydroelectricity sites. The projected increase in the uptake in the near-term of natural gas combined cycle plant is mainly due to the 13% QLD gas target. The lack of an explicit CO_2 price under BAU means that generation from zero emission renewable technologies is isolated to existing capacity and the influence of mandatory renewable schemes.

Another feature is that under BAU, Australia's electricity generation is mainly supplied by centralised generation with distributed generation accounting for approximately 2 per cent of national generation in 2005 rising modestly to 3.5 per cent by 2050. DG uptake principally consists of gas cogeneration in the commercial and services sector with internal combustion diesel engines in rural areas.

5.2. EMS

Given the stringent GHG abatement task (electricity sector emissions 60% below 1990 levels by 2050), existing base-load brown (black) coal-fired plant becomes increasingly uneconomic, and is forced to shut down by around 2025 (2035). Compared to BAU there is projected to be an initially greater deployment of natural gas combined cycle plant and wind generation followed by significant uptake in near-zero emission black coal IGCC with carbon capture and sequestration (CCS). The projected initial trend towards gas and wind preceding a more sustained uptake of CCS technologies occurs because where the emission target first begins to take hold (around 2012) gas plants and wind farms can be deployed faster to bring emissions down quickly. The transition towards CCS technologies occurs due to the impact of increasing gas prices and the intermittent constraint taking hold. However, as the national emission target becomes more onerous and the projected CO_2 price increases, further CCS deployment is halted by zero emission renewable technologies, biomass and solar thermal (some centralised but mainly distributed generation). Refer to Figure 5 below.

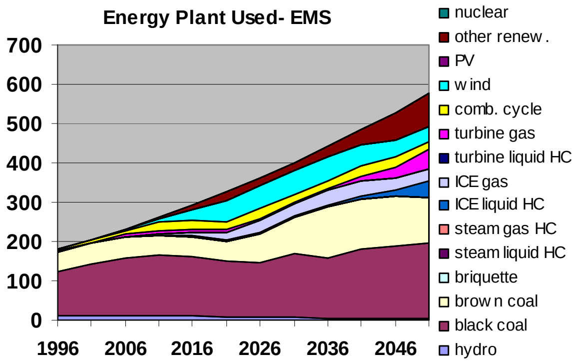


Figure 5. The mix of different technology uptakes in the EMS scenario

An emissions trading scheme results in greater deployment of distributed generation: rising from approximately 2 per cent of national generation in 2005 to around 20 per cent by 2050. Compared to BAU, DG uptake accelerates around 2025 with gas micro turbines followed by increased gas cogeneration in the commercial and services sector. However, once the projected CO_2 price increases above $\$100/tCO_{2-e}$, there is a surge in deployment of solar thermal DG in residential and rural areas.

5.3. Carbon dioxide

Figure 6 presents a comparison of CO_2 emissions resulting from the two different scenarios. By 2050 the difference between BAU and EMS is about 500Mt CO_2 per year. Coal powered electricity generation accounts for much of the CO_2 emissions in BAU and, where it is attenuated in the EMS scenario, it accounts for much of the reduction in CO_2 emissions.

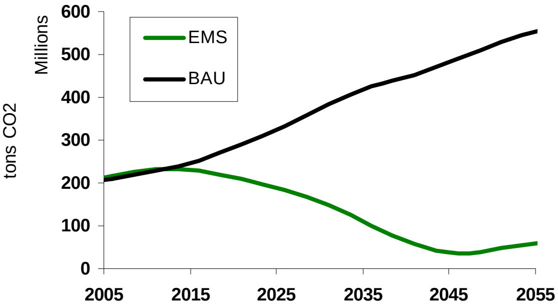


Figure 6. Comparison of CO_2 produced in BAU reference case and the EMS.

A notable feature of the EMS scenario is the complete replacement of all coal fired power stations to coal power with carbon capture and sequestration (CCS) technology by 2050. The ASFF calculations show that carbon sequestration has a massive impact on the difference between the BAU and EMS scenarios. In fact, using the ESM results and ASFF we are able to isolate the effect of CCS in EMS. Figure 7 demonstrates that the comprehensive adoption of CCS explains 85% of the emission reductions within the EMS scenario and it accounts for nearly 70% (~300 Mt of CO_2 at 2050) of the difference between EMS and BAU.

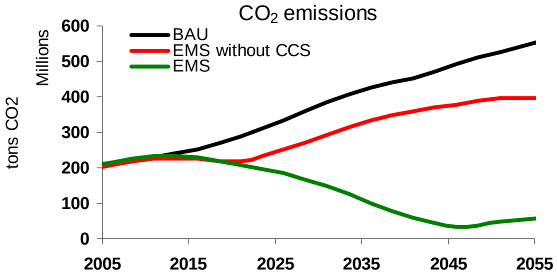


Figure 7. Comparison of CO2 emissions for the BAU, EMS scenarios and EMS without CCS.

5.4. Water

According to the ABS water accounts for 2004-05 ABS, (2006) the water consumed by the electricity generation sector was 271Gl for that year– that's approximately half the total amount of water needed by a major Australian city. From the simulations in ASFF we can say that at 2050 there is a significant difference between water consumption in the BAU scenario and that in EMS; a difference of approximately 100 Gl/yr (see Figure 8).

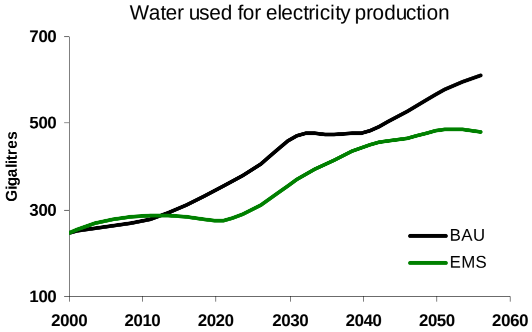


Figure 8. Comparison of water used for electricity generation in BAU reference case and EMS.

The difference may be attributed to a number of factors: DG uses far less water, for cooling, when generating the equivalent amount of electricity compared with current centralised coal and gas fired power stations. Coal uses 1.5 Ml/GWhr and centralised gas uses 0.6 Ml/GWhr whereas DG technologies use less than 0.1 Ml/GWhr, ABS, (2006) (some DG technologies such as wind effectively use zero water).

6. DISCUSSION

The simulations using ASFF suggest that, by 2050, the difference between a continuation of current practises and systems of power generation (BAU) and one focussed on delivering more decentralised energy (EMS), could be approximately 500 Mt of $C0_2$ emissions and 100 Gl of water per year.

The emissions reduction undoubtedly relies the ESM simulation of a complete replacement of coal powered generation plant with coal power and CCS, by 2050.

The savings in water arises mostly because of the uptake of a mix of DG technologies.

The main difference between DG and centralised power stations is in their operation. DG offers approximately double efficiency when supplying both heat and electrical power, and it uses less water, for cooling, when generating the equivalent amount of electricity compared with current centralised coal and gas fired power stations.

Even if DG were to use the same amount of water per GWhr as centralised electricity generation, DG offers a significant gain in efficiency when supplying both heat and electrical power. By virtue of the end-use of the energy being satisfied with less fuel, there is also a saving in water.

There are air-cooled coal powered technologies currently available and these may be considered in further refinements to future scenarios used in ESM and ASFF.

Note also that there are other impacts to be calculated, for example, land area disturbance labour requirements for servicing different generation plant and there is also the consideration of the environmental impacts of sourcing the raw fuel for each technology type.

7. CONCLUSION

The ESM modelling results indicate that a stringent target of reducing CO_2 emissions to 60% below 1990 levels by 2050 and an emissions trading scheme results in greater deployment of distributed generation: 20 per cent of national generation in 2050 compared to 3.5 per cent under BAU.

Through 4 key variables we have been able to reproduce the scenarios of the ESM model in ASFF and the results from the ASFF show that the benefits of distributed generation extend beyond electrical generation efficiencies to reduced CO_2 emissions and water savings.

One important component to an emissions management scenario (EMS) is the comprehensive adoption of CCS which explains 85% of the emission reductions within the EMS scenario and 70% of the difference between EMS and BAU.

The significant potential savings in water is attributable to the uptake of a mix of DG technologies. This information combined with the pricing of water might inform further economic analysis and simulation about the uptake of DG and/or water saving technologies.

These initial results demonstrate the effective interaction between economic modelling of ESM and the Australian Stocks and Flows Framework. Another potential interaction is with the sociological research concerning the end–use of energy and different modes of supply. This social science is already being conducted within the Intelligent Grid project.

Ultimately, the results of these interactions and this whole iterative modelling and simulation exercise, will provide inputs to a multi-criteria analysis designed to inform decision making about energy futures.

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