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Assessing "gas transition" pathways to low carbon electricity – An Australian case study

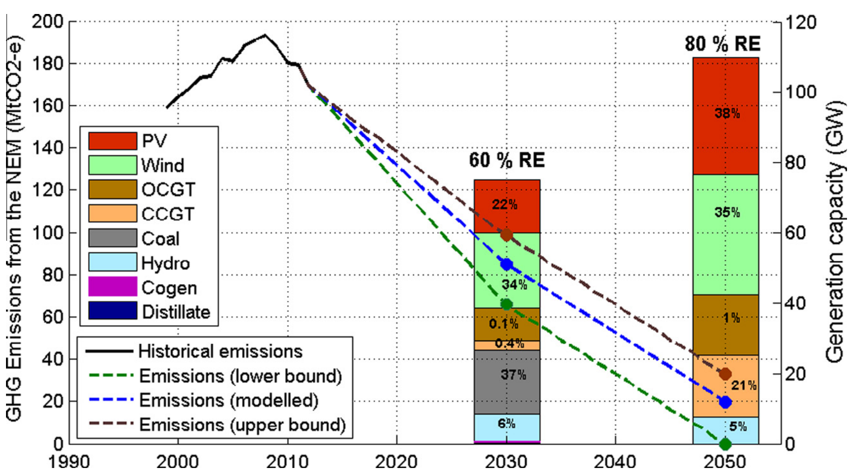
Jenny Riesz *, Peerapat Vithayasrichareon, Iain MacGill

UNSW Australia, School of Electrical Engineering and Telecommunications and Centre for Energy and Environmental Markets, Sydney, NSW 2052, Australia

HIGHLIGHTS

- High gas electricity portfolios are higher cost and risk compared with renewables.
- High gas portfolios do not achieve required greenhouse gas emissions reductions.
- Optimal portfolios are 60% renewables by 2030 and 80–100% by 2050.
- Firm capacity is provided by coal-fired plant in a peaking role rather than gas.

GRAPHICAL ABSTRACT



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ABSTRACT

Future generation portfolios including varying quantities of gas-fired and renewable generation were compared on the basis of expected costs, cost risk and greenhouse gas emissions, with a view to understanding the merits and disadvantages of gas and renewable technologies. A Monte-Carlo based generation portfolio modelling tool was applied to take into account the effects of highly uncertain future gas prices, carbon pricing policy and electricity demand. Results suggest that portfolios sourcing significant quantities of energy from gas-fired generation in 2030 and 2050 are likely to be significantly higher cost and significantly higher risk than the other alternatives considered. High gas portfolios also do not achieve the greenhouse gas (GHG) emissions reductions levels that appear required to avoid dangerous global warming. For example, portfolios that source 95% of energy from gas-fired generation in 2050 experience expected generation costs that are $65/MW h (40%) higher than portfolios that source only 20% of energy from gas-fired generation. These high gas portfolios also exhibit a cost risk (standard deviation in cost) that is three times higher. The lowest cost portfolios in 2050 source less than 20% of energy from gas with the remaining energy sourced from renewables. Even in the absence of a carbon price, the lowest cost portfolio in 2050 sources only 30% of energy from gas-fired generation, with the remaining 70% of energy being sourced from renewable technologies. Results suggest the optimal strategy for minimising costs, minimising cost risk and reducing GHG emission levels in future electricity industries may involve minimising energy sourced from gas, and increasing renewable generation. In the Australian case study considered, the modelling suggests it is appropriate to target renewable energy penetrations

* Corresponding author.
E-mail addresses: j.riesz@unsw.edu.au (J. Riesz), peerapat@unsw.edu.au (P. Vithayasrichareon), i.macgill@unsw.edu.au (I. MacGill).

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approaching 60% of energy by 2030 and 80–100% by 2050. In the lowest cost and lowest risk portfolios, firm capacity is provided primarily by the transition of existing coal-fired plant into a peaking role, and later by further investment in peaking open cycle gas turbine plant. These results are found to be robust to a wide range of assumptions around future carbon prices.

1. Introduction

Recent work including that of the International Energy Agency [1] and Intergovernmental Panel for Climate Change [2] has highlighted the increasingly urgent need for large, rapid and sustained global emission reductions, and the key role that the electricity industry will need to play in this transition.

However, there is ongoing debate about the best way to reduce the emissions intensity of electricity industries around the world. Recent setbacks for the global nuclear industry [3] raise questions about its future role in achieving low carbon electricity industries, particularly in those countries where there is no nuclear power at present. Some governments have advocated a key role for carbon capture and storage, but the poor progress seen over the past decade in demonstrating the technology has also raised concerns about its future contribution. Given their proven technical capabilities and commercial availability, renewables and gas-fired generation are the obvious immediate options. This analysis aims to determine the optimal mix of renewables and gas for achieving both low cost and low risk greenhouse emissions reductions from the electricity industry given a wide range of future uncertainties.

An industry transition pathway focused on gas-fired electricity could be expected to primarily rely upon Combined Cycle Gas Turbines (CCGTs), a mature and flexible generation option that offers high dispatchability by comparison with variable and somewhat unpredictable wind and solar, and with an emissions intensity of a half to a third of current coal-fired generation. This approach could represent a "gas transition" to low carbon electricity, with gas playing a significant role in delivering large quantities of energy in future power systems. This could be achieved by investment in new CCGT plant, or perhaps by conversion of coal-fired units to CCGTs [4].[1] Growth in distributed gas-fired generation may also be a significant contributor in some countries, particularly where there are advantages to Combined Heat and Power (CHP) technologies [5]. Carbon Capture and Storage (CCS) may also be an option for CHP technologies, providing efficient electricity and heat provision with low emissions [6]. There are a number of electricity industries which rely predominantly on CCGT generation so the approach is clearly possible when sufficient, and affordable, gas is available. Similarly, there are a number of electricity industries that rely predominantly on hydro generation. However, there is less experience with large generation contributions from novel wind and solar generation, although this situation is changing rapidly in a number of electricity industries around the world, particularly through growth in distributed generation in the case of photovoltaics [7]. The question remains how gas and renewables might complement, or perhaps compete with, each other as jurisdictions strive to reduce electricity industry emissions.

Previous studies of electricity sector transitions have generally focused on a small number of generation portfolios, modelled under a limited number of scenarios. For the example of the Australian electricity industry, the Australian Government has modelled optimal future low-carbon generation mixes for 2050 that delivered emission reductions through a mix of renewables, gas-fired generation and Carbon Capture and Storage (CCS). The actual mix varied with the strength of the emission reduction target (core and higher carbon price scenarios) and gas price [8]. Molyneaux et al. modelled the costs and GHG emissions of two generation portfolios in 2035 (exploring investment in primarily gas-fired generation or renewable generation respectively) [9]. The Australian Energy Market Operator (AEMO) annually undertakes a National Transmission Network Development Plan (NTNDP) which explores a small number of scenarios (two were modelled in the 2012 NTNDP) for the Australian National Electricity Market (NEM) [10]. A number of studies have also explored the potential for 100% renewable energy (RE) in the Australian NEM [11,12]. The methods applied for studying other electricity industries are usually similarly focused upon a very limited number of scenarios, such as for example [13–16]. While such efforts can have considerable value, these studies have generally considered only a very small subset of the possible generating portfolios that might eventuate over time, and sampled only a few of the possible market conditions under which those portfolios may need to operate. Inevitably, such approaches inadequately account for the high degree of uncertainty over important driving factors such as future gas and carbon prices. As such, they do not provide a detailed analysis of the future risks associated with particular portfolio choices.

There are number of studies applying generation portfolio analysis concepts based on the Mean Variance Portfolio (MVP) technique, which more adequately assesses future risks. Some of these examine the role of renewable energy in generation portfolios, such as studies in Japan [17], Brazil [18], Taiwan [19,20], Spain [21] and Ireland [22]. However the majority of these studies only model low to moderate levels of renewable generation, and do not explore the potential implications of high renewable penetrations.

This study is intended to explore possible pathways towards decarbonisation of emissions intensive electricity sectors, using the Australian NEM as a case study. Australia faces the particular challenge of having amongst the highest per-capita greenhouse emissions [23] and highest emissions intensity electricity industry in the world [24]. However, it also has the significant advantages of having both major and diverse renewable energy resources and considerable gas reserves [25]. As such it provides an interesting case study of possible transition pathways towards future low-carbon electricity industries, particularly for comparison of pathways that focus upon use of gas technologies, versus pathways that primarily utilize renewable technologies.

This paper is structured as follows. Section 2.1 provides an overview of the model applied for this analysis. Section 2.2 outlines the manner in which the considerable uncertainty in key input variables has been managed in the model. Section 2.3 describes the other input assumptions used in the model. Section 3 presents the findings of the modelling, with discussion of modelling limitations included in Section 3.5. Significant conclusions and their policy implications are summarised in Section 4.

[1] CCS technology is not explored in this analysis, because previous analysis has indicated that CCS technologies can only compete with renewable technologies in the NEM under a few, seemingly unlikely, combinations of cost assumptions [30].