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Assessing the value of wind generation in future carbon constrained electricity industries

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HIGHLIGHTS

- ► A probabilistic portfolio analysis tool to assess generation portfolios with wind power.
- ► Explore the impacts of wind penetrations and carbon prices under uncertainties.
- ► Wind generation increases overall portfolio costs but reduces cost risks and emissions.
- ► The value of wind power depends on the carbon price and the technology mix.
- ► Complex interactions between wind penetration level and carbon pricing.

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ABSTRACT

This paper employs a novel Monte-Carlo based generation portfolio assessment tool to explore the implications of increasing wind penetration and carbon prices within future electricity generation portfolios under considerable uncertainty. This tool combines optimal generation mix techniques with Monte Carlo simulation and portfolio analysis methods to determine expected overall generation costs, associated cost uncertainty and expected CO_2 emissions for different possible generation portfolios. A case study of an electricity industry with coal, Combined Cycle Gas Turbines (CCGT), Open Cycle Gas Turbines (OCGT) and wind generation options that faces uncertain future fossil-fuel prices, carbon pricing, electricity demand and plant construction costs is presented to illustrate some of the key issues associated with growing wind penetrations. The case study uses half-hourly demand and wind generation data from South Eastern Australia, and regional estimates of new-build plant costs and characteristics. Results suggest that although wind generation generally increases overall industry costs, it reduces associated cost uncertainties and CO_2 emissions. However, there are some cases in which wind generation can reduce the overall costs of generation portfolios. The extent to which wind penetration affects industry expected costs and uncertainties depends on the level of carbon price and the conventional technology mix in the portfolios.

1. Introduction

Wind generation is fast becoming a significant generation source worldwide, and particularly so in some European countries such as Denmark, Germany, Portugal, and Spain, where it is now contributing greater than 10% of overall electricity generation (EWEA, 2011). With increasing international concern over the threat of global climate change, a growing number of countries have established regulatory frameworks and policies to reduce carbon emissions in their electricity sectors and promote renewable generation. Currently, electricity generation is responsible for approximately 40% of global CO_2 emissions and this contribution is still rising (IEA, 2009a). Renewable generation from sources such as wind is, therefore, increasingly recognised as an important low-carbon complement to existing generation technologies. Furthermore, growing uncertainties over future fossil-fuel prices and their availability have heightened concerns over the security of electricity supply in numerous countries and this has also contributed to the recent promotion of renewable generation.

Wind has proven to be one of the most cost effective 'new' (non-hydro) renewable energy options and is the first intermittent energy source to reach significant penetrations in large power systems (MacGill, 2010). Wind energy, however, possesses different characteristics from conventional generation sources due to its highly variable and somewhat unpredictable nature. Given the wind industry's rapid growth, there are increasing concerns regarding the potential operational and economic impacts of incorporating wind generation into power systems (Smith et al., 2007). High wind penetrations increase the complexity of electricity industry operation in terms of generation dispatch and scheduling (Traber

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and Kemfert, 2011). Furthermore, it also places additional requirements for ancillary services and more sophisticated economic dispatch and unit commitment (Tuohy et al., 2009).

From a planning and investment perspective, which is a main focus of this paper, large-scale deployment of intermittent generation sources such as wind power seems likely to have significant implications for conventional generating plant investment and planning in the industry. In providing highly variable yet very low operating cost generation, wind almost invariably changes the requirements placed on conventional generation capacity to meet electricity demand (Bushnell, 2010).

Currently, numerous countries around the world are also establishing mechanisms to 'price' carbon emissions within the electricity industry. However, there is continuing uncertainty surrounding the longer-term impacts of climate change policies and the level of carbon price likely to be required to deliver effective action on climate change (IEA, 2007; Newcomer et al., 2008). Nevertheless, significant carbon prices are likely to be one of the critical factors in driving future generation investment towards low emission and renewable technologies such as wind power. Beyond present uncertainties regarding climate change policies, increased uncertainties about future fossil fuels prices, fluctuating capital costs for generation plant and recent reductions in demand growth in many countries following the Global Financial Crisis (GFC) have also all increased the challenge for generation investment decision making in the electricity industry.

Wind power is a capital intensive technology but its operating costs are very low due to its 'free' fuel. Furthermore, a carbon price will have no impact on these costs. Although the direct costs of wind power are currently higher than conventional technologies in most countries, it has been suggested that adding wind can help to hedge against fossil fuel and carbon price uncertainty, and therefore reduce the risk of generation portfolios (Awerbuch, 2006; Doherty et al., 2006).

This paper employs a novel generation investment decision support tool developed in Vithayasrichareon and MacGill (2012a) to explore the potential impacts of increasing wind penetrations on the expected cost, associated cost uncertainty and carbon emissions of different future conventional generating plant portfolios. The tool is used to assess the potential performance of different mixes of wind, conventional pulverised coal, Combined Cycle Gas Turbine (CCGT) and Open Cycle Gas Turbine (OCGT) plants under future uncertain, coal and gas prices, carbon price, electricity demand and plant capital costs. Of particular interest are the interactions between varied wind penetrations, carbon prices and fossil-fuel plant mix on overall portfolio costs and uncertainties, as well as carbon emissions. This study extends our previous work by incorporating different wind penetrations into possible generation portfolio options.

Section 2 describes the decision support tool used and its application to evaluate generation portfolios that include varied levels of wind generation. Section 3 describes the case study, which is based on wind generation and demand in South Eastern Australia, as well as regional new-build plant and fuel costs. The results and analysis are presented in Section 4 followed by some tentative conclusions on the potential implications and interactions of wind generation and carbon prices on different conventional plant portfolios in Section 5.

2. Monte Carlo based decision-support tool for generation investment including wind generation

The generation investment and planning decision-support tool presented in this paper is intended to facilitate policy-makers and planners to gain high-level insights into some of the challenges associated with different wind penetrations and carbon pricing policies in future generation portfolios. Hence, the tool adopts a long-term overall societal perspective where the key concern is how best the electricity industry might meet future demand at lowest societal cost within acceptable levels of risks and environmental constraints (Jansen et al., 2006). Therefore, it focuses on overall industry generation costs without considering issues associated with privately undertaken generation investment within liberalised electricity markets such as strategic behaviors of electricity industry participants. The tool also permits decision-makers to identify future generation portfolios which suit their particular risk preferences and consider wider multi-criterion objectives including industry-wide greenhouse emissions and exposure to different fuel markets.

2.1. Monte Carlo model for assessing generation portfolios

The tool used in this paper extends deterministic load duration curve (LDC) methods for solving optimal generation mixes by incorporating uncertainties for key input cost assumptions through Monte Carlo Simulation (MCS). The tool then applies financial portfolios analysis techniques to determine an efficient frontier of expected overall industry generation costs and associated cost uncertainties for different generation portfolios. The tool determines a probability distribution of overall industry costs and CO_2 emissions for each possible generation portfolio from the MCS. Since the technique is based on MCS, it does not depend upon only normal distributions being used to model uncertainties—arbitrarily complex and interacting probability distributions can also be applied (Duenas et al., 2011; Roques et al., 2006; Spinney and Watkins, 1996). For simplicity, log-normal probability distributions are used to represent fuel cost, carbon costs, and plant capital costs in the case study in Section 3. Hence the cost spread of each generation portfolio can be represented by a standard deviation (SD) which is referred to, here, as 'cost uncertainty'. It has a similar meaning to 'risk' in the economic and financial context. However, the MCS techniques which the tool incorporates provide a rich analytical framework for assessing various risk measures other than variance to suit particular risk preferences.

Although the tool employs an efficient frontier approach to analyse its results that has been previously used in Mean Variance Portfolio (MVP) analysis (Awerbuch, 2006; Huang and Wu, 2008), the method for obtaining the expected generation portfolios costs and associated cost uncertainties is different. In standard MVP techniques, the expected portfolio cost is calculated from the weighted average of the individual technology costs (based on an assumed capacity factor) in the portfolio while the expected portfolio risk is determined from the weighted average of risks of the individual technology based on their expected correlations and covariances. In our method, by contrast, the expected cost and risks of different generation portfolios are directly obtained from running MCS for several thousand scenarios of uncertain input parameters. With this approach, uncertain parameters which include fuel prices, carbon price, future demand, and plant capital costs are all characterised by user-specified probability distributions. Furthermore, correlations among gas, coal and carbon prices can also be taken into consideration. There is no restriction on using only normal distribution to model these uncertainties as seen with some other approaches—almost any form of distribution can be incorporated through the MCS technique.

Standard portfolio analysis assumes that the portfolio costs or returns are characterised by normal distributions and therefore can be described using only the first two moments, which are mean and variance. However, the distributions of energy commodity prices have been frequently observed to exhibit major deviations from normality due to their asymmetry and tail fatness (Eydeland and Wolyniec, 2003). The tail fatness reflects a greater