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The regional electricity generation mix in Scotland: A portfolio selection approach incorporating marine technologies

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ABSTRACT

Standalone levelised cost assessments of electricity supply options miss an important contribution that renewable and non-fossil fuel technologies can make to the electricity portfolio: that of reducing the variability of electricity costs, and their potentially damaging impact upon economic activity. Portfolio theory applications to the electricity generation mix have shown that renewable technologies, their costs being largely uncorrelated with non-renewable technologies, can offer such benefits. We look at the existing Scottish generation mix and examine drivers of changes out to 2020. We assess recent scenarios for the Scottish generation mix in 2020 against mean-variance *efficient* portfolios of electricity-generating technologies. Each of the scenarios studied implies a portfolio cost of electricity that is between 22% and 38% higher than the portfolio cost of electricity in 2007. These scenarios prove to be mean-variance "inefficient" in the sense that, for example, lower variance portfolios can be obtained without increasing portfolio costs, typically by expanding the share of renewables. As part of extensive sensitivity analysis, we find that Wave and Tidal technologies can contribute to lower risk electricity portfolios, while not increasing portfolio cost.

1. Introduction

What technologies should comprise an effective electricity generation mix for Scotland? Recent attempts to answer this question have looked at future policy targets and drivers of change to the electricity generation mix. These studies produce scenarios for the generation mix in Scotland in order to inform current policy practice.[1] For example, these scenarios might identify whether specific targets for the proportion of generation from renewable sources will being met by the intended date. If these targets are not met then some additional policy would be required which will in turn cause the real outcome to differ from that imagined in the scenario.

In this paper, we use mean-variance portfolio theory (MVPT) to provide an additional piece of evidence in the evaluation of alternative scenarios for the generation mix in Scotland. Portfolio selection theory was initially developed in financial economics to explain and prescribe methods for holding assets whose returns are uncertain. However, this approach has recently been carried over to applications in the energy and electricity generation field (e.g. Bazilian and Roques, 2008a, 2008b). More widely, it has found favour for the study of a number of research areas where outcomes (e.g. financial returns, or the cost of electricity) not only depend upon the characteristics of each of the individual options (e.g. technology costs, or their variability), but also the interactions between the generation characteristics of each option (e.g. correlations between technology costs).

This paper differs in three ways from previous applications of portfolio selection theory to the electricity generation mix. First, we explicitly address the issue of the efficiency of electricity generation mix from a regional perspective. This is of interest given the distinctive energy policy emerging in Scotland as compared to the UK. This policy divergence is reflected in a set of more ambitious targets for renewable electricity and the ruling out of new nuclear power stations. We discuss these policy drivers for Scotland's electricity generation mix in Section 2.2.[2]

Second, we are able to examine the mean-variance efficiency of alternative electricity scenarios for Scotland in 2020. Assessing existing scenarios from an explicit portfolio selection approach

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[1] Some scenario work involves looking at individual technologies, e.g. Forum for Renewable Energy Development in Scotland: Marine Energy Group (FREDS: MEG) (2009), but in this paper we are only concerned with scenarios for the electricity mix as a whole.

[2] The nature and rationale for energy policy distinctiveness in Scotland as compared to the UK is discussed in detail in Allan et al. (2008). We do not add to this here. It is sufficient for our purposes to note that a distinctive focus on the electricity generation mix in Scotland motivates a separate appraisal of alternative electricity generation mixes at the regional level.

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provides complementary information that may be useful from a policy perspective. In fact, we find that none of the scenarios examined are mean-variance efficient. The implication is that there appear to exist opportunities to lower electricity costs for no greater risk, or reduce risks while incurring no additional costs, a result that presumably is, potentially at least, of considerable policy interest. However, two notes of caution are required. Firstly, in line with most other applications of portfolio theory in this field we assume zero transactions costs and do not incorporate current energy infrastructure as a constraint. Our results would therefore require further exploration before concluding that Pareto improvements are feasible.[3] Secondly, and also in line with most other applications in this area, we only consider the costs from the perspective of a "private" developer of electricity generation capacity, rather than the full (social) costs of alternative generation technologies.[4] Nonetheless, we believe our results provide a *prima facie* case for exploring alternative scenarios for the Scottish electricity generation mix.

Third, to our knowledge this is the first application of portfolio theory to include marine generation in electricity mixes. Our consideration of these Wave and Tidal technologies reflects the high marine renewable resource in Scotland, and the anticipated contribution of these technologies to the generation mix. Currently these technologies are largely in their development stages with limited commercial deployment and typically have higher standalone levelised costs than other renewable and non-renewable technologies (see Allan et al., 2010). However, our application of portfolio theory does offer support for the view that there is a potentially important role for marine technologies in future electricity mixes, even at existing cost levels. Allowing for learning rates further reinforces this view.

We begin in Section 2 with an historical perspective on the existing electricity generation mix in Scotland and examine the drivers of changes in the mix to 2020. We then discuss in some detail a number of recently published scenarios for the future generation mix in Scotland. In Section 3 we begin by outlining the rationale for examining these electricity generation mixes from a portfolio theory perspective, show how such analyses are conducted, and note the results of previous applications. In Section 4 we report the results of our application to the Scottish electricity generation mix, before examining the impact of relaxing a number of (necessary) assumptions through detailed sensitivity analysis. We conclude in Section 5 with a discussion of the implications of our analysis for policy and suggest how the analysis can be refined in future research.

2. Scotland's electricity mix and historical basis for current position, plus factors affecting future generation mix

2.1. Development of the existing electricity generation mix in Scotland

Tables 1a and b show the development of operational electricity generation capacity in Scotland. Reading along the rows for each technology in Table 1a, gives the decade in which the capacity (in MW) that is operational today was installed. Reading down the columns in this table shows us how much of the capacity operational today was installed in each decade. The same format is used in Table 1b but in this case each cell shows the number of separate facilities commissioned, by technology and decade. These two tables combine to allow us to identify a number of issues regarding the evolution of the existing operational generation mix in Scotland.

Table 1a shows the scale of the major periods of activity in terms of the existing generation mix in Scotland. Almost one-third of the installed capacity was commissioned in the 1970s, with over 75% of the existing capacity installed between the 1960s and 1980s. During the 1990s there was only a fraction of the investment compared to earlier decades. Only 65 MW of new capacity were commissioned, 63 MW of which came from wind generation. Table 1a shows that of the 1419 MW of capacity commissioned since 2000, over 90% has come from renewable technologies, with most coming from onshore wind projects. During this time period 1117 MW of onshore wind capacity and 34 renewables projects have been installed. This is a greater annual average level than occurred in the period of great investment in renewables generation capacity which followed the Second World War. That period saw the formation of the North Scotland Electricity Board with its plans to generate electricity from the glens of Scotland using hydroelectric technologies (Hannah, 1982). These investments in the 1950s led to 792 MW of capacity installed across 39 projects. Each of these individual hydro-schemes were part of larger schemes, such as the 262 MW Sloy installation. The Sloy scheme began operation at different times from 1950 to 1963, with a total of ten separate facilities operating in this area. The Great Glen scheme was a similar proposal, with a total capacity of 225 MW. Its constituent parts date from 1955 to the most recent addition of 100 MW to this scheme which occurred in 2008.

Tables 1a and b also identify the development of major capacity in non-renewable facilities: the coal stations at Longannet and Cockenzie in the 1960s and 1970s, the gas station at Peterhead in the 1980s, and the nuclear facilities in the 1970s and 1980s. Since 1991, much of the new development, leaving aside any maintenance of existing plants which would have necessarily occurred, took place in renewables, with much of this occurring since the year 2000. We explore possible changes to the existing generation mix later in this section.

The amounts (GWh, rather than capacities) and share of electricity generation in Scotland coming from different technologies in 2007 is given in Table 2. 48,217 GWh was generated, with approximately 20% coming from renewable technologies.[5] For 2007, the most recent year for which data are available, coal, gas and nuclear each contributed more than 25% of the total amounts of electricity generated.

2.2. Factors affecting the future electricity generation mix in Scotland

Several interconnected factors are expected to produce significant changes in the future capacity and electricity generation mix in Scotland. These factors fall under two broad headings: technical and policy.

Technical reasons for changes in the way in which electricity is generated in Scotland include, but are not limited to, two points. These are: network and grid constraints and developments, and the remaining lifetimes of existing plant. We attempt to

[3] Van Zon and Fuss (2008) relax the former assumption and Doherty et al. (2008) relax the latter.

[4] We do not, for example, apply to any technologies in our study which would typically produce electricity intermittency the additional (system) costs of having a larger share of "intermittent" technologies in the generating mix, or the additional costs to society of pollution generation by those technologies which emit (different types of) pollution. Omitting the costs of intermittency will favour renewables, while omitting the costs of emissions would typically be expected to favour fossil-fuel generation. A full cost–benefit appraisal of alternative electricity generation portfolios is beyond the scope of this paper.

[5] Note that this is significantly lower than renewables share of installed capacity in Scotland due to the lower capacity factors of these technologies.