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Research and deployment priorities for renewable technologies: Quantifying the importance of various renewable technologies for low cost, high renewable electricity systems in an Australian case study

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HIGHLIGHTS

- Photovoltaics saturate early, suggesting they need complementary measures.
- Biofuelled gas turbines or another peaking technology are important for low costs.
- Limits on the non-synchronous penetration are relatively expensive.

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ABSTRACT

This study aims to identify research priorities to enable low cost, high renewable power systems. An evolutionary program optimises the mix of technologies in 100% renewable energy portfolios (RE) in the Australian National Electricity Market. Various technologies are reduced in availability to determine their relative importance for achieving low costs. The single most important factor is found to be the integration of large quantities of wind; therefore wind integration is identified as a research priority. In contrast, photovoltaics are found to "saturate" the system at less than 10% of total energy (in the absence of storage or demand management, installation of further photovoltaics does not contribute significant further value). This indicates that policies to promote utility-scale photovoltaics should be considered in partnership with complementary measures (such as demand side participation and storage). Biofuelled gas turbines are found to be important; a complete absence of bioenergy increases costs by AU$20–30/MWh, and even having only 0.1 TWh per year of bioenergy available reduces average costs by AU$3–4/MWh. Limits on the non-synchronous penetration (NSP) are found to be relatively expensive, suggesting a significant research priority around finding alternative approaches to providing synchronous services, such as inertia. Geothermal and concentrating solar thermal technologies do not appear essential as long as sufficient wind and peaking bioenergy is available.

1. Introduction

With the majority of new investment in power generation now being in renewable technologies, future electricity industries with a high proportion of renewable generation appear likely. For example, in 2014, renewables represented more than half (approximately 59%) of net additions to global power capacity (REN21, 2015). By the end of 2014, renewables comprised enough to supply an estimated 22.8% of global electricity (REN21, 2015). Research institutions and funding bodies around the world are now investing in research to enable larger quantities of renewable generation in power systems, suggesting that guidance as to the most effective relative priorities for investment in different technologies and enabling solutions would be valuable.

Some jurisdictions, such as New Zealand (Mason et al., 2010), Norway (Christiansen, 2002) and Brazil (Geller et al., 2004), are already close to 100% RE due to their development of conventional renewable resources such as hydro and conventional geothermal. Other jurisdictions where these technologies are not available at sufficient scale may find it more challenging to approach 100% RE. For example, modelling (Elliston et al., 2013, 2014) suggests that the lowest cost 100% RE portfolios in Australia might source 50–60% of energy from wind, and an additional 15–20% of energy from photovoltaics (PV). Wind and PV have a number of characteristics

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that make them different from conventional generation technologies, including being highly variable and somewhat uncertain in availability, non-synchronous (meaning that they do not contribute system inertia, which is important for maintaining frequency stability), capital intensive (with high capital costs and low operating costs), and utilising renewable energy resources that are often located far from the existing transmission grid (Riesz and Milligan, 2014). Existing electricity system operational practices and electricity markets were not designed with these characteristics in mind, meaning that changes are likely to be required in a range of ways to efficiently integrate these new technologies as their penetration grows (Riesz and Milligan, 2014; Smith et al., 2007).

Despite these challenges, a growing number of modelling studies suggest that very high renewable systems (including 100% renewable systems) are technically viable in Australia (Elliston et al., 2013, 2014, 2012; Riesz et al., 2015a; AEMO, 2013; Vithayashrichareon et al., 2015; Wright and Hearps, 2010, 2016; Lenzen et al., 2016), and in other jurisdictions such as the USA (Hand et al., 2012), Ireland (Connolly et al., 2011), New Zealand (Mason et al., 2010), Portugal (Kraja et al., 2011), The Republic of Macedonia (Ćosić et al., 2012), Denmark (Lund and Mathiesen, 2009), Europe (Rassmussen et al., 2012), Northern Europe (Sørensen, 2008) and globally (Sørensen and Meibom, 2000; Mathiesen et al., 2011; Jacobson and Delucchi, 2011; Delucchi and Jacobson, 2011). Whilst all these studies involve significant assumptions and limitations, they do suggest that scenarios of 100% RE are likely to be feasible and reasonably cost effective based upon future cost estimates for key RE technologies.

The Australian NEM provides a useful case study for analysis of high renewable energy (RE) scenarios. The NEM serves approximately 80% of the electrical load in Australia (AEMO, 2014) over a wide range of distinct climate zones. As a relatively large but isolated system (without transmission connections to other grids), the NEM must manage the variability, uncertainty and other challenges associated with integrating highly variable and only somewhat predictable renewable technologies by itself. Australia has significant renewable resources in wind, solar, wave and potentially geothermal technologies, and therefore is well placed to achieve high renewable penetrations without utilisation of more conventional renewable technologies such as hydro. This makes it an interesting case study for analysis of novel high renewable systems.

There remains significant uncertainty around the availability, performance and future costs of some renewable technologies that are frequently used in studies on high renewable systems. For example, many modelled high renewable systems rely upon the firm, dispatchable and synchronous properties of geothermal technology, but the potential availability of geothermal technologies is uncertain in many jurisdictions. In Australia, it is questionable whether geothermal technologies will achieve commercial viability in the coming decades (ARENA, 2014). Australia does not have access to high temperature conventional (ie. hydrothermal) geothermal resources, but there are two possible geothermal resources that may eventually become available: Hot Sedimentary Aquifer (HSA), and Engineered Geothermal Systems (EGS) (Bureau of Resources and Energy Economics, 2012). HSA systems are characterised by hydrothermal groundwater resources in a sedimentary basin, while EGS involves extracting the earth's heat from rocks with no pre-existing high permeability. HSA systems are relatively less expensive, but the number of sufficiently shallow systems with the right characteristics remains relatively unknown. Neither type of geothermal technology has yet been deployed commercially, and there is significant uncertainty around the potential for eventual deployment. The impact of geothermal availability upon the costs of high renewable systems has not yet been explored, which makes it challenging to estimate how much funding should be targeted towards bringing these technologies to commerciality.

There is also uncertainty around the degree to which the utilisation of bioenergy technologies may be limited due to competition with food production, and other uses of land and water resources. In 2011–12, Australia sourced 2.3 TWh of electricity from bioenergy sources, representing 0.9% of total electricity generation, with 50% of the installed bioenergy generating capacity being fuelled by bagasse (Geoscience Australia and the Bureau of Resources and Energy Economics, 2014). Landfill and sewage biogas plants also contribute a significant proportion of bioenergy in Australia at present. It has been projected that this could be expanded significantly by accessing a wider range of bioenergy sources, including agricultural-related wastes, energy crops, woody weeds, forest residues, pulp and paper mills wastes and a wider range of urban wastes (Clean) Energy Council, 2008). However, it remains unclear to what degree these waste streams can be economically accessed, and to what degree energy crops may compete with other uses (Geoscience Australia and the Bureau of Resources and Energy Economics, 2014). Many high renewable scenarios in Australia rely upon the availability of bioenergy resources for peaking generation, and if these resources are constrained more severely than anticipated, the system cost impacts could be considerable. This has not yet been quantified.

Similarly, significant cost reductions are typically assumed for concentrating solar thermal (CST) technologies, which may not eventuate. CST is a demonstrated technology, with utility-scale plants operating, and nearly 4.8 GW installed internationally (Wright and Hearps, 2010; REN21, 2016). However, the technology remains at an early stage of deployment, meaning there is likely to be significant potential for cost reductions, as deployment grows. The widely used Australian Energy Technology Assessment projects solar thermal plant using central receiver technology with storage falling in cost from an average of AU$8308/kW in 2012 to around AU$4500/kW in 2030 (Bureau of Resources and Energy Economics, 2013). If these cost reductions do not occur as projected, this technology may remain prohibitively expensive, and may not be a viable component of future high renewable systems. The impacts of this cost uncertainty upon future high renewable systems has not yet been investigated.

There are also significant questions around the potential for integrating large quantities of wind and photovoltaics. Although these technologies are widely available for commercial deployment, their non-synchronous nature and highly variable and somewhat uncertain generation creates challenges for system integration. There are questions around what proportion of energy can be realistically and cost effectively sourced from these variable, non-synchronous sources. The cost impacts of potential constraints on non-synchronous penetrations has not yet been explored, which means there is a lack of robust evidence on which to assess how much funding should be dedicated to enabling more efficient system integration of these technologies.

This study aims to explore the potential impact that various limitations on technology availability may have upon 100% RE NEM scenario costs. In particular, are there particular RE technologies which really need to succeed in achieving major deployment to achieve low-cost high renewable penetrations? Also, are there particular technologies which have key roles to play, even at small penetration levels? We seek to answer these questions using an evolutionary algorithm to optimise generating portfolios with time sequential, hourly representation of wind and solar generation. Various technologies are progressively removed from the portfolio mix to examine the impact upon portfolio costs. The intent is that such modelling work can assist key electricity industry stakeholders (particularly policy makers, but also