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Impacts on the biophysical economy and environment of a transition to 100% renewable electricity in Australia

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HIGHLIGHTS

- ► Simulation of a 100% renewable electricity (RE) system in a process-based model.
- ► The RE scenario achieves zero GHG emissions in the electricity sector by 2060.
- ► Consumption of secondary materials is higher and more variable in the RE scenario.
- ► The RE scenario has lower water use, unemployment, foreign debt and oil imports

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ABSTRACT

We investigate the impacts on the biophysical economy, employment and environment of a transition scenario to an energy-efficient, 100% renewable electricity (RE) system by 2060, based on wind, solar and biomass technologies, and an introduction of electric vehicles. We employ a CSIRO process-based model of the physical activity of Australia's economy and environmental resources, the Australian Stocks and Flows Framework. The RE systems are assumed to be manufactured in Australia to identify possible employment benefits. In comparison with the business-as-usual (BAU) scenario, on a national scale, the RE scenario has much lower economy-wide net emissions, remaining below contemporary levels and becoming zero in the electricity sector by 2060. Compared with BAU, the RE scenario also has significantly lower industrial water use, somewhat higher materials use, slightly lower unemployment, lower net foreign debt (relative to a GDP proxy) and, resulting from the growth in electric vehicles, reduced oil imports. The GDP per capita growth, based on the physical stocks of capital and labour, is virtually the same in both scenarios. Hence, from the viewpoint of the biophysical economy, there are no major barriers to implementing policies to facilitate the transition to a 100% renewable electricity system for Australia.

1. Introduction

Growing scientific and political concern about global climate change caused by the emission of greenhouse gases has driven rapid growth in policies to promote efficient energy use and renewable energy in several regions of the world. The European Union has policies to implement its '20–20–20' targets for 2020: a reduction in EU greenhouse gas emissions of at least 20% below 1990 levels; 20% of EU energy consumption to come from renewable resources; and 20% reduction in primary energy use compared with projected levels, to be achieved by improving energy efficiency (EC, 2010). By the end of 2010 China had the world's largest wind power capacity, was the world's largest manufacturer and user of solar hot water and was the world's largest manufacturer of solar photovoltaic (PV) modules (WI, 2011). At the same time Spain had the largest generating capacity of concentrated solar thermal (CST) power in operation (632 MW) plus about 950 MW under construction, much of it with thermal storage ranging from 7.5 to 15 h of rated power equivalent (WI, 2011). In 2011, Denmark generated an estimated 26% of its electricity from the wind (EWEA, 2012) and Spain and Portugal generated 16% and 15.6%, respectively (EWEA, 2012). In 2011, total annual new global investment in 'clean energy' was estimated to be $263 billion (Bloomberg, 2012). In 2012, the government of Denmark announced a goal of producing 100% renewable energy (not just electricity) by 2050 (DMCEB, 2012).

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To what extent can renewable energy substitute for fossil fuels? Numerous scenario studies have been published that model the potential for countries, regions, and the entire world, to meet 80–100% of end-use energy demand from renewable energy by some future date, typically mid-century. Scenarios exist for Australia (Elliston et al., 2011, 2012; Wright and Hearps, 2010), Ireland (Connolly et al., 2011), New Zealand (Mason et al., 2010), Japan (Lehmann, 2003), the United Kingdom (Kemp and Wexler, 2010), Germany (Klaus et al., 2010) and Denmark (Lund and Mathiesen, 2009). Regional studies exist for northern Europe (Sørensen, 2008) and the European Union (Zervos et al., 2010). Several studies of the global situation have been published (e.g., Delucchi and Jacobson, 2011; Ecofys, 2011; Jacobson and Delucchi, 2011; Sørensen and Meibom, 2000). These scenario studies do not typically specify a transition path. However, they are valuable in showing that aggressive reduction in fossil fuel use is possible, and provide a vision of how the future energy system might look. Most have focused on the electricity system, without analysing the range of cross-sectoral impacts such as material and water requirements.

This paper complements previous and ongoing technological studies of the potential for 100% renewable electricity (RE) in Australia by investigating the impacts on the biophysical economy and environment of a transition scenario to an energy efficient, 100% RE system over the period 2010–2060. More specifically, the paper compares a business-as-usual (BAU) scenario with a RE scenario with respect to electrical energy generation, net greenhouse gas emissions, water use, unemployment, net foreign debt (relative to GDP proxy) and, resulting from the growth in electric vehicles, oil imports. It also compares an indicative measure of GDP per capita growth, based on the physical stocks of capital and labour, in both scenarios.

2. Method

2.1. The modelling framework

We employed a CSIRO model of the physical activity of Australia's economy and environmental resources. This model, the Australian Stocks and Flows Framework (ASFF), is a process-based simulation that covers the physically significant elements of each sector of the Australian economy, including some service aspects, and has been applied to a variety of studies (Turner et al., 2011). Natural resources (land, water, air, biomass and mineral resources) are also represented explicitly. Throughout the ASFF, physical accounting relationships based on irrefutable mass and energy balances represent the key processes, such as converting the requirement for transport of goods into the size of the freight transport fleet and the fuel requirement. All variables representing physical stocks and flows obey the thermodynamic constraints of conservation of mass and energy.

The framework provides a means for exploring the implications of different scenario settings within a modelling system that coherently covers all sectors of the economy and environment. Cross-sector impacts, synergies and trade-offs can be properly identified in the ASFF (e.g., (Turner and West, 2011)), unlike other models or analysis with less scope.

Essentially, population and consumption rates are set, along with the activity of primary industries and various technological parameters. The framework calculates the necessary physical activity, including the labour required, throughout the economy to provide for the population, infrastructure and underlying economic activity. Ultimately this may require imports of goods and commodities, or allow for exports if there is excess production. Additionally, emissions and wastes (allowing for recycling) are produced, and environmental resources are harvested.

In the case of greenhouse gas (GHG) emissions, these have been calculated for the three major gases (CO_2, CH_4 and NO_2) using process-based emission intensities (DCC, 2009) and combined with the major emission activities modelled in the ASFF in each sector, and then converted to CO_2 equivalents. All sectors of the economy, other than those associated with land use and land use change (LULUC), have been incorporated to provide full context for the reductions that are achieved in the RE scenario. Emissions associated with LULUC were omitted due to the present difficulty in establishing reliable gross or net intensities for the various biophysical processes. Consequently, the aggregate GHG emissions presented below are not calibrated to reproduce closely the reported historical figures, but approximate the contemporary emission rates (of about CO_2-e 560 Mt/year) at the beginning of the scenarios.

2.2. Scenario settings and assumptions

This section describes the settings and assumptions of the two comparative scenarios, namely business-as-usual (BAU) and the renewable electricity (RE) scenarios.

2.3. Business-as-usual (BAU) scenario

Background features of the BAU scenario are settings and feedbacks that aspire to healthy economic conditions. We assume typical growth rates of labour productivity of about 1% pa, alongside moderate efficiency gains (see below). Subsequently, both production (primary and secondary industry output) and final demand consumption are iteratively adjusted to maintain a target unemployment rate at about 5% (as well as a target ratio of net foreign debt to GDP proxy—see below) (Turner, 2011). The modelling calculations also allow for service workers supporting the physically productive sectors of the economy. The adjustments result in economic growth that is endogenous to the simulations, rather than it being a direct assumption imposed on the simulation.

This growth is quantified using an indicative measure of gross domestic product (GDP) based on the physical stocks of capital and labour. This GDP proxy approximates an income-based GDP (ABS, 2000). The 'compensation of employees' component of GDP was estimated by combining labour numbers in the ASFF with salary and wages data, and the 'gross operating surplus' component was estimated using the stocks of productive capital in the ASFF combined with calibrated data on the cost of capital and an assumed rate of return upon investment of 10% for all sectors. The income-based GDP was calibrated to reproduce observed historical GDP. For the scenarios, no assumptions were made about movement in future labour salaries and price of capital or rates of return.

The other key macro-economic indicator simulated is the international trade balance (relative to the GDP proxy). High rates of net foreign debt (NFD) relative to GDP proxy are considered to be contrary to a stable national economy (as are relatively high surpluses). The NFD in the ASFF was adjusted by changes to exports and imports, and international travel (inbound visitors, and outbound Australians), and investment. Adjustments to exports were made by altering activity in both primary and secondary industry, after allowing for domestic requirements to be met from these industries (where Australian exports are a large fraction of Australian production). International travel and investment are adjusted by the same proportion as exports. Imports were adjusted by changing the fraction of the domestic demand for goods/commodities that is obtained from overseas. These changes also alter the GDP proxy, so that an iterative feedback calculation is necessary to achieve the specified NFD to