'Can renewables meet total Australian energy demand: A “disaggregated” approach

Ted Trainer

ARTICLE INFO

Keywords:
Renewable energy limits

ABSTRACT

Attempts to assess the possibility of deriving all energy from renewable sources typically deal only with the aggregate amount of energy required, and do not consider the implications and difficulties arising from the need for differing forms of energy. In a 100% renewable system some of these forms will have to be provided by conversion from others, mostly from electricity. Conversion involves inefficiencies, losses, and embedded energy costs of infrastructures, and thus energy and dollar costs. In this study an attempt has been made to determine the magnitude and effect of this general problem, by beginning with estimates of the quantities required by different sectors and of the different forms they use. How these needs might best be met in a renewable system is then considered. Although there is insufficient data to enable confident conclusions, this “disaggregated” approach indicates that a 100% renewable system to meet Australian energy demand would involve costs that would probably constitute an unacceptably large fraction of GDP.

1. Introduction

The recent simulations of a 100% renewable power supply system for Australia by Elliston et al. (2012, 2013) and by Lenzen et al. (2016) have significantly advanced understanding of the feasibility and cost of such a scenario. However at present electricity makes up less than 20% of total Australian energy demand in a rich country, and it is the form most easily provided by renewables. Biomass is the only renewable form that does not directly produce electricity. To provide all forms of energy needed (e.g., liquid fuel) from renewables would be a much more difficult task than simply scaling up the power supply system by a factor of five. This is mainly because most of the remaining 80% of energy needed sets problems to do with a) the nature and number of these other uses and forms, and b) costs and losses in switching uses to electricity c) the amount that cannot conveniently be switched, and d) the energy and dollar costs of converting electricity or biomass into these more difficult forms (e.g., hydrogen).

2. Method

To analyse the situation satisfactorily we would need to have confident answers to several unsettled questions, such as, what quantities of what kinds of energy are currently needed in the total energy budget, how much liquid fuel is needed for what purposes, and to what extent can electricity replace each of these. How might trucks, ships, aircraft, remote mines etc. be run? How much demand could be met by available biomass in an ecologically sustainable way? How much demand could not be shifted to electricity or available biomass and what transformations of electricity (e.g., to hydrogen) might be feasible, in what quantities and at what efficiencies and costs.

Unfortunately there is little information on several of these issues, especially the quantities of demand in the sectors other than power and transport. Therefore the following exploration is offered as uncertain and indicative only, but it does provide strong reasons for thinking that achieving a 100% renewable system will at best be very difficult and costly, and possibly unaffordable.

It is hoped that the approach being taken here will be followed by more thorough future studies. It might be regarded as a "disaggregated" approach as it does not work with a simple total energy figure but attempts to estimate what quantities of energy in what forms might be needed in Australia by 2050. A number of previous approaches to the issue of 100% renewable supply have given little or no attention to the significance of the differing forms needed. (For instance, Greenpeace, 2015, The Greens, 2016, Teske et al., 2016.) It will be seen below that significant difficulties and costs emerge when it is recognized that there is a need for much energy in forms that are not easily provided by renewable energy sources.

3. Data

Following is a summary of the data used and assumptions made regarding forms and quantities needed in the Australian economy by 2050, followed by derivations based on these. Almost all arithmetic is set out, possibly complicating the text but enabling all assumptions and
derivations to be transparent and capable of independent critical reassessment.

3.1. Estimating a 2050 Australian total energy budget

The 2050 “business as usual” (BAU) demand cannot be estimated with confidence. Australian power demanded from the grid declined in the 2010–2014 period, but this has been partly due to the lingering post GFC recession, the closure of some larger scale industrial power users, steeply rising electricity prices, and to the rapid uptake of rooftop PV. More recently demand has begun to increase again. The approach here is to consider what 2050 demand would be given continuation of the longer term BAU trend, then add the effect of various factors such as a shift to electric vehicles. It will be assumed that BAU demand will increase in proportional to population, and thus be 7520 PJ. There is reason to think this could be an underestimate because since 1974 energy consumption has shown a smooth increase that has been faster than population growth. Again this assumption is quite uncertain and the implications of taking a much lower 2050 BAU target will be discussed later (Table 1).

Also highly uncertain is the likely effect of energy conservation effort. There is considerable scope for this and quite optimistic possible reductions are often claimed. However there seem to be few if any numerically based technical estimates of whole system savings (as distinct from discussions of specific areas in which spectacular achievements are likely to be made; Amory Lovins’ works provide many of these, e.g. Lovins and Von Weisacher, 1997, Lovins, 2011.) The possible effect of this conservation factor will be considered later, and brief reference will be made to the many factors likely to increase energy demand and to overwhelm reduction achievements.

Thus 2050 final BAU energy demand will be taken as,

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>1472 PJ</td>
</tr>
<tr>
<td>Transport</td>
<td>2917 PJ</td>
</tr>
<tr>
<td>Remainder</td>
<td>3131 PJ</td>
</tr>
<tr>
<td>Total</td>
<td>7520 PJ</td>
</tr>
</tbody>
</table>

3.1.1. Electricity provision

It will be assumed that 94% of electricity can be provided by wind, solar and hydro, plus 6% from biomass used for back up purposes. These figures are drawn from the simulations by Elliston et al. (2012, 2013) which assume up to 58% of electricity can come from wind. They are quite optimistic assumptions for wind and solar; others point to evidence of increasing difficulties and costs where wind contributes more than 30% of supply (Lenzen et al., 2016, refer to several studies making this point.) The biomass quantity is less challengeable, but is in the region of one-third of the amount found to be needed in the “real-world probable” scenario discussed by Lenzen et al. This means that the assumption made in this analysis leaves much more biomass available for use in meeting liquid fuel demand than might be realistic.

The Australian Energy Market Operator (Crawford et al., 2013) estimates that Australia could harvest c. 96 million tonnes p.a. for biomass energy, i.e., 1728 PJ/y, including municipal wastes. These figures are likely to be considerably too high as AEMO notes that they do not include energy costs for biomass production and transport, nor any embodied energy costs in plant, trucks etc. Farine et al. (2012) arrived at a figure around half as large. However Foran (2008) assumes much greater amounts could be provided (…considered again below.) It will be assumed here that a net amount of about 1600 PJ can be provided. Thus after backing up power (at c. 26% conversion efficiency; Crawford et al., 2013), about 1260 PJ of biomass would be left. (A larger assumption will be considered below.) The amount of electricity to be generated from non-biomass sources is therefore 94% of 1472 PJ = 1384 PJ.

3.1.2. Transport energy provision

It will be assumed that a) all passenger vehicles can be electric, doubling energy efficiency (not trebling, in view of the high embodied energy cost of EVs (Sharma et al., 2013; Mateja, 2000), b) that electricity, ethanol and hydrogen can each power one third of light trucks, and c) half of heavy trucks run on ethanol and half on hydrogen. (Friedmann, 2016; and Bossel, 2004, below, explain the reasons for not assuming heavy truck transport based on electricity or hydrogen.) Transfer of much freight to rail is not accounted here; it would reduce heavy truck use but would greatly increase light truck use for distribution from rail heads. Air transport will be assumed to be fuelled by ethanol. No figures for shipping are included although the amount involved in the Australian economy would be significant. Almost all vessels carrying imports and exports to Australia are foreign owned so fuel quantities are not recorded in Australian accounts. In a 100% renewable world shipping fuel would have to be liquid or hydrogen etc., not electrical, so production from renewable sources would be problematic, given the scarcity of biomass.

From above the amount of transport energy required in 2050 would be 2917 PJ.

The breakdown of present amounts and proportions, (from Australian Bureau of Statistics, 2014), would be:

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road</td>
<td>2129 PJ</td>
</tr>
<tr>
<td>Passenger</td>
<td>1235 PJ</td>
</tr>
<tr>
<td>Light trucks</td>
<td>362 PJ</td>
</tr>
<tr>
<td>Heavy trucks</td>
<td>468 PJ</td>
</tr>
<tr>
<td>Other</td>
<td>64 PJ</td>
</tr>
<tr>
<td>Rail.</td>
<td>87 PJ</td>
</tr>
<tr>
<td>Air.</td>
<td>554 PJ</td>
</tr>
<tr>
<td>N.e.i.</td>
<td>120 PJ</td>
</tr>
</tbody>
</table>

Amounts and forms of transport energy required in 2050:

Passenger vehicles: 1235 PJ needed if BAU. It will be assumed all are electric vehicles, but at only double present energy efficiency, not treble (see above), therefore 617 PJ of electricity would be needed. Light trucks: 362 PJ needed if BAU. Some trucks for light deliveries can be electric vehicles, but some for heavy distribution would have to be hydrogen or biomass-ethanol. It will be assumed one third each will be fuelled by electricity, hydrogen and biomass ethanol, therefore the need will be for 120 PJ of hydrogen and of biomass ethanol and 60 PJ electricity for EV light trucks. (This unrealistically assumes light trucks would use no more energy than passenger vehicles. It is assumed that short distances would enable frequent refuelling by hydrogen, and thus avoidance of heavy tanks.) Heavy trucks: Under the BAU assumption 468 PJ would be needed. Friedmann (2016) and Bossel (2004) detail the reasons why they are not likely to be ERVs or fuelled by hydrogen. Very large and heavy tanks would be necessary to store sufficient compressed hydrogen for long distance transport meaning that the net freight weight that could be moved long distances would be quite low. In addition the equipment needed to produce, compress, store and distribute hydrogen would significantly reduce net energy delivered. Finally the efficiency of the electricity-hydrogen-fuel cell path would be in the region of 30%. Therefore it will be assumed that the 468 PJ needed would have to be biomass ethanol.
Table 2
Total energy needed for transport.

<table>
<thead>
<tr>
<th>Energy forms to be generated</th>
<th>Electricity</th>
<th>Biomass</th>
<th>Hydrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>To meet power demand.</td>
<td>1386 PJ</td>
<td>340 PJ</td>
<td>179 PJ</td>
</tr>
<tr>
<td>To meet transport demand</td>
<td>764 PJ &gt; = 3004 PJ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>To meet remaining demand.</td>
<td>2227 PJ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Totals</td>
<td>4377 PJ</td>
<td>3344 PJ</td>
<td>179 PJ</td>
</tr>
<tr>
<td>...as final energy:</td>
<td>4377 PJ</td>
<td>88 PJ</td>
<td>179 PJ</td>
</tr>
<tr>
<td>...that is, total final energy required:</td>
<td>904 PJ</td>
<td>3004 PJ</td>
<td>5845 PJ</td>
</tr>
</tbody>
</table>
would not have been the worst year ever to occur), alternative assumptions (especially re the solar thermal component, see below), and several factors that determine the difference between wholesale and retail price. (For the present coal-fired supply the retail price of electricity is around 8 times the production cost determined by the four factors Lenzen et al. took into account, i.e., capital, O and M, transmission and “fuel” costs.) The limited evidence available on these factors enabled an estimation of cost increase implications for only four of the ten identified as increasing the Lenzen et al. production cost to a retail price. These were, the difference in the exchange rate between 2014 and the much more favourable value when the capital cost estimates for mostly imported plant used were made, a cost multiplier for remote area construction, inclusion of embodied energy costs, and an estimate based on Bureau of Meteorology data to take into account evidence on how much less favourable than 2010 weather patterns might at times be. The result was a retail price of at least 68c/kW h, (i.e., assuming a production cost of 20c/kW h) and reasons are given for anticipating 90c/kW h or even higher.

4.1. Estimating total energy supply costs

If the retail price is taken as 50c/kW h (rather than 68c/kW h), the cost of providing the amount derived above would be $814 billion p.a., or approximately 54% of GDP. For a retail price of 30c/kW h the cost would be over 18% of GDP. (See Note 1.)

To these sums various additional costs would need to be added, such as the cost of converting 1260 PJ of biomass to 504 PJ/y of ethanol (equivalent to 30% of current passenger car fuel use) and the cost of the renewables transmission infrastructure.

The present rich country total expenditure on energy is usually well under 10%. (After recent significant rises the Australian figure has been estimated at 8.2%. Pears, 2017.) But this includes sales taxes added on after all production and distribution costs. For example 40% of the retail price paid for petrol in Australia today is a tax added by government to the retail supply price. If taxes could be taken out of the calculation the retail price paid for energy in Australia today would probably be closer to 5% of GDP. Hall and Klitgaard (2014) are among others reporting that when energy expenditure remains above about 5.5% of US GDP for some time recession occurs.

4.2. More optimistic assumptions?

From here on BAU energy demand might not increase as fast as population. If the multiple is 1.4 rather than the 1.82 assumed above then the 2050 total energy cost would be c. 77% of the above figure, i.e., around 21% of 2050 GDP.

The electricity generating task would be reduced if the biomass contribution could be greatly increased beyond the AEMO estimate (Crawford et al., 2013), which Foran (2008) believes is possible. However this would be unlikely to make a major difference. If 40 million ha could be planted at a yield of 10 t/ha/y, providing 7200 PJ/y of biomass (equivalent to 30% of current passenger car fuel use) and the cost of the renewables transmission infrastructure.

The present rich country total expenditure on energy is usually well under 10%. (After recent significant rises the Australian figure has been estimated at 8.2%. Pears, 2017.) But this includes sales taxes added on after all production and distribution costs. For example 40% of the retail price paid for petrol in Australia today is a tax added by government to the retail supply price. If taxes could be taken out of the calculation the retail price paid for energy in Australia today would probably be closer to 5% of GDP. Hall and Klitgaard (2014) are among others reporting that when energy expenditure remains above about 5.5% of US GDP for some time recession occurs.

4.3. More pessimistic assumptions?

Weighing against the optimistic possibilities there are several factors that are likely to greatly increase the magnitude of the future supply task. It is likely that in 2050 many functions will require greatly increased energy inputs, such as water desalination, mining poorer ores, processing poorer ores, and dealing with greater levels of mining waste material and environmental pollution. Denser settlements will involve much high rise construction and living, complex infrastructure upgrading, and high rates of movement of inputs and waste outputs. The present commuting rates to centralized cities are major sources of transport energy consumption, especially for infrastructures, and this pattern is likely to intensify. The quest to improve productivity will probably increase energy demand, as it has recently been realized that productivity growth is significantly due to adoption of more energy-intensive ways. Global freight and especially tourism and air traffic are expected to increase faster than population or GDP.

Another major category concerns the energy that will be needed to cope with accelerating ecological deterioration, especially climatic challenges to agriculture and food supply. Dealing with the many effects of climate change will add large energy costs that do not have to be met at present, including defensive works such as sea walls, settlement relocation, salt water incursions into agricultural land, remediating storm damage, dealing with environmental refugees, adapting to altered rainfall patterns (which for instance will make some dams redundant), dealing with pest surges and algal blooms, and developing new crops for altered conditions. Warming weather will significantly increase air conditioning use, adding greatly to the task of providing for peak supply. The need to deal with accelerating biodiversity loss will also add to demand on energy supply.

Probably the greatest problem will be set by the fact that the IPCC greenhouse targets assume taking very large amounts of carbon out of the atmosphere after 2050 and this would involve enormous energy costs. Anderson (2017) points to the general neglect of this issue, and the danger that it is being assumed to legitimate the avoidance of taking urgent measures in the near future. The magnitude of the task being left for future generations and technologies is easily overlooked. The required technologies are problematic and have not been demonstrated at scale, but Anderson points out that they will probably be called on to take 18 GT of CO2 out of the atmosphere each year, which is almost equivalent to half the amount currently being emitted.

In view of these considerations it is not obvious that conservation effort and technical advance will achieve reductions that outweigh these sources of increased energy demand. In addition it is necessary to give separate attention here to the reasons for believing that the CSP assumptions built into the Lenzen et al. derivation are unduly favourable.

4.4. The CSP issue

Given the complexity of the modeling and computing tasks involved...
in the Lenzen et al. analysis it made sense to proceed with commonly held assumptions regarding CSP, but following is a summary of the case that some of these assumptions are much too optimistic.

The foregoing derivation of costs is based on the Lenzen et al. findings, which depend significantly on the contribution of CSP in periods when renewable energy is least available. There are three important elements in the Lenzen et al. study which are questionable but could be refined when the approach is further elaborated.

Firstly Lenzen et al. assume the efficiency of generation to be 30%, based on a table given by Lovegrove et al. (2012, p. 49) However that text points out that this figure is an estimate of what technical advance might achieve. There is considerable evidence in reports on the CSP systems operating today that current efficiencies are around 14%. Some foresee possible improvements to the region of 19% (Lovegrove et al., 2007; Hinkley et al., 2012, Fig. 7; NREL Solar Advisory Model, undated; Kearney Consulting, 2010; Viebahn et al., 2004; Abengoa, 2016; Marin, 2015; De Castro, 2017; Solarstor, 2017).

The second issue concerns efficiency and net output in poor conditions, especially winter. The Lenzen et al. findings depend considerably on the contribution that CSP can make in periods when the renewable resource is at its lowest. Their Fig. 6 representing five difficult days shows that due to the lack of wind and PV input CSP is called on to provide a lot of electricity, almost always over 15 GW and at times apparently up to 19.4 GW, which is 84% of average demand.

In this initial investigation it was in order to minimize the already complex computational task by assuming that CSP generation efficiency would be the same at all seasons and levels of DNI and times of the year. However this is not the case; the actual efficiency of a plant in winter is in general significantly lower than in summer and varies according to the priorities underlying its design (Jones et al., 2001; Wood et al., 2012, 4–14; Siangsukone and Lovegrove, 2003; Odeh et al., 2003; Kanef, 1991).

That the effect is not trivial is evident in data from the Torresol generating company which operates Gemasolar in Spain (Marin, 2015), and from Solarstor, (2017) The Solarstor device has an average “Field efficiency” in summer that is twice its winter value i.e., the ratio of heat collected to solar radiation intersected by heliostats. This falls sharply as DNI falls, that is, faster than the fall in DNI. For instance at 400 W/m² “field efficiency” is 61% below its level when DNI is 1000 W/m², and heat is being collected at only 15% of the 1000 W/m² rate.

The data on Gemasolar confirms the indication from Solarstor that the effect is marked. When DNI is 463 W/m² the efficiency of heat delivery is only c. 20%. If a turbine efficiency of 33% is added the efficiency of solar to electricity generation would appear to be under 7% (...and this does not take into account loss of parasitic energy;) If this reasoning is more or less valid the CSP contribution represented in Fig. 6 in Lenzen et al. would have required more than four times the 61 GW capacity found to be needed (or would have required resort to be made to some other storage strategy.) Note that average Australian demand is 23 GW.

Finally the capital cost assumption (taken from AETA 2012 and ‘Scenario 1 2030’ in AEMO 2013) represents a large (56%) fall from the present cost given by AEMO, which is almost double that assumed for the other renewable technologies. The 20 MW Gemasolar Plant in Spain was the first to be equipped with15 hour storage, assumed by Lenzen et al., and its capital cost has been reported as $US419 million, or a remarkable $21,000/kW (Wilson, 2011) and three to four times the Lenzen et al. cost assumption.

Thus if future applications of the Lenzen et al. approach can incorporate more complex CSP assumptions they are likely to arrive at a significantly higher production cost estimate than that informing the above derivation.

5. Conclusion and policy implications

This analysis does not arrive at confident conclusions as much depends on uncertain assumptions regarding the situation in 2050. However it does indicate grounds for suspecting that the total cost of 100% renewable energy supply will be very high, probably seriously economically disruptive, and possibly unaffordable. Note that these estimates apply to Australia, which has possibly the most favourable renewable energy conditions in the inhabited world, including approximately five times the world per capita biomass potential, (IPCC, 2011; European Biomass Industry Association, undated). Some estimates of future European biomass potential put it at sufficient to meet at most a mere 3% of transport fuel demand, and possibly only a quarter as much (European Commission, 2013; Wetterlund et al., 2012; Bentsen and Folly, 2012).

Without their considerable access to this renewable energy source for the purposes of getting through difficult periods the scenarios from Elliston, Diesendorf and MacGill, and from Lenzen et al. would have yielded much higher production costs for electricity.

The probably surprising magnitude of these cost findings is due primarily to the previously largely neglected consideration of the differing forms of energy required, and the difficulties and costs in meeting some of these requirements via energy and dollar costly conversions from electricity. It is important that future attempts to simulate 100% total energy supply systems should take an approach of this kind, that is, one which “disaggregates” and deals with the differing forms of energy required and conversion costs.

The belief that 100% renewable energy supply is possible and affordable is probably the main element in the “tech-fix” faith which seems to be held by most governments and people, including those who are technically sophisticated and participants in green and left energy camps. The dominant assumption is that there is no need to shift from something like the present energy and resource intensive lifestyles and systems, or from an economy driven by market forces, the profit motive and growth. The immensity of the policy implications of the above findings requires little elaboration. If the position arrived at in this reassessment is sound then it would seem that if a solution is to be sought on the supply side it will have to be in the form of breeder reactors. This commitment would have to be very large, given the above finding that to run everything on electricity would require a great deal of generating capacity to enable conversion to non-electrical energy forms.

The alternative policy option is to seek a solution on the demand side, that is to opt for a “De-growth” transition to some form of “Simpler Way”. From this perspective energy is only one of the major global problems currently threatening and these cannot be solved unless there is dramatic reduction in rich world per capita levels of consumption, the present economy is largely abandoned, there is a shift to mostly self-governing localized communities, and there is immense cultural change away from individualistic, competitive acquisitiveness to frugal, cooperative and non-material values. Such an option is far from the centre of policy debate at present but this might change if the global situation deteriorates as some anticipate (see especially Ahmed, 2017.) The case that an alternative of this kind would be workable and attractive is detailed at thesimplerway.info/. In particular the item “Remaking Settlements” (Trainer, 2016) derives the tentative conclusion that the suburbs of cities might be restructured in ways that cut per capita energy, resource and dollar costs to the region of one-tenth their present typical values.

Notes.
1. To provide 5867 PJ/y of electricity, i.e., 1629 billion kW h/y, at 50c/ kW h would cost $814 billion p.a., which is around 54% of 2015 GDP, or 27% of 2050 GDP assuming 2% economic growth. (An approximate croscheck; this amount of electricity is about 8.5 times the 2015 c. 200 TWh electricity production which retails at c. 25c/ kW h indicating a cost of $50 billion/y. If the 2050 retail price was 50c kW h, i.e., twice as high, total annual energy supply would cost 8.5 x $50b × 2 = c. $850 billion.) If a retail price of 30c/kWh had
been assumed, total energy provision would have cost over 18% of GDP.

2. From the 1002 PJ/y derived via the AEMO 0.26 assumption 179 PJ/y \times 1.7 = 304 PJ/y of biomass energy would be needed, i.e.698 PJ/y.

References

Friedmann, A., 2016. Diesel is finite. Trucks are the bedrock of civilization. So where are the battery electric trucks? energyskeptic, July 1.
Lovins, A., 2011. Reinventing Fire; Bold business solutions for the new energy era, Rocky Mountains Institute, Chelsea Green.
Pears, A., 2017. 2017 will be a big year for Australia’s energy system: here’s what to look out for, The Conversation, January 25.
Trainer, T., 2015. Comments on the proposal for 100% renewable energy electricity supply for Australia, by Elliston, Diesendorf and MacGill. thesimplerway.info/EDMcrit.htm.

T. Trainer