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1 I am grateful to Professor Tooraj Jamasb, Durham University, UK for bringing some relevant references to my attention.

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The *Economics, Environment and Ecology* set of working papers addresses issues involving environmental and ecological economics. It was preceded by a similar set of papers on *Biodiversity Conservation* and for a time, there was also a parallel series on *Animal Health Economics*, both of which were related to projects funded by ACIAR, the Australian Centre for International Agricultural Research. Working papers in *Economics, Environment and Ecology* are produced in the School of Economics at The University of Queensland and since 2011, have become associated with the Risk and Sustainable Management Group in this school.

Production of the *Economics Ecology and Environment* series and two additional sets were initiated by Professor Clem Tisdell. The other two sets are *Economic Theory, Applications and Issues* and *Social Economics, Policy and Development*. A full list of all papers in each set can be accessed at the following website: http://www.uq.edu.au/economics/PDF/staff/Clem_Tisdell_WorkingPapers.pdf

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In addition, the following working papers are produced with the Risk and Sustainable Management Group and are available at the website indicated. *Murray-Darling Basin Program, Risk and Uncertainty Program, Australian Public Policy Program, Climate Change Program* :http://www.uq.edu.au/rsmg/working-papers-rsmg

For further information about these papers, contact Professor John Quiggin, Email: j.quiggin@uq.edu.au

Public finance for renewable energy use and for the renewable energy sector's development: externalities, sustainability and other issues

Abstract: This article outlines the case for increasing our dependence on solar and wind power to generate electricity. It outlines the economic reasons why governments should provide financial incentives for the increased use and production of electricity from solar and wind power and identifies the policy instruments able to provide these incentives and encourage the development of this green electricity sector. Although wind and solar resources are usually classified as renewable resources, it is argued that classifying them as flow resources is more appropriate. Basic sustainability concerns about the use of alternative energy resources differ. The nature of these different concerns is clarified. Pigovian-type economic analysis is employed to provide an illustration of the superior social economic benefits of using solar and wind power to generate electricity rather than fossil fuels. However, it is also pointed out that there are economic and political constraints on increasing our reliance on solar and wind power to generate electricity. These include the unsatisfactory flow of these resources in some parts of the world, and constraints on economically and sustainably storing the electricity generated by using these resources. However, technological progress is likely to improve the prospects for storing electricity. Given that the demand for electricity can be expected to increase due to technological change and economic growth, it is more important than ever to pay attention to methods of electricity production (such as those utilizing solar and wind power) which are more environmentally friendly and which have superior sustainability qualities compared to the use of fossil fuels. In many parts of the world, greater reliance on solar and wind power will have these beneficial effects and positive social economic benefits.

Keywords: battery electricity storage; electricity economics; environmental externalities; energy policy; fossil fuels; lithium; renewable energy; solar power; sustainability; wind power.

JEL Codes: G18, Q40

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1. Introduction

Human induced global warming and climate change pose a serious threat to worldwide ecological, economic, and social sustainability. The major contributor to global warming (but not the only one) is the release into the atmosphere of greenhouse gases (particularly carbon dioxide) as a result of the combustion of fossil fuels, especially coal (Liski and Vehviläinen 2016). Despite the dismissal of this interconnection by climate change deniers (such as Mr Donald Trump, the current President of the USA), scientific evidence in support of the above relationship is extremely strong. As a result, several governments (for example, in Australia and China)[1] are providing financial support to increase renewable energy use and to foster the development of their national renewable energy sectors in order to reduce their dependence particularly on coal (and to a lesser extent on natural gas) as sources of electricity generation. At the federal level in Australia, a government body, the Clean Energy Finance Corporation is investing in new renewable projects and the government is underwriting loans for clean energy projects and guaranteeing a floor price for the energy produced (White 2018, p. 13). Several Australian State Governments are also providing economic incentives for increased use of clean electricity. The International Energy Agency reported in 2015 that worldwide, a quarter of a trillion euros is being spend annually to foster the renewable energy sector (Liski and Vehviläinen 2016, , p. 2)

Dependence on electricity as a source of power is likely to increase in the coming years, as combustion engines are increasingly replaced by electric motors, for example, as electric cars become more common. Electronic technologies are also highly dependent on the supply of electricity, and their use is expanding rapidly. Consequently, the demand for electricity is likely to rise substantially in the future. This will increase the importance of producing 'clean' electricity.

The purpose of this article is to consider (as well as to assess, in the light of economic and other principles) why and how many governments have and are providing financial support for the use of renewable energy resources and for the development of their renewable energy sectors. The main focus will be on solar and wind energy and the challenges that dependence on these energy sources pose. However, in order to appropriately analyse the type of resources and environmental challenges we face and the relevance of public financial policies for retarding global warming, it is important to realize that a better classification of energy resources (than the current one) is needed. In addition, we must distinguish clearly between the different (general) types of environmental/sustainability concerns that arise in assessing the desirability of alternative sources of electricity (energy) production.

The method adopted in developing this article is to take into account relevant current literature about this subject and to apply economic principles to its consideration. In addition, original concepts will be presented in order to provide new insights into this field of enquiry.

This article is developed in the following sequence:

[1] Several studies in the United States have also adopted economic policies to promote the use and development of renewable energy technologies (Joskow 2011, , p. 238). However, at the federal level, the Trump administration has adopted policies that favour fossil fuel use, unlike the previous administration.

- An improved and more relevant classification of energy resources for sustainability purposes is proposed;
- Sustainability concerns are identified;
- The types of government financial measures are outlined which could encourage the use of flow energy resources (mainly solar and wind) for electricity production;
- The reasons why governments do and should support the development of and the use of solar and wind power are presented;
- The difficulties faced as a result of increasing the reliance on solar and wind power for electricity generation are examined; and
- Concluding comments follow.

2. Improving the classification of energy resources for sustainability assessments

As mentioned above, it is important to improve our classification of energy resources. Classifying these as either renewable or non-renewable is too crude and can be misleading (Tisdell 2009, , Section 7.3). Some are stock resources and others are flow resources. Fossil fuels, biofuels and nuclear fuels are stock resources. Biofuels are renewable within limits but the other two energy sources are not.

Solar, wind, and hydro can be regarded as flow resources and the challenge for humanity is to convert them economically into energy stocks to be drawn on when their available supply (which fluctuates) is insufficient to meet demands for power, e.g. electricity. Joskow (2011) considers solar and wind power to be intermittent resources and fossil fuels to be dispatchable resources for electricity production. Both solar and wind power can be regarded as having a finite amount of availability (they are relatively scarce in economic terms) (see, for example, Liski and Vehviläinen 2016, for evidence of this in the Nordic area) and the use of each leaves a negative environmental footprint. The magnitude of this footprint varies with the type of resource used for energy production and the method of its production. Furthermore, the scarcity of these flow resources varies seasonally, is time-dependent, and their availability differs regionally.

The adverse environmental externalities (spillovers) caused by the production of heat and power from fossil fuels are substantial, especially from the use of coal, but the production and use of biofuels can also have serious negative environmental effects (Tisdell 2011). Less serious negative environmental effects are associated with the use of solar and wind power for energy production. Rough economic estimates of the environmental costs of using different energy resources to produce power (taking into account the nature of their utilization) can be made. However, up-to-date estimates which take account of recent and projected development of technologies meeting energy demands are not available yet.

The ability of different energy resources to meet variations in the demand for electricity varies. Currently, the use of stock energy resources (excluding nuclear), primarily natural gas, coal, petroleum fuels, display greater flexibility in this regard (they are more dispatchable) than do solar and wind power, the supply of which is intermittent. The supply of solar and wind power depends on prevailing weather conditions. Solar is only available in the daytime and away from the equator, the length of the daylight varies throughout the year. Atmospheric pollution (dust and haze) can also adversely affect solar electricity generation, as does cloud cover. Electricity production by nuclear power plants provides a continuous (non-variable) supply of electricity (Tisdell 1997). At present, adjusting electricity supplies to demands requires a balance between the various sources of energy supplies. Phasing out the use of fossil fuels for electricity generation and replacing their supply by solar and wind power is restricted by the desire to supply sufficient electricity to meet demands when the supply of electricity from flow resources is insufficient to do this.

However, it is likely that battery storage (or other forms of retaining solar and wind power) will in the future, enable energy from these sources to be stored and to be available to meet differences (that would otherwise occur) between the demand for electricity and its supply from these resources. These electricity storage technologies will be able to convert energy in flows into stocks of energy.[2]

Although increases in the price of electricity could theoretically be used to reduce the demand for electricity when this exceeds its supply, very large fluctuations in supply could cause considerable economic disruption. Political unrest is likely if such a policy is adopted given the high degree of dependence of contemporary societies on electricity for economic production and to meet personal needs. In modern societies, the demand for electricity is very inelastic, at least in the short-run and is likely to become even more so in the future. Consequently, an important constraint on the speed of transition from fossil fuels to solar and wind power for electricity supply is the availability of technologies able to economically convert energy from the latter resources from flows to stocks (Tisdell 2009, , Ch. 11). In the future, it is likely that improved and new technologies could be developed that will facilitate this conversion process and make it more economical.

3. Relevant sustainability concerns

A variety of sustainability concerns have been expressed about the use of different resources to provide heat and power and the emphasis on these concerns has altered with the passage of time. The following provides a sample of such concerns.

As the world began to depend more heavily on fossil fuels to meet its energy requirements, concern was expressed about the depletion of fossil fuels and the possibility of their scarcity increasing. For example, Jevons (1865) raised this concern in the 19th century. In the 1970s, the Club of Rome (Meadows, Ronders, and Behrens 1972) argued that a shortage of fossil fuels could imperil the sustainability of economic development. However, the Club of Rome underestimated the availability of fossil fuel resources, and did not take into account the availability of flow energy resources.

Global reserves of coal are extremely large. According to the World Coal Association (no date), proven economically renewable coal reserves are estimated to last for around 150 years, given current levels of consumption. Similar estimates for natural gas and oil availability are about 50 years (World Coal Association no date; Singh and Singh 2012). However, the economical length of life of these energy resources is likely to be even longer than this. The duration of the economic life of the available reserves of these energy resources depends on many factors (Tisdell 1982, , Ch 15; 2009, , Section 7.3.4). More of these reserves are usually identified as their proven stocks decline. Technological change, alterations in the prices of energy derived from different sources, and other factors are also consequential for estimating how long fossil fuel resources will last.

As recently pointed out by Ritchie and Roser (no date, , p. 28), there is a global abundance

[2] These technologies may also be applied to other sources of electricity production, e.g. the output of nuclear plants, as a way of better aligning electricity availability with demand.

of fossil fuels, even though the stocks of these resources are finite. They point out that from a climate change perspective, we should leave most of these fuels in the ground. They state: "If we are to have any chance of keeping global temperature increases below our 2ºC target, we have to leave the majority (up to 80 per cent) of our fossil fuels in the ground" (Ritchie and Roser no date, , p. 28).

In 2014, fossil fuels accounted for about 62% of world electricity production with the remainder coming from other sources, mainly hydro, nuclear, wind and solar power. Coal was the largest single contributor to electricity supply. Current predictions are for electricity production in the future to become less dependent on fossil fuels, especially coal, and for solar energy and wind power to considerably increase their contribution (Rutledge 2011, , p. 31). However, as pointed out later in this article, this transition away from fossil fuels may not be frictionless because of the political obstacles raised by vested interests.

Currently, the main worldwide sustainability concern about using fossil fuels to produce power and energy is the impact of this on global warming and climate change. The latter environmental changes are a threat to global economic development, ecological, and social sustainability; as well as the sustainability of regional economies.

However, even in the absence of climate change, the mining of fossil fuels raises significant sustainability issues. Communities which base their economies on the extraction of fossil fuels often have a limited period of existence because they often become economically unsustainable once the source of their wealth is exhausted.

Furthermore, limited reserves of some minerals used in battery production could restrict their use to store electricity. For example, the demand for lithium for battery production is rising but global reserves of lithium are believed by some researchers to be relatively small relative to the likely demand for these. However, opinions differ about how economically scarce lithium in-ground reserves are likely to become (Hunt 2015; Narins 2017; The Greenage 2017). Furthermore, there is still much unrealized scope for recycling the lithium in batteries and extending the length of useful life of lithium-based batteries, including for them to have second applications, even though there are important economic and organizational hurdles which need to be more satisfactorily addressed to achieve greater lithium recycling (King, Boxall, and Bhatt 2018). It has also been estimated that resources for producing other types of batteries, e.g. lead and zinc, could become economically scarce in the foreseeable future (Mohr et al. 2018).

It is possible that as a result of R&D, different types of batteries to the existing ones and forms of storing solar and wind power could be developed and the current battery and other power storage technologies might be made more efficient. Consequently, constraints on storing energy will become less severe than they might otherwise be. Nevertheless, the sustainability of local communities reliant on the extraction of minerals for battery production will still be an issue.

4. Government financial incentives to increase the use of solar and wind power and to develop the sector supplying this power

Several financial instruments are available to governments to foster the substitution of wind and solar energy for power derived from fossil fuels. These can be divided into demand-side and supply-side economic incentives. Let us consider some of these incentives.

4.1 Demand-side government financial incentives for increasing the substitution of wind and solar power for that derived from fossil fuels

Purchases of electricity (from the grid) derived from solar and wind power can be subsidized by governments. This subsidy can be distributed to buyers by electricity retailers on behalf of the government. This last mentioned type of policy has been adopted by some Australian State Governments but some have phased out this approach. The size of the subsidy can be varied depending on the amount of economic stimulus considered to be desirable for fostering the switch to wind and solar power. Indirectly, this policy provides an economic gain to producers of electricity from solar and wind power. This is because it stimulates the demand for this type of green electricity and may raise the effective price they receive for their sales of electricity. If the supply curves for these types of green energy have normal slopes (are neither perfectly inelastic nor completely elastic) the desired substitution will occur and the price received from green energy supplies will rise. This is so given that from the point of view of most buyers of electricity, green electricity is highly substitutable for non-green electricity.

It is of course, important that subsidization discriminates in favour of green electricity, that is, that it not be offset by subsidies for the use of non-green electricity. Any subsidies for the latter could also be reduced. Furthermore, the fraction of green electricity purchases eligible for a subsidy can be varied.

4.2 Supply-side government financial incentives for increasing the substitution of wind and solar power from that derived from fossil fuel

Green electricity producers can be paid a subsidy on the value of their sales (via the grid) of electricity derived from solar and wind power. Other things being held constant, this is likely to increase their competitiveness with suppliers of non-green electricity. Normally, this will lower the market price for green electricity and may raise the economic surplus of suppliers of green energy, as is illustrated in the next section of this article. The level of the subsidy can be varied to manage the transition to greater reliance on wind power and solar power for electricity production.

Government financial support can also be provided for investment in equipment for electricity production from solar and wind power. Possibilities include subsidies for the purchase of equipment or tax concessions, for example, accelerated depreciation allowances and 'soft' loans.

Furthermore, R & D can help improve the development of the green energy sector and governments can provide support for these activities. The main research and development areas worthy of support seem to be those

- For developing more efficient and economical methods of generating electricity from solar and wind power;
- Those for discovering improved ways of storing electricity (or energy) obtained from solar and wind power; and
- Those for the development of more efficient and environmentally friendly ways of recycling material in batteries and extending their useful life.

Government support for these types of R & D can be justified because the negative environmental externalities associated with the use of those forms of green power are considerably less than for power derived from fossil fuels, and their use has superior sustainability consequences.

5. Additional economic analysis favouring government financial support for the increased use and supply of electricity from solar and wind power

It is worthwhile giving attention to the economic analysis of why it is socially desirable to provide government financial support for the production of electricity from solar and wind power. The basic reasons are:

- The negative environmental spillovers from the use of fossil fuels to produce electricity considerably exceed those from the generation of electricity by using solar and wind power; and
- Dependence on the latter resources for electricity production results in better sustainability outcomes than dependence on the former resources.

Note that the threat to sustainability of relying on fossil fuels to generate electricity arises in part because their use produces larger negative environmental spillovers than does dependence on solar and wind power. However, there are also negative environmental effects from the use of fossil fuels, especially coal, which are independent of the sustainability of the supply of these fuels. These include negative health effects, e.g. respiratory diseases arising from air pollution caused by fossil fuels. These can be severe.

The negative environmental spillovers associated with the production of electricity using wind and solar power tend to be low. However, the environmental consequences of this production depend on the location of the production units. For example, if solar panels are located on buildings (used for purposes other than supplying solar energy), their environmental impact is likely to be lower than when they are located on solar farms. In the latter case, significant removal of vegetation may occur, and existing ecosystems are altered. [3]

The whole chain of electricity production and distribution needs to be considered when assessing the environmental impacts of alternative forms of producing electricity. For example, the environmental effects of manufacturing equipment for producing electricity for solar and wind power should be taken into account. When this is done, the environmental costs of supplying electricity from solar and wind power are likely to be much lower than for depending on fossil fuels, particularly coal, for this purpose. For example, the environmental costs of mining and transporting coal are often high and coal combustion adds considerably to air pollution and global warming. However, it might be noted that there are also likely to be some negative environmental consequences from the supply of batteries intended to store electricity generated by solar and wind power. Furthermore, the whole life cycle of units involved in electrical supply needs to be taken into account when assessing environmental costs. These include those costs associated with their decommissioning. The full extent of all these environmental costs have yet to be measured.

The environmental costs involved in battery production include those which result from mining materials for batteries, their manufacture, the recycling of the components of batteries and in many cases, the disposal of batteries in solid waste (King, Boxall, and Bhatt 2018; Messenger 2018). A high proportion of lithium batteries are dumped as solid waste globally and the percentage is high in Australia (King, Boxall, and Bhatt 2018). There is some risk of water and soil contamination as a result. Overall, however, the environmental costs of relying

[3] In some cases, visual amenity is negatively impacted. Also, solar farms located on valuable agricultural land (or land valuable for alternative uses) can have a high economic opportunity cost.

on a combination of solar and wind power for electricity production and storage using batteries can be expected to be substantially lower than relying on fossil fuels, especially coal, for this purpose.

Fig. 1 provides an analytical illustration (example) of the increase in social benefits which can be attained by subsidizing the supply of electricity obtained from the use of solar and wind power.[4] Line DD represents the demand for this type of electricity and line AS indicates the private supply (equals the private marginal cost) of electricity produced from solar and wind power. It is assumed that the extra social marginal benefit of supplying electricity from solar and wind power compared to supplying it from fossil fuels, is equivalent to AB dollars per unit of energy produced. Taking this into account, the marginal social cost of supplying electricity from solar and wind power is shown by the line BS′. There may still be some negative externalities from the supply of electricity from solar and wind but these are supposed to be negligible. Note that the comparative social economic benefit of supplying electricity from solar and wind power (rather than fossil fuel) could include an allowance not only for the lower environmental spillovers involved but also for the better sustainability outcomes associated with the use of solar and wind power.

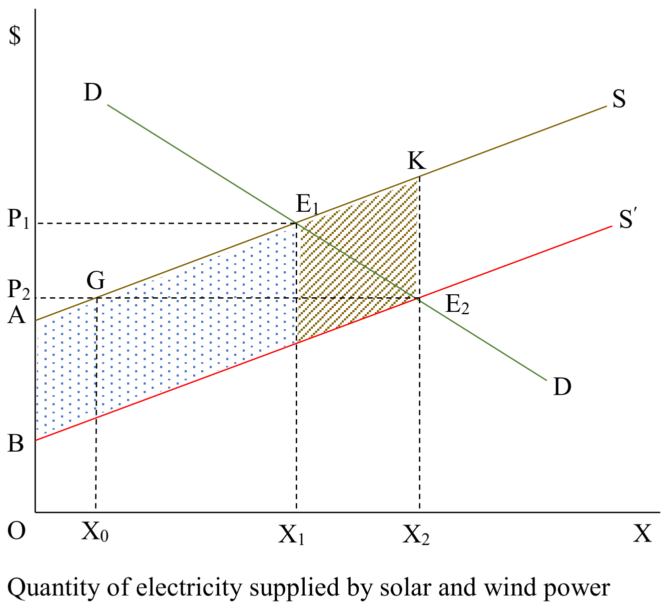

Fig. 1 An analytical illustration of the case for providing government financial support for the supply of electricity from solar and wind power. See the text for the interpretation of this diagram.

In the absence of a subsidy for the supply of electricity from solar and wind power, the market for this source of electricity in the case shown in Fig. 1, comes into equilibrium at E_1. The price per unit of this electricity is then P_1 and its market supply is X_1. However, this is not a socially ideal situation. A superior outcome would be for this market to be in equilibrium at E_2. This would result in additional social economic benefits indicated by the area of the hatched quadrilateral. This could be achieved by paying a subsidy of AB dollars per unit on all

[4] It is supposed that at this stage of development, electricity production from solar and wind power (particularly the former) is still in the infant industry phase. However, electricity supply from these sources can be expected to become increasingly competitive with the supply of fossil fuels in some parts of the world.

electricity produced by solar and wind power and sold on the market.

The subsidy paid to suppliers of electricity obtained from solar and wind power could be interpreted as being a payment for environmental services provided by this economic sector. Nevertheless, the economic benefits of this subsidy in the case illustrated (which is a normal case) are distributed in the short-run between buyers of green electricity and suppliers of it. As a result of the subsidy, the buyer's economic surplus rises by an amount equivalent to the area of the quadrilateral $P_1P_2E_1E_2$. Prior to the subsidy, the economic surplus of suppliers of green electricity is equal to the area of triangle AE_1P_1. After the subsidy, it is equal to the area of triangle P_2BE_2. The latter triangle is greater in area than the former one because the distance BP_2 exceeds AP_1 and also the distance P_2E_2 exceeds P_1E_1. Market forces influencing the incidence of the subsidy are similar to those of a tax on production (see Tisdell and Hartley 2008, , pp. 117-120).

It is possible to pay a smaller amount of subsidy to producers of green electricity and still reach the short run market equilibrium corresponding to E_2 in Fig. 1. This can be achieved by paying a subsidy per unit of output which rises with the volume of production. For example, if a miserly payment is desired in the case illustrated in Fig. 1, the subsidy on each unit of production could be paid on each unit of output greater than X_0, rising by an amount on each additional unit of production equal to the difference between the line GK and GE_2. However, this can result in green electricity producers having a lower economic surplus than before the subsidy (compare Duncan and Tisdell 1971). The negative effect of this miserly policy (or a similar one) is that by failing to raise the economic surplus of supplies of green electricity, it reduces their incentive to invest in the development of this sector and restrains the entry of new firms into this sector.

Taking this observation into account, using comparative static market analysis to analyse social desirability of subsidizing the supply of green electricity provides a limited policy perspective. This is because it does not pay enough attention to economic dynamics. Nevertheless, static equilibrium analysis is widely relied on, for example, by Liski and Vehviläinen (2016).

In my view, infant industry considerations (List 1856) provide the strongest case for government financial support for the development of green electricity production. Eventually, this support is likely to be no longer necessary once the green electricity sector has developed sufficiently. As this sector becomes increasingly self-reliant economically, the sustainability and environmental externality benefits of greater dependence on green electricity will then flow on to the population at large.

Nevertheless, in transiting to greater reliance on green power for electricity production, the reliability of the whole electricity system must be taken into account, that is, its ability to meet fluctuating electricity demands. In the absence of adequate storage facilities for energy derived from solar and wind power, increasing reliance on these energy sources reaches a point (if electricity is supplied via the grid system) where the system can have insufficient electricity to always meet demands. As a result, blackouts and brown outs can occur.

6. Concluding comments

There are other ways that governments could encourage the use of solar and wind power for supplying electricity. These include the imposition of taxes on the supply or purchase of electricity obtained from fossil fuels and the use of tradeable permit systems for the generation of electricity from these sources. In normal circumstances, these will increase the price of electricity to buyers and may result in a political backlash from buyers and suppliers of electricity generated by the use of fossil fuels. Therefore, even if there is an economic case for making the polluter pay, politics may limit the adoption of this approach. Vested special interests can be expected to lobby against it. However, as the green energy sector expands and the fossil fuel sector declines, the balance of political power can be expected to alter in favor of green energy. In practice, economic policies cannot be divorced from political realities.

The question has arisen also of whether or not users of electricity should continue to depend on the electricity grid for their supplies. In some regions, it is possible for some households and businesses to go off grid and collect solar power by relying on solar panels and storing electricity by using batteries. This tends to make electricity grids less economic and can impose extra costs on those who continue to rely on electricity grids for their supply of electricity, including households and businesses that buy and sell solar energy via the grid. The economics of off-grid self-efficiency in electricity supplies requires future research.

This short article has presented a case in favour of governments providing financial support for the increased use of solar and wind power as a means for supplying electricity. In doing so, it has suggested an improved classification of energy resources for sustainability assessments, and has identified the nature of sustainability concerns about the use of different energy resources for generating heat and power, particularly electricity. In this regard, it has focused on the use of solar and wind power in comparison to the use of fossil fuels, especially coal. Different types of government financial incentives which can be employed to increase the demand and supply of electricity from solar and wind power were outlined. Furthermore, an illustrative example was provided of the social economic case for subsidizing the supply of electricity obtained from solar and wind power.

Nevertheless, at present, there are limitations on the extent to which it is possible to rely on the supply of electricity from solar and wind power. Storage constraints are one such restriction but these may be overcome in due course. Also some regions of the world are not well placed to produce electricity from solar and wind power. In some areas, wind velocities are low and unreliable, and while some regions are blessed with a lot of regular sunlight, this is not so in all places on earth. Solar and wind power resources are geographically unevenly distributed. The extent to which regions can import green electricity also varies. These factors all limit the ability of humankind to depend on solar and wind energy for their electricity requirements. Despite this, there is still considerable scope in many countries and regions to make increased use of solar and wind power for electricity production and thereby raise social welfare by making economic development more sustainable and reducing the magnitude of adverse environmental externalities (costs) associated with electricity production

7. References

Duncan, R, and Clem Tisdell. 1971. Research and technical progress: the returns to producers. *Econ Rec* 47:124-129. http://ideas.repec.org/a/bla/ecorec/v47y1971i117p124-29.html.

Hunt, T. 2019. *Is There Enough Lithium to Maintain the Growth of the Lithium-Ion Battery Market? Are we nearing peak lithium?* Greentech Media 2015 [cited 9 January 2019]. Available from https://www.greentechmedia.com/articles/read/is-there-enough-lithium-to-maintain-the-growth-of-the-lithium-ion-battery-m#gs.IGpbj3tI.

Jevons, W.S. 1865. *The Coal Question*. London: Macmillan.

Joskow, Paul L. 2011. Comparing the Costs of Intermittent and Dispatchable Electricity Generating Technologies. *Am Econ Rev* 101:238-241. http://www.jstor.org/stable/29783746.
King, S., N.J. Boxall, and A. Bhatt. 2018. Lithium battery recycling in Australia. https://www.csiro.au/~/media/EF/Files/Lithium-battery-recycling-in-Australia.PDF?la=en&hash=924B789725A3B3319BB40FDA20F416EB2FA4F320.
Liski, M., and I. Vehviläinen. 2016. Gone with the Wind? An Empirical Analysis of the Renewable Energy Rent Transfer Cambridge: University of Cambridge.
List, F. 1856. *Das Nationale System der politischen Oekonomie (The National System of Political Economy)*. Translated by G. A. Matile. Philadelphia, USA: J B Lippencott and Co.
Meadows, Dennis, H., J. Ronders, and W. Behrens. 1972. *The Limits of Growth: A Report for the Club of Rome's Project on the Predicament of Mankind*. New York: Universe Books.
Messenger, B. 2019. *In depth: Lithium battery recycling - the clean energy clean up*. Waste Management World 2018 [cited 9 January 2019]. Available from https://waste-management-world.com/a/in-depth-lithium-battery-recycling-the-clean-energy-clean-up.
Mohr, Steve, Damien Giurco, Monique Retamal, Leah Mason, and Gavin Mudd. 2018. Global Projection of Lead-Zinc Supply from Known Resources. *Resources* 7:17.
Narins, Thomas P. 2017. The battery business: Lithium availability and the growth of the global electric car industry. *The Extractive Industries and Society* 4:321-328. https://doi.org/10.1016/j.exis.2017.01.013.
Ritchie, H., and M. Roser. 2018. *Fossil fuels*. Our World in Data no date [cited 20 December 2018]. Available from https://ourworldindata.org/fossil-fuels.
Rutledge, David. 2011. Estimating long-term world coal production with logit and probit transforms. *Int J Coal Geol* 85:23-33. https://doi.org/10.1016/j.coal.2010.10.012.
Singh, B.R., and O. Singh. 2012. Global change of fossil fuel reserves adn climate change in the 21st Century. In *Fossil Fuel and the Environment*, edited by S. Kahn. London: IntechOpen.
The Greenage. 2019. *Are we facing a lithium shortage?* The Greenage 2017 [cited 9 January 2019]. Available from https://www.thegreenage.co.uk/facing-lithium-shortage/.
Tisdell, C A. 1997. The Environment and Sustainable Development in the Asia-Pacific: Views and Policies. *Asian-Pac Econ Lit* 11:39-55. 10.1111/1467-8411.00003.
Tisdell, C.A. 1982. *Microeconomics of Markets*. Brisbane: John Wiley.
Repeated Author. 2009. *Resource and Environmental Economics: Modern Issues and Applications*. Hackensack (NJ), London and Singapore: World Scientific.
Repeated Author. 2011. The production of biofuels: Welfare and environmental consequences for Asia. In *Climate Change and Growth in Asia*, edited by M. Hossain and E. Selvanathan. Cheltenham, UK and Northampton, MA, USA: Edward Elgar.
Tisdell, C.A., and K. Hartley. 2008. *Microeconomic Policy: A New Perspective*. Cheltenham, UK and Northampton, MA, USA: Edward Elgar.
White, A. 2018. Canberra's big stick hurts gentailers as nimble rivals rush to invest. *The Australian*, December 26, 13-14.
World Coal Association. 2018. *Where is coal found?* no date [cited 20 December 2018]. Available from https://www.worldcoal.org/coal/where-coal-found.

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