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Renewable energy in the equilibrium mix of electricity supply sources

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ABSTRACT

A method to derive the long-run supply curve for a given renewable energy source and technology is proposed. The method accounts for the spatial complexity arising from the distribution of the energy source and the energy transport infrastructure of the territory. The use of the resultant supply curve within the partial equilibrium competitive model for the design and evaluation of renewable energy support schemes and for the determination of optimal supply mixes is illustrated. A case study with the application of the method for wind energy in Rapa Nui (or Easter) Island is presented.

1. Introduction

Anthropogenic climate change has been called the greatest market failure the world has ever seen (Stern, 2007). It has been characterised as the greatest threat to future generations (Obama, 2015) and is viewed by the public as a top global concern second only to terrorism (Pew Research Center, 2015). Renewable energy support schemes are one of the main interventions undertaken by countries to address the problem. This is because the world's energy sector is the largest contributor to greenhouse gas emissions (IPCC, 2014), it is expected to continue growing with economic development (Bruns et al., 2013), and the belief exists that there is ample space in it for efficient emission abatement (IPCC, 2011). But the unexpected termination or drastic curtailment of national schemes in countries like Spain, the UK and Germany in the last years endorse the view that an improved method to set up such schemes is needed. Misleading regulation signals brought about by inadequate support schemes result in sub-optimal levels of renewable energy infrastructure investment, of fiscal expenditure, of technical development efforts, of carbon reduction targets and of energy prices, bringing economies farther away from the economically efficient energy matrix.

Increasing international pressure for energy subsidy reform (Coady et al., 2015), growing hunger for energy of developing economies (Wolfram et al., 2012; King et al., 2015), the advent of the electric car and the pressing commitments made at the 2015 UNFCCC Paris conference foretell demanding times for policy makers working on renewable energy schemes. The IPCC (2014) estimates that fulfilling by 2100 the main goal of the Paris Agreement[1], would require anthropogenic greenhouse gas emissions to be by 2050 in the range of 60 to 30% those of 2010. There is little doubt that these challenges require major transitions in the worldwide energy system (Van Vuuren et al., 2015), a key outcome to our subsistence on Earth.

Energy supply can be classified as coming from non-renewable and from renewable sources. The supply mix of the non-renewable part can be optimised using a set of criteria based on least cost or profit maximisation. However, the optimal supply mix of the renewable part is more complex to determine, as it depends on each territory's potential for that kind of generation. It is here where energy policy may fail to provide proper regulation, hence one of the reasons for the constant need for revision of support schemes. In fact, the territorial potential for incorporating renewable energy becomes the central problem when studying policy interventions to favour the development of

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[1] The main goal of the Paris Agreement consists in "holding the increase in global average temperature to well below 2 °C above pre-industrial levels" (UNFCCC, 2015).

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0140-9883/

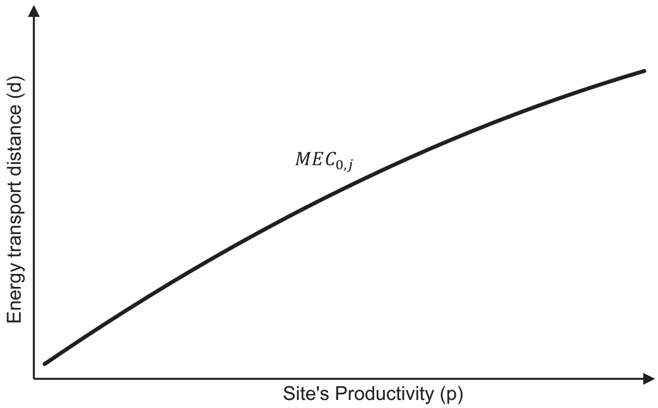

Fig. 1. Hypothetical isoprofit $MEC_{0,j}$ curve.

some generation means over others. The knowledge of this territorial potential should enlighten society's decision about what policy objectives (e.g. emission targets, supply cost, or the proportion of energy to be imported) are desirable, achievable and optimal.

In this article, I propose a way to determine the supply-demand equilibrium composition of the electricity generation mix of a territory in the presence of renewables that need to be "harvested" over large areas such as wind or solar energy. The model proposes a "positive" approach to solve the problems of how much "green" energy is achievable under a given set of prices and where it should be located. By capturing the effect of incentives at the investor's cash flow level and working its way up to the supply-demand equilibrium, the model also provides a base for evaluating policy interventions that should be done (if any) to market-based economies in order to achieve the policy objectives set out by society. I also put forward the idea that support schemes should be designed taking into account the long-run supply curve of renewables which is highly specific to each territory or country.

Although the model is of greater use when applied to large regions or complete countries, where it could help refine policy schemes that affect the allocation of larger investment amounts, a case study of its application to the isolated electrical system of Easter Island is presented due to its reduced size and simplicity.

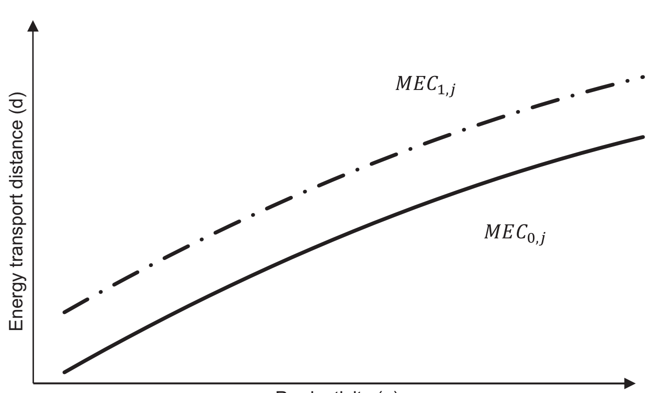

Fig. 2. Displacement of the isoprofit curve as a result of an increase in the selling price of energy.

2. Theoretical framework

Modelling the expansion of generating infrastructure has been traditionally approached by solving an operation and investment cost minimisation problem subject to meet demand. Later, as electricity markets were liberalised, modelling development efforts shifted towards a profit maximisation approach. Game Theory has been especially useful for this approach as it allows to investigate the strategic behaviour of generation companies as they try to maximize their profits affecting each other. Among the most urgent improvements to these tools and procedures, is the incorporation of the geographical scope in order to account better for the fastest-growing low-CO2 generation technologies such as wind and solar photovoltaic (Ryan et al., 2011; Power Systems Engineering Research Center, 2009).

Other methods such as portfolio theory, scenarios and investment rate projections can be used successfully for various purposes within the energy sector, but they are limited when it comes to predict the growth of renewables as they don't attend properly the geographical constraints in which renewables develop.

The partial equilibrium competitive model is probably the most widely used tool to study prices and it provides a framework to the problem of determining optimal sets of electricity supply sources and support schemes for renewables. A territory-specific long-run supply curve for a given renewable source is a result of the spatial complexity arising from the distribution of the energy source and the energy transport cost, themes central in classic spatial economic theory.

If we derive such long-run supply curves for the different renewable energy technologies in a territory, we could obtain a set of supply-demand equilibrium quantities of electricity to be provided by say wind, photovoltaic, biomass or ocean derived energy technologies. The gap between the sum of renewable energy supply and total demand could be met by traditional means of generation, after giving attention to the relevant (technical, environmental, social, etc) restrictions. In this way, it is possible to obtain an economically efficient energy matrix.

2.1. The ISOPROFIT model

The ISOPROFIT model (Faúndez, 2007) says that for a fixed set of prices "$i = 0$", a given renewable energy technology and source "j" (such as wind, biomass, solar radiation, etc.) and a given region, the space available for the development of renewable energy projects can be delimited by a curve of constant marginal efficiency of capital ($MEC_{0,j}$) in the energy transport cost - productivity space. This MEC_{0j} corresponds to the current available rate of return available to investors, and can be called isoprofit $MEC_{0,j}$ curve. Using transport distance as a proxy for transport cost, Fig. 1 shows the hypothetical isoprofit curve $MEC_{0,j}$.

Distance "d", may be expressed for example in kilometres and is the distance that energy should be transported from the source to the selling point.[2] Depending on the source, productivity "p" may be expressed as an average wind speed or solar radiation per unit of area, kilograms per hectare of biomass or, more generally, as a measure of energy per unit of area ($\text{MWh} * \text{m}^{-2}$) that is possible to extract in a given period.

In line with investment theory, investors should "colonise" the space available for development of new projects starting from the lower right corner of Fig. 1 and continue until they reach isoprofit $MEC_{0,j}$. Spatial economists would say that rent of projects located over $MEC_{0,j}$ is zero.

[2] The use of Euclidean transport distance as a proxy for energy transport cost is made in order to keep this presentation simple, but it's not a requisite for the application of the model.