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Have fossil fuels been substituted by renewables? An empirical assessment for 10 European countries[☆,☆☆]

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ABSTRACT

The electricity mix worldwide has become diversified mainly by exploiting endogenous and green resources. This trend has been spurred on so as to reduce both carbon dioxide emissions and external energy dependency. One would expect the larger penetration of renewable energies to provoke a substitution effect of fossil fuels by renewable sources, in the electricity generation mix. However, this effect is far from evident in the literature. This paper thus contributes to clarifying whether the effect exists and, if so, the characteristics of the effect by source. Three approaches, generation, capacity and demand, were analysed jointly to accomplish the main aim of this study. An autoregressive distributed lag model was estimated using the Driscoll and Kraay estimator with fixed effects, to analyse ten European countries in a time-span from 1990 until 2014. The paper provides evidence for the substitution effect in solar PV and hydropower, but not in wind power sources. Indeed, the generation approach highlights the necessity for flexible and controllable electricity production from natural gas and hydropower to back up renewable sources. Moreover, the results prove that peaks of electricity have been an obstacle to the accommodation of intermittent renewable sources.

1. Overview

The demand for electricity is growing due mainly to population expansion, but also because of the continuous electrification of the residential, industrial, services and heating sectors. Electricity has been a major driver of economic growth (Hamdi et al., 2014; Omri, 2014), but it is essential that cleaner and green electricity sources should be introduced into electricity systems in order to reduce the effects of climate change, and to obtain sustainable development. In other words, if the shift towards electrification is made through the burning of fossil fuels to generate electricity, then the advantages of that shift are cancelled out. In fact, there is a growing debate about fossil-fuel-based electricity generation and its harmful effects on the environment. At the same time, these harmful effects on the environment could have negative consequences for economic growth and for societies as a whole (International Energy Agency, 2016a). Therefore, the diversification of the domestic electricity mix has been proposed to European (EU) countries. This complex struggle has been motivated by Directive 2009/28/EC of the European Parliament and of the Council, which proposes as objectives for 2020: (i) 20% reduction in EU greenhouse gas emissions; (ii) 20% of EU energy from renewable energy sources (RES); and (iii) 20% improvement in EU energy efficiency. In fact, the EU countries have been designing and implementing public policies to develop and increase the deployment of wind power, solar photovoltaic (PV), bioenergy and hydropower in their electricity production systems (Aguirre and Ibikunle, 2014; Polzin et al., 2015).

The IEA argues that the Paris pledges are mainly focused on the electricity sector, and on their scenario for 2040 of nearly 60% of new power generation capacity coming from RES (International Energy Agency, 2016b). The cleaner RES could increasingly replace fossil fuels, namely highly polluting oil and coal. Globally, the benefits of electricity production from RES are taken for granted. However, the characteristics of RES may be restricting their expected benefits, such as the reduction of carbon dioxide (CO_2) emissions, energy security and energy affordability. The EU countries have deployed high levels of wind power and solar PV, to meet the 20% goal of RES contribution to the energy supply, and they are on the right path, revealing a clear increasing tendency. Nevertheless, as RES increases, the expected decreasing tendency in the installed capacity of electricity generation from fossil fuels, has not been found. Despite the high share of RES in the electricity mix, RES, namely wind power and solar PV, are characterised by intermittent electricity generation. The increase in the

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installed capacities of intermittent renewable energy sources (RES-I) can be compatible with effective generation, but it can also increase idle capacity. So, it should be highlighted that this notion of idle capacity is quite different from traditional excess capacity.

The traditional concept of excess capacity, comes from the industrial economic field, and is sensitive to different points of view. Excess capacity is the set of resources available for firms producing goods or services, to mitigate the effects of demand uncertainty. The industrial economics literature also considers that excess capacity is a market competition strategy. In contrast, none of these strategies is appealing for RES-I producers. The lack of demand, or demand uncertainty, is of no great concern, since they have priority dispatch to the grid. Furthermore, the guaranteed prices over long-term contracts, given by feed-in tariffs, makes excess capacity a pointless market competition strategy for RES-I players. In conclusion, the unexploited installed capacity of RES-I is a consequence of the absence of availability of natural resources, rather than the lack of electricity demand or competition strategy behaviour (Flora et al., 2014). The electricity production systems have maintained or increased the installed capacity of non-renewable energy sources (NRES) to overcome the idle phenomenon of RES-I. Indeed, electricity production systems have required the standby capacity of fossil fuels to satisfy demand when demand is high and renewable source availability is low. This procedure often generates an installed overcapacity of fossil fuels, and therefore also generates economic inefficiencies. To overcome this economic inefficiency, cross-border market capacities have been expanded, mainly in EU countries. They have been essential for managing the surplus and scarcity of electricity production from RES, exporting excess RES in the electricity grid, and importing excess RES from other countries to meet the demand at a lower cost (Fig. 1).

The inability of RES-I to satisfy high fluctuations in electricity consumption on its own constitutes one of the main obstacles to the deployment of renewables. This incapacity is due to both the intermittency of natural resource availability, and the difficulty or even impossibility of storing electricity on a large scale, to defer generation. As a consequence, RES might not fully replace fossil sources, and recent literature has been analysing the causal relationship between RES and NRES, but only from the perspective of production (Al-mulali et al., 2014; Dogan, 2015; Salim et al., 2014). The literature proves the existence of a unidirectional causality running from RES to NRES (Al-mulali et al., 2014; Dogan, 2015; Salim et al., 2014). This unidirectional causality proves the need for countries to maintain or increase their installed capacity of fossil fuel generation, because of the characteristics of RES production. Furthermore, the literature reaches no consensual conclusion on the substitution effect between electricity production from RES and NRES (Al-mulali et al., 2014; Saidi and Ben Mbarek, 2016; Salim et al., 2014). Thus, integrating and promoting RES should not be done just through building new wind farms and PV plants. This solution promotes inefficiency in resource allocation, mainly because RES intermittency does not allow the full exploitation of the installed capacity. Flora et al. (2014) argue that the development of more efficient technology is the solution for overcoming the intermittency phenomenon, and more accurately incorporating RES into the electricity mix. Nonetheless, recent literature claims that the full integration of RES, into electricity systems, should be done by the disciplining consumption (e.g. Meyabadi and Deihimi, 2017). Demand-side management (DSM) could provide virtual resources to accurately accommodate RES-I. Moreover, shifting electricity demand towards periods with a high availability of natural resources also enables RES integration (Meyabadi and Deihimi, 2017).

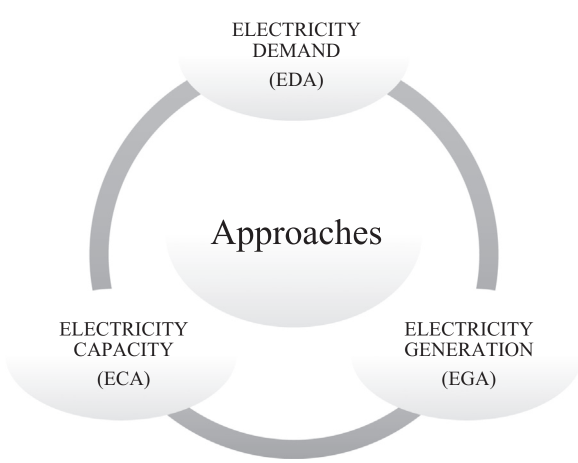

Fig. 1. Approaches applied to explain electricity generation from fossil fuels, hydropower and RES-I.

These facts together constitute the main motivation of this research, which aims to answer the following research questions: (i) does the installed capacity of wind power, solar PV, and bioenergy provoke similar effects on NRES electricity generation?; (ii) is there a substitution effect between hydropower and other RES (wind power, solar PV, bioenergy, geothermal, tide, wave and ocean) and fossil-source electricity generation?; (iii) how is the system dealing with demand peaks? To do this, this paper empirically assesses ten EU countries' electricity production systems, over a time-span from 1990 to 2014, with an autoregressive distributed lag (ARDL) methodology. This methodology allows the short-run dynamics, and the long-run equilibrium of the three approaches applied jointly, to be studied, namely the *electricity capacity approach* (ECA), the *electricity generation approach* (EGA), and the *electricity demand approach* (EDA). The literature that has studied the relationships between NRES and RES, only focused on their electricity generation, and avoided the consequences of installed capacities. However, the substantial difference between the installed capacity of RES and its effective generation must be considered, because of an undesirable phenomenon, namely that of idle capacity. This substantial difference has motivated some literature working on the drivers of the capacity factor and idle capacity (Boccard, 2009; Flora et al., 2014). This research provided new insights into earlier literature, which studied the interactions between electricity sources, and into the literature that studied the RES capacity factor and idle capacity. Accordingly, this paper contributes to the literature by not only analysing the relationships between RES and NRES electricity production, but also, by considering the dynamics adjustments, and the long-run equilibrium of the interactions between RES electricity capacity and NRES electricity generation. This paper also provides new insights by analysing the interactions between the characteristics of electricity consumption and maintaining fossil fuels in the electricity mix. Therefore, the combined econometric approach proposed, with the ECA, EGA, and EDA, represents the barriers and the difficulties that electricity management systems encounter in effectively matching electricity supply with demand, and compared to earlier literature, represents a novel approach.

Firstly, the ECA aims to identify whether additions to installed capacity can cause an increase in electricity generation. The decision to assign licensing is focused on capacity and not on generation. However, additional capacity of RES-I, namely wind power and solar PV, does not correspond to the actual capacity used, and thus does not allow electricity generation from fossil fuels to be abandoned. As the installed capacity of bioenergy has the potential to substitute fossil fuels, because of its flexible electricity generation and storage facilities, it was also scrutinized. Secondly, the objective of EGA is to analyse electricity generation from RES. Because the policy decisions of the European Commission have been focused on the contribution of RES to the energy supply, it is crucial verify whether there is a substitution effect between electricity generated from RES and NRES. In fact, the EGA approach could show whether the share of electricity generation from hydropower, and other RES, have been effective in reducing the burning of fossil fuels to produce electricity. Lastly, the EDA aims to identify the effects on fossil fuel dependency in electricity production systems, of