INTERACTIONS OF ELECTRICITY SUPPLY, DEMAND, EMISSIONS, AND DIVERSIFICATION: A DAILY ANALYSIS OF FRENCH ELECTRICITY SYSTEM

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I. Overview

The coming era of energy transition will require a shift from conventional sources to renewable energy sources (RES), within a context of the increasing electrification of economies. This energy transition will face several challenges and barriers, such as peaks in electricity demand. Thus, it is imperative to provide careful guidance on policy that will produce flexibility in electricity systems, not just in terms of supply, but also in terms of demand. The diversification of domestic electricity mixes must not be a merely theoretical goal, it is essential to analyse and understand the conditions of both the supply and demand sides to achieve successful diversification. Decisions on energy cannot just be about consuming and supplying more electricity, the crucial decisions concern what sources to develop, the consequences of deploying each source, the consequences of peak consumption, and how to shift consumption to best exploit production from intermittent renewable energy sources (RES-I).

High levels of RES-I deployment have shown the crucial importance of matching electricity demand with supply availability. Thus, recent literature has presented one solution, demand-side management (DSM), to enable and enhance the flexibility of electricity systems through the demand side (Meyabadi et al., (2017)). The main objectives of DSM are to shift electricity consumption patterns, and raise consumer concerns about the harmful effects of electricity generation on the environment (Alasseri et al., (2017); Bahl et al., (2017); Meyabadi et al., (2017)). DSM programmes could be helpful in achieving the desired transformations in the electricity load shape, namely peak-clipping, valley-filling, and the adaptation of consumption to the availability of natural resources, such as wind and solar (Alasseri et al., (2017); Bahl et al., (2017); Meyabadi et al., (2017)). Therefore, the application of DSM measures, along with the advent of smart grids, and distributed energy sources, has been indicated as a way of mitigating the harmful effects of the electricity sector on the environment, energy access, energy affordability, and energy security.

These issues constitute the main motivation for this paper. In fact, this research intends to contribute to the literature, by identifying the conditions needed to successfully diversify the electricity mix. The main and innovative contributions of this paper are thus: (i) its focus on the French case of planning a nuclear phase-out, by assessing its transition from nuclear power to RES; (ii) highlighting the appropriateness of the disaggregated analysis of electricity demand levels and electricity sources; (iii) the empirical evidence provided about key factors to successfully integrate RES, diversify the electricity mix, and mitigate CO2; (iv) putting forward and discussing additional measures for DSM, to achieve an effective energy transition, without compromising sustainable development.

II. Methodological approach

In this paper, a Vector Autoregressive (VAR) model was used, to analyse electricity supply and demand in France from 1 January 2012 until 28 February 2017, revealing the daily relationships between: electricity sources, disaggregated into wind power, solar PV, biomass, hydro power, coal, oil, natural gas, and nuclear power; the differing periods of electricity demand levels, namely morning peak, off-peak, and night-peak consumption; the ratio between electricity imports and exports; wholesale electricity market prices; CO2 emissions from electricity production; and the degree of diversity in the electricity mix, represented by the Shannon-Weaver Index. Thus, this research could break new ground and contribute to the literature, by answering the following research questions: (i) how does France meet its oscillating daily electricity demand, using rigid nuclear production and RES-I generation?; (ii) what has been the daily role of fossil fuels in the French electricity production system?; (iii) how effective has RES been in substituting both fossil and nuclear sources, in the daily mix?; (iv) what have been the effect of the electricity mix on daily CO2 emissions?; (v) what electricity source has been effective in promoting diversification?; (vi) how are the daily peaks being satisfied?; (vii) what have been the consequences of daily demand peaks in reducing CO2 emissions and diversifying the electricity mix?; and (viii) how can DSM policies be effective in reducing electricity consumption?

III. Results and discussion

The assessment of the daily dynamics between consumption levels, electricity sources, CO2 emissions, and electricity mix diversification, proved to be important for identifying opportunities to improve the energy transition, in France. The results have highlighted opportunities to deploy RES-I without compromising either economic activity or the electricity market, such as: (i) the implementation of wind power to satisfy consumption in off-peak and night peak periods; (ii) the deployment of solar PV to meet consumption in morning peak periods; (iii) the use of biomass, and hydropower with pumping systems, to replace the backup role played by fossil fuels. However, it will also be necessary to stimulate changes in consumption to successfully transition from both nuclear power and fossil fuels to RES. In particular: (a) shift night peak consumption to off-peak periods; (b) generate an incremental reduction in overall consumption through energy efficiency or energy saving policies; and (c) adapt consumption to RES-I production, namely by matching morning peaks with solar PV generation, and off-peak and night peaks with wind power production.

In France, the consumption in morning peaks seems to be rational and desirable. In fact, there is a daily load transfer from the night peak towards the morning peak intended to exploit solar PV production. Besides this, the high share of RES in morning peaks, has allowed a reduction in the use of both nuclear power and fossil fuels, which has also decreased CO_2 emissions. Thus, a higher penetration of solar PV should be pursued. Firstly, the lower capital investments needed to deploy solar PV, on a small and medium scale, could create decentralized employment, dispersed electricity generation and, in particular, promote the generation of electricity for self-consumption. Secondly, large-scale solar deployment along with energy storage systems, such as pumping systems, batteries, and electric vehicles, should be used to defer excess PV generation to periods when fossil fuels are currently required, namely night peaks.

The night peaks have had harmful effects on the environment, because of the use of fossil fuels to meet the demand. However, the availability of natural resources, namely wind, coincides with both the off-peak and the night peak periods. Therefore, France has an opportunity to explore this endogenous resource, which could exert a positive effect on the economy, and decrease electricity prices during peak night periods. The transition to using wind power could be quite complex, so the economy ought to be prepared to: (i) increase the installed capacity and the capacity factor of wind power generation; (ii) reduce electricity consumption during night peaks, through policies of energy saving and efficiency; and (iii) transfer peak night loads to off-peak periods. Indeed, the results highlight that a diversified electricity mix, using RES, could easily be achieved in off-peak periods, i.e. with a smoothed electricity demand curve. Nonetheless, the advent of smart grids, information systems, and generation prediction, could be used to transmit the availability of wind power, through price signals, to the economy. Residential consumers could then adapt their consumption to the power generated by wind.

IV. Conclusions

The consumption in France, which is constituted mainly by residential consumption, has been problematic for the management of the electricity system. High peak consumption, mainly in night peaks, has increased the need for flexible plants to instantaneously match supply with demand. In fact, this match has been made through fossil fuels. Moreover, this necessity has led to the de-activation of the rigid base load source in France: nuclear power. Therefore, DSM programmes are needed to alert French consumers to the harmful effects of the electricity sector for the environment, and to encourage them to incorporate RES. It is important that the rigid patterns of consumption and the transfers of loads from off-peak to night peak periods, highlighted in this research, are prevented through price signals and price responsive programmes.

French electricity system has demonstrated a high capacity to substitute both nuclear power and fossil fuels with a portfolio of RES-I and controllable RES, such as biomass and hydro power. However, on the demand side, France still has several barriers and challenges in its path. This research provides considerable evidence that incorporating RES into the national electricity system requires a contribution from the demand side. Indeed, the demand side is critical for better matching the time of consumption with the time of generation, which will vary according to the availability of sun and wind. Electricity demand cannot be dissociated from periods of generation. Thus, the government and policymakers should intervene, and design DSM programmes to provide the electricity market with a new balance between flexible demand and available green supply.

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