ENVIRONMENTAL IMPACTS OF REDISPATCHING IN THE DECARBONIZED ELECTRICITY SYSTEMS

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Overview

In the market clearing of the pan-European day-ahead electricity market, in most cases only network congestions in cross-border relevant network elements are considered. This is often referred to as zonal pricing, with in most cases bidding zones being equal to national territories. Potential network bottlenecks within countries (i.e., bidding zones) are ignored. This simplification of the representation of the network in the market clearig becomes more problematic in recent years (see e.g., Eicke and Schittekatte (2022)). An important reason is that the rapid replacement of conventional generation technologies by renewable energy sources (RES) entails relevant changes in the electricity flows through the networks, while the expansion of networks is a slow process. Network flows are changing as RES generators are not necessarily sited at the same locations of historical generators and that RES production profiles are highly dependent on weather climate conditions: wind, sun or hydrological cycles. Consequently, both the transmission system operators (TSO) and the distribution system operators (DSO) more frequently need to alter the generation, load pattern, or both, after the day-ahead market clearing in order to change physical flows in their grids and relieve physical congestions to ensure system security. In Europe, these measures are known as redispatching and their costs are socialized across all the customers connected within each bidding zone.

There are many theoretical and empirical analysis about the potential impact of RES on the grid congestions (Costa-Campi, 2020), the corresponding volumes of needed redispatched energy, and the costs of such actions (Joos, 2018; Schermeyer, 2018). However, and up to our knowledge, the literature has not empirically assessed the impact of increasing redispatch actions on CO2 emissions. More specifically, RES generators often replace polluting technologies in the day-ahead market clearing but, due to grid congestions, redispatch actions can result in curtailing RES and starting up or increasing the output of a polluting generator. In such case, the environmental benefits from RES are a function of the need to perform redispatch and the technologies that are used to perform such redispatch.

In this research, we analyze the relationship between higher RES productions in the day-ahead market and potentially increased CO2 emissions via redispatch actions. To do so, we use the day-ahead hourly scheduled energy data from the Spanish market operator, namely OMIE, and between 2019-2021. Spain is a representative case due to its high share of RES in the gross annual electricity consumption (42.9% in 2021), and the low cross border capacity with the rest of Europe continental. Results might be very interesting for countries that are in an earlier stage in the decarbonization of their generation mix. In Spain, redispatching accounts a relevant cost for consumers (249M€ in 2019 and 500M€ in 2020), and an important share of CO2 emissions from the power sector: 6.3% in 2019, 11.4% in 2020 and 9.2% in 2021. In our estimations we find a positive relationship between higher wind and photovoltaics production in the day-ahead market and higher CO2 emissions in the redispatching processes. They account between +0.0160 and +0.00310 tn of CO2 by each additional MWh of wind or solar.

Methods

The empirical approach is an ARIMA time-series estimator, where variables are differentiated to ensure their stationarity and the lagged endogenous variable is included to capture the time dynamics. Our endogenous variable is the hourly CO2 emissions associated to the redispatched energy and the explicative variables correspond to the daily base operating schedule for each technology and before redispatching. Data comes OMIE and covers from 2019 to 2021.

We perform three different estimations, one for each year (2019, 2020 and 2021) as there are annual differences in this period. First, photovoltaics and wind capacity significantly increases: +212% up to 15.048MW and +20% up to 28.175MW. Second, coal capacity decreases -62,5% up to 3.764MW. Third, 2020 includes the pandemic containment during some months, which clearly affected the economic activity and the national electricity demand. Fourth, the average wholesale price is quite heterogeneous (47,78€/MWh in 2019, 33,95€/MWh in 2020 and 111,97€/MWh), which determine the technologies operating at each time. Finally, the Spanish TSO is on-going commissioning new grids and substations precisely aimed to avoid redispatching.

Results

In our results, we find that higher RES productions in the day-ahead energy schedule induce higher CO2 emissions in redispatched energy: each additional MWh of wind increases redispatching emissions between +0.00571 and +0.00750 tn of CO2, and each additional MWh of photovoltaics between +0.0160 and +0.00310 tn of CO2. Considering the CO2 emission factors of pollutant technologies, we find the following average ratios of upward redispatched energy to RES: +1MWh of combined cycle by 119MWh of photovoltaics, +1MWh of combined cycle by 65MWh of wind, +1MWh of coal by 306MWh of photovoltaics, and +1MWh of coal by 127MWh of wind.

These positive correlations highlight that integrating RES in the power system induce relevant indirect CO2 emissions via redispatching actions. There are several explanations: (i) some RES should be downward redispatched owing to grid bottlenecks and the corresponding deficit of generation is replaced by pollutant technologies; and (ii) alternative synchronous generators, made of pollutant technologies such as coal and combined cycles, should be upward redispatched to ensure the grid system stability or to control the network voltage. If so required, there might be a surplus of generation that also entails curtailing RES. In all these cases, curtailing RES means a waste of clean resources since storage is not widely implemented. We also find that higher generation from combined cycle or coal in the day-ahead energy schedule saves CO2 emissions in the subsequent redispatched productions energy: each additional MWh of combined cycle saves between -0.00417 and -0.0360tn of CO2, and each additional MWh of coal saves between -0.134 and -0.276tn of CO2. This shows that some of the day-ahead scheduled energy is downward redispatched with their corresponding savings on the CO2 emissions.

Conclusions

Our results highlight that achieving a full clean decarbonized generation mix requires addressing specific operational challenges as redispatching, which clearly represent relevant environmental and economic costs for consumers. In this paper, we identify the environmental benefits from RES to be conditional upon the availability of the grid and the way that redispatch is performed. The relevance of these findings will only become more important with more RES in the generation mix and increasing volumes of redispatch actions under the status quo market design and progress in grid expansion. In this context, there are several policy recommendations aimed to limiting the need for redispatch and the "greening" of redispatch actions.

First, the regulatory framerwork should provide geographical incentives to efficiently locate RES and avoid concentrating them, such as including more locational granular pricing by having smaller bidding zones or locational incentives in future RES auctions, including regional Use of System (UoS) charges or deep connection charges. As such RES developers will be better informed about the trade-off between maximising their generation and grid investment needs. Second, consumption should participate to redispatch in equal footing than generation in redispatching. Demand response and storage would be an efficient choice to consume a surplus of RES in specific heavily congested nodes, or to solve a deficit of generation instead of an upward redispatching of pollutant technologies. In this context, the Electricity Regulation (EU) 2019/943 already mandates that the redispatching of generation or demand response should be based on objective, transparent and non-discriminatory criteria, and it shall be open to all technologies, storage devices or demand response. Besides economic benefits of these assets providing redispatch, the environmental benefits should also be considered when developing redispatch markets. Third, RES should actively participate in the voltage control services, which would reduce the activations of synchronous generators for this aim. Obviously, the procurement of this service made by RES would increase the ancillary service costs, but this would be traded-off with lower costs and emissions associated to the redispatching processes. Fourth, future cost-benefit-analysis related to grid expansion shall also consider the environmental impacts of reduced need of redispatch. Not only the amount of avoided curtailment is relevant but also the amount of avoided upwards redispatch from potentially polluting resources. We quantify in this research the impacts and demonstrate that the accompanying emissions with redispatch actions are not trivial.

References

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