NUCLEAR OPERATIONS WITH A HIGH PENETRATION OF RENEWABLES: THE CASE OF FRANCE

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Overview

Most power systems around the world are engaged in a transition away from fossil fuels. In the past two decades, policy efforts have mostly focused on installing large amounts of wind and solar photovoltaic power plants. Indeed, in developed countries at least, new hydropower capacity can hardly be deployed because the most suitable locations have already been equipped. In addition, nuclear power, the other mature and scalable technology available to generate carbon-free electricity, has faced significant opposition after the Fukushima accident and has increasingly been perceived as a non-competitive substitute to renewables.

In recent years, however, we observe a renewed interest in nuclear power, especially in Europe where it is often seen as a way to diversify energy sources and to speed up decarbonation. For example, countries such as France, Poland and the United Kingdom have have started or are contemplating building new nuclear reactors. Therefore, the future carbon-free mix of several countries will include both nuclear units and large amounts of intermittent renewables. Will the former, generally believed to be relatively inflexible assets, be able to cope with the latter without raising massive operational challenges?

This work studies this question empirically for the case of France between 2015-2024. With 61 GW of installed nuclear capacity, and a total capacity of wind (resp. solar) which grew from 9 GW (resp. 5 GW) as of 31 December 2014 to 23 GW (resp. 19 GW) as of 31 December 2023, France indeed offers a unique case study to explore the following questions. First, to which extent do nuclear units adjust their output to renewable supply and, if so, how? Second, how often are the operating constraints of nuclear units binding and do they relate to their degree of "exposure" to renewable output?

Methods

We gather multiple sources of public data, including hourly unit-level output, day-ahead prices, country-wide renewable output and cross-border power flows, as well as geocoded installed capacities over time. We then deploy several econometric techniques to answer the above questions.

Results

First, at the aggregate country-wide level, we find that the output from the nuclear fleet is very responsive to renewable output. On average, a 1 MWh increase in wind and solar is associated with a 0.6 MWh decrease in nuclear output. This decrease is predominantly achieved through load-following, with units sometimes decreasing their output all the way to their minimum output level. Consistently, we observe an increasing trend in the occurrence of hours during which unit-level minimum output constraints bind.

Second, we explore whether this latter trend may be exacerbated by grid constraints. To do so, we compute a plant-specific "exposure" metric of nuclear units to wind and solar output, defined as a distance-weighted average of the installed capacity of these technologies. We find some evidence that nuclear units that get more exposed to solar generation see a greater increase in the frequency at which they face minimum output constraints.

Finally, a couple of empirical observations seem to deserve further investigation. First, despite the large increase in renewable output, the capacity factors of nuclear units conditional on operating have remained relatively constant. In other words, the rate of planned and forced outages have being increasing at a commensurable pace, with many

plants experiencing major retrofits (as they were reaching the end of their original technical life) and a large fraction of the fleet being down in 2022 due to stress corrosion cracking. Although such events may be purely idiosyncratic, whether outage rates are sensitive to renewable penetration will be explored further. Second, although nuclear units are found to be much more flexible than generally believed, we observe that their "supply response", that is, the extent to which they respond to low or negative prices, is far from being perfect. The underlying mechanisms behind this imperfect response will be studied in more detail in order to assess to which extent it may evolve as the share of renewables increases further.

Conclusions

Ultimately, this work will provide detailed empirical evidence on the operational and economic challenges that future power systems with large shares of both nuclear and renewables will have to address.

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