THE STAKES OF NUCLEAR PLANNING OPTIMIZATION IN ELECTRIC SYSTEMS OPERATION WITH RENEWABLE ENERGY

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Overview

The recent development of variable renewable technologies in electric systems calls for prospective work regarding, among others, the future optimal capacity mix as well as its related carbon footprint, security of supply, and overall costs. In the context of diminishing and fickle residual electric demand, each generating technology's operational flexibility will partly determine whether they shall participate in future decarbonized electric systems, and nuclear technology is no exception. Hence, assessing the available nuclear flexibility is crucial to evaluating nuclear power's economic and technical interactions and the newly-built renewables capacities. This paper identifies the underlying physical mechanisms that frame this technology's flexibility and operations and focuses its analysis on nuclear planning optimization, a structural characteristic of nuclear fleets. We develop a method to simulate this optimization to reflect how plants managers maximize their plants' availability during peak-demand periods. We compare two simulation hypotheses, one where the fleet's planning is optimized and another where the fleet's availability is considered constant, a standard practice in the energy systems modeling literature. The paper conducts a sensitivity analysis highlighting the links between the fleet's planning optimization, the relative share of nuclear and renewables in the capacity mix, and the simulation models' results. We find that modeling the nuclear fleet's optimization is of greater importance as the relative share of nuclear in the capacity mix is high. The planning's importance holds as renewables' installed capacities heighten, as the residual demand level decreases with higher volatility. Ultimately, this paper aims to highlight the potential benefits of modeling the fleet's planning optimization in simplified low-carbon electric systems with a significant share of renewable energy.

Methods

The paper proposes a novel Mixed-Integer Linear Programming model based on realistic refueling constraints of PWRs to simulate fleet planning optimization. Using the resulting nuclear planning, we simulate a simplified electric system's operations with the unit-commitment/economic-dispatch model Antares-Simulator. The considered electric system is based on the French electric system due to the historically high share of installed nuclear power, meaningful feedback on nuclear fuel-cycle management, and data availability regarding renewables and electric demand. We then compare two nuclear planning assumptions, one where the fleet's planning is optimized and another where nuclear availability is considered constant. The objective is to determine whether the nuclear planning optimization does influence the modeled electric system's operation. We conduct a sensitivity analysis on VRE penetration and nuclear fleet sizes to explore different capacity mix scenarios.

Results

We find that the nuclear planning optimization does not influence electric systems operations in cases with low VRE penetration and few nuclear reactors in the capacity mix –i.e., when nuclear power plants run as baseload. In cases with higher VRE penetration and greater nuclear fleet, we find that nuclear planning optimization does reduce operational costs, energy curtailments, peaking plant use, and environmental impacts linked to electricity generation.

Conclusions

The present paper explores nuclear planning optimization benefits to integrate renewable energy in power systems such as wind and solar. We present a novel heuristic formulation of nuclear refueling and maintenance planning that frames nuclear operations, including irradiation-cycle and outage lengths. Using the resulting heuristic planning, we find that nuclear planning optimization does reduce operational costs, energy curtailments, peaking plant use, and environmental impacts linked to electricity generation. Another key finding is that nuclear planning optimization's relevance increases as the relative share of VRE and nuclear capacity in the capacity mix heighten, with low influence on simulation results in cases with few reactors and limited VRE penetration and significant impacts in other cases. However, the impact of planning optimization on market prices and technologies' revenues is ambiguous, as the revenue benefits linked to the decrease of negative price occurrence can be offset by a decreasing number of peak prices.

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