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# The role of nuclear (in-) flexibility in the transition toward climate-neutral power systems

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Achieving the climate neutrality objective necessitates a fundamental transformation of the electricity sector. This, in turn, requires a comprehensive system value assessment of low-emission technologies, including variable renewable energy sources (VRES), nuclear power, and electricity storage. Policy and investment decisions should account not only for the deployment of new assets but also for the implications of existing infrastructure and associated sunk costs. Furthermore, the flexibility constraints and costs of nuclear power must be critically examined.

We develop a mixed-integer optimization model that incorporates discrete investment decisions for nuclear power plants, along with binary operational constraints capturing the status of each unit. These reflect economically driven load variations, temporary shutdowns, maintenance periods, and flexibility limitations linked to the nuclear fuel cycle. Other technologies—such as VRES, fossil-fired gas power plants, short-term battery storage, and long-term hydrogen storage—are represented using linear constraints.

In a case study, we explore multiple energy system scenarios and evaluate both the composition of the optimal asset portfolio and spot market outcomes in the electricity and hydrogen sectors. In particular, we conduct a sensitivity analysis across different $CO_2$ price levels and hydrogen demand trajectories.

Preliminary findings suggest that higher $CO_2$ prices and increasing hydrogen demand significantly amplify the need for supply-side flexibility. In scenarios where nuclear plants are assumed to be flexible, their ability to modulate output becomes increasingly valuable as VRES penetration rises, contributing to system balancing during periods of low wind or solar availability. Conversely, when nuclear generation is modeled as inflexible, the system relies more heavily on VRES expansion and battery storage, which emerge as more cost-effective investment options.

Overall, the results highlight the importance of accounting for operational flexibility in long-term energy planning, particularly in countries with legacy nuclear capacity, as it can substantially affect optimal pathways toward a climate-neutral electricity system.

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