Assessing the role of nuclear energy in Italy with FENICE model through different infrastructure scenarios

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Overview

Under the pressing need for decarbonization, the role of nuclear energy in future energy systems has gained renewed interest. This study employs the open-source Future Energy traNsition multI-seCtor modEl (FENICE), a tool developed for analyzing multi-vector and multi-sector energy systems, to explore the potential development of nuclear energy in Italy. Unlike conventional analyses that focus solely on the technological and economic competitiveness of nuclear power, this work evaluates its systemic implications. Specifically, the study examines nuclear energy in relation to infrastructure development, such as electrical grid expansion and the deployment of hydrogen pipelines, analyzing its role in the decarbonization pathway of the Italian energy system.

Methods

The analysis utilizes the FENICE model to assess scenarios for the Italian energy system up to 2050. The modeling framework considers a regional (NUTS-2) resolution and employs a double-layer clustering scheme to manage the hourly temporal scale. The model includes the most energy demanding sectors (transport, industry and civil) and considers the conversion processes between the five main energy vectors (electricity, hydrogen, fossil and biogenic CH_4, biogenic and synthetic liquid fuels, biomass). Input data includes detailed projections for sectorial energy demands and cost trajectories of energy technologies. Nuclear energy is assessed in scenarios changing its investment costs and with different energy-vector infrastructure development, such as investments to improve interconnection capacity in electricity grids and hydrogen pipelines. Cost-optimal pathways are derived under constraints on CO_2 emissions and installation rates for emerging technologies.

Results

Preliminary results indicate that the role of nuclear energy is significantly influenced by the consideration of infrastructure investments, as depicted by Figure 1 and Figure 2. In scenarios with infrastructure improvements, the deployment of nuclear plants is reduced, as the enhanced network facilitates the integration of decentralized renewable energy sources. Conversely, in the absence of such infrastructure developments, nuclear installations increase, reflecting their role in providing stable baseload power in a less interconnected system. These outcomes highlights that the feasibility and competitiveness of nuclear energy extend beyond its direct costs, encompassing broader systemic and infrastructural considerations.

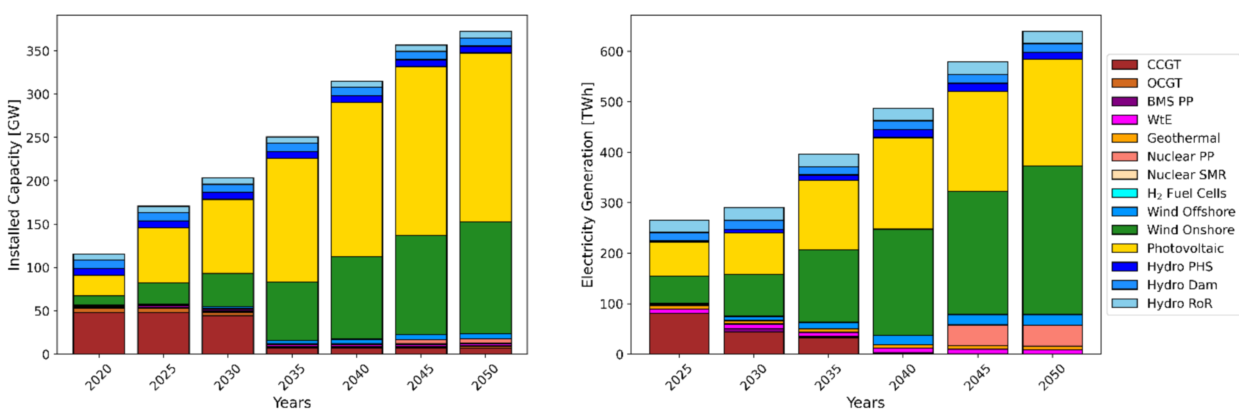

Figure 1: Installed power generation capacities and annual electricity generation from 2025 to 2050, for scenario with electrical grid and hydrogen pipelines improvements.

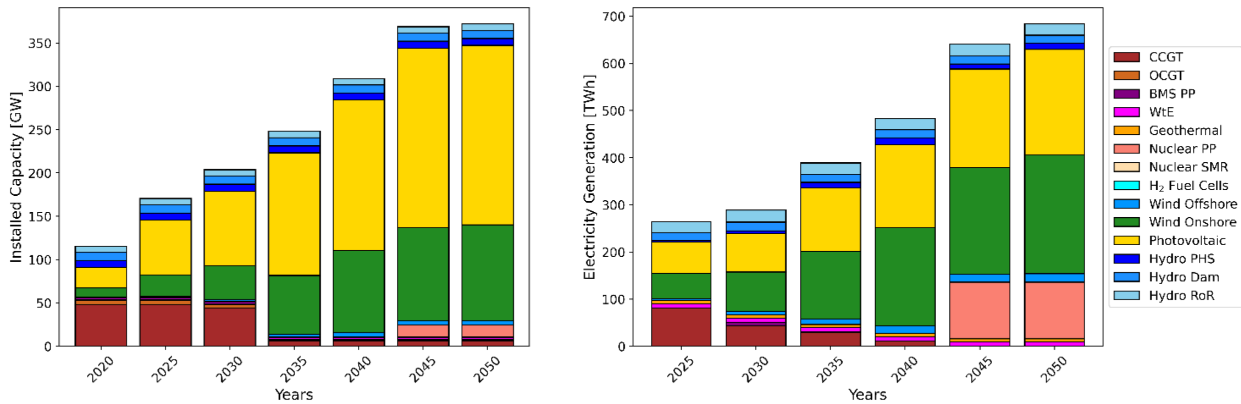

Figure 2: Installed power generation capacities and annual electricity generation from 2025 to 2050, for scenario without electrical grid and hydrogen pipelines improvements.

Conclusions

The analysis demonstrates that nuclear energy in Italy cannot be evaluated solely in competition with other electricity generation technologies. Instead, its potential must be assessed within the context of the overall energy system, particularly the availability and development of supporting infrastructure. When infrastructure improvements such as grid expansion are considered, the reliance on nuclear energy diminishes, whereas limited infrastructural investments favor greater nuclear deployment. This systemic perspective highlights the critical need for policymakers to align infrastructure planning with energy technology strategies, ensuring an optimized and holistic approach to meeting long-term decarbonization targets.