Assessing the Contribution of Small Modular Reactors (SMRs) to the Energy Transition

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ABSTRACT

Romania's transition towards a low-carbon electricity system requires the replacement of coal- and lignite-fired generation while maintaining security of supply, system adequacy, and operational flexibility. Nuclear energy is expected to play a significant role in this process alongside variable renewable energy sources (vRES) and energy storage. In addition to the continued operation and refurbishment of the Cernavodă nuclear power plant and the development of Units 3 and 4, small modular reactors (SMRs) are emerging as a potential complement to conventional large reactors (LRs).

This study evaluates alternative pathways for replacing 2 GWe of coal-fired generation in the Romanian electricity system, focusing on the contribution of nuclear power and the integration of renewable energy. Four scenarios are investigated: (i) vRES combined with LRs, (ii) vRES combined with SMRs, (iii) a hybrid configuration combining LRs and SMRs, and (iv) a vRES-dominated configuration. The analysis is performed using the Framework for Analysis of Energy Systems (FRAMES) modelling tool, which simulates the national electricity system over a full year at hourly resolution. The reference case represents the Romanian electricity system in 2025 and is based on historical grid data. System configurations are optimized by minimizing total system cost, subject to constraints reflecting electricity demand, system operating conditions, and decarbonization requirements. The assessment distinguishes between installed-

capacity replacement, annual electricity generation, peak-demand adequacy, and hourly energy balance.

The results indicate that the lowest total system cost is obtained in the scenario with a high penetration of vRES. However, this configuration reduces the SMR capacity factor to 66–69% and increases the curtailment of renewable and hydropower generation. Conversely, scenarios incorporating SMRs achieve the lowest emissions among the pathways investigated, highlighting their potential contribution to electricity-system decarbonization. These findings demonstrate the trade-offs between economic performance, nuclear reactor utilization, renewable energy integration, and emissions reduction. The study provides insights into the potential role of SMRs in Romania's future electricity mix and underscores the importance of integrated, hourly-resolution energy-system modelling when evaluating alternative decarbonization pathways.