

Assessing the energy performance and decarbonization potential of hybrid nuclear-renewable energy systems

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In this paper, we analyzed the environmental and economic impact of implementing a hybrid nuclear-renewable energy system in Romania, in order to support national decarbonization goals and contribute to the global energy transition. Using Romanian-specific generation data and energy supply/demand models we simulated a nuclear- solar/wind system. The simulations were conducted using the Nuclear-Solar/Wind Hybrid Energy System Part-Task Simulator developed by the International Atomic Energy Agency (IAEA). We analyzed the energy impact of such a system on the electricity grid and industrial processes in Romania, as well as possible integration challenges. We analyzed a nuclear-solar configuration combining a nuclear reactor with a Concentrated Solar Power (CSP) field. This system led to an increase in thermodynamic cycle efficiency from 34.6% to 38.1%, and a rise in net electrical output from 706 MWe to 837 MWe. These improvements highlight the value of the solar input for feedwater preheating or additional steam generation, achieved without altering the core thermodynamic structure of the plant. For the nuclear-wind configuration, we examined system behavior under varying wind speeds (0 m/s, 9 m/s, and 25 m/s). The results demonstrated the system's operational flexibility, with the wind farm supplying up to 78% of the grid load at optimal wind conditions (25 m/s), allowing the nuclear reactor to operate in a reduced mode. Additionally, 213.99 MWe of surplus energy was utilized for hydrogen production. In the extended configuration, with the integration of a biomass processing plant, the hybrid system operated in a completely closed regime, where renewable and nuclear energy is converted into: biofuel, hydrogen and process heat. Thus, the ability of the proposed model to simultaneously meet electricity demand, produce unpolluted fuels and actively contribute to the circular economy was demonstrated. Our study demonstrates significant potential of hybrid nuclear-renewable systems to enhance energy efficiency, flexibility, and sustainability. By integrating solar and wind energy into a CANDU-based nuclear infrastructure, Romania can make substantial progress toward its decarbonization and energy transition objectives

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