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# "ECONOMICS FOR ECOLOGY"

*(“EU practices of education for sustainable development”)*

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For scientists, scientists, students, graduate students, representatives of business and public organizations and higher education institutions and a wide range of readers.

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# SHAPING THE DECARBONIZED FUTURE OF THE ELECTRICITY INDUSTRY IN UKRAINE

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Today, the primary goal for many nations is to attain carbon neutrality by transitioning to green power. Since technologies using renewable energy sources convert energy mostly into electric power, the national electricity sectors are expected to be the locomotive of the green energy transformation. Therefore, numerous recent research studies delve into renewable energy sources matters within the electricity sector, aiming to establish a carbon-neutral blueprint for this industry across various nations.

Ukraine urgently needs to transition to green power due to its heavy reliance on energy imports, high energy and carbon intensity of the gross domestic product, and mounting challenges with electricity supply exacerbated by the destruction of domestic electricity infrastructure because of the ongoing Russian-Ukrainian war. Within its international commitments [1; 2], Ukraine should achieve carbon neutrality by 2060 and has formulated a national strategy to address this objective.

Amid the ongoing hostilities, the future of the United Energy System of Ukraine is becoming increasingly uncertain. This casts doubt on the viability of current energy system models and strategies [3; 4], necessitating updated solutions for rebuilding the United Energy System of Ukraine in the post-war era. Consequently, the research endeavors to propose cost-effective scenarios for the development of the electricity sector of Ukraine by 2035, considering various constraints on the available electricity technologies in the market. These scenarios aim to align with national decarbonization targets.

In our research, we simulated the United Energy System of Ukraine in 2035 using the spatial and regional EXPANSE model, which was customized for Ukraine [5; 6; 7]. Previous studies that modeled the national electricity industry typically employed macro models like TIMES-UKRAINE and constructed scenarios for the entire national economy and its key sectors [3; 4]. In contrast, the UKRAINE_EXPANSE model diverges from TIMES-UKRAINE by capturing the regional distribution of the facilities of the United Energy System of Ukraine. This enables a regional examination of generation, storage, and transmission technologies, along with an evaluation of their social, economic, and environmental repercussions.

Besides Ukraine, the newly built model encompasses five neighboring countries (Poland, Romania, Slovakia, Moldova, and Hungary), represented as single-country nodes, and 24 administrative regions of Ukraine (excluding Crimea and the territories in Donbas occupied by Russia in 2014), connected to 11 nodes.

Within the model, we involved 17 electricity generation technologies (including onshore and offshore wind, solar power, biogas, wood biomass, agricultural and municipal waste, energy crops, small hydro, run-of-the-river, hydro dams, geothermal, gas, coal, lignite, oil, and nuclear energy), along with three storage technologies (pumped hydro storage, hydrogen, and batteries), and two transmission technologies (direct current for neighboring countries and alternating current for Ukraine's domestic lines).

12 cost-optimal scenarios for the United Energy System of Ukraine and five neighboring countries in 2035 were developed. These scenarios used combinations of constraints on the utilization of nuclear, coal, renewable energy resources (solar and wind), hydro dam, and pumped hydro storage technologies, as well as greenhouse gas emissions, as outlined in the country's commitments [1; 2].

For each scenario, there were computed the total installed capacities of electricity generation, storage and transmission technologies in 2035, considering the projected power demand for Ukraine and neighboring countries. Subsequently, we determined the annual electricity volumes generated by these technologies in 2035, along with the composition of the annual electricity technology mix, export and import flows for Ukraine. Additionally, we evaluated overall air pollution emissions, annualized direct electricity sector jobs, direct land use, and total system costs associated with each scenario.

The examination reveals a decrease in the total installed capacity across all scenarios in 2035, attributable to the rationalization of capacity structure, despite the growth of domestic electricity demand by 25%. While the combination of nuclear and coal capacities prevails, solar, onshore wind, hydro dam, and pumped hydro storage facilities play a significant role too, along with gas and offshore wind having less weight. Choosing any scenario will keep a large share (46-75%) of fossil fuels in the domestic electricity industry in 2035, including nuclear, coal, and gas in different proportions.

All scenarios adhere to the current pattern of the electricity generation mix, predominantly featuring nuclear and coal. Consequently, by 2035, Ukraine will persist in prioritizing nuclear power while scaling back coal capacity in alignment with national decarbonization objectives. Disregarding these targets would perpetuate coal as the primary resource for electricity generation due to its economic viability, even amidst some renewable energy sources development in line with established green power objectives. However, fulfilling national decarbonization plans necessitates embracing an alternative ecologically optimal option and allocating up to 14% more funds.

In addition to coal and nuclear, the notable components in the electricity generation mix will be hydro dams, solar, onshore wind, gas, and pumped hydro storage. However, their contribution is significantly lower compared to the combined outputs of coal and nuclear power. Scenarios featuring a decreased share of coal necessitate higher costs and larger land areas for accommodating electricity installations. Nonetheless, they are expected to generate more employment opportunities in the sector and lead to reduced greenhouse gas emissions.

The rise in electricity demand projected for 2035 requires expanding domestic grids primarily in central regions of Ukraine across all scenarios. The expanded nuclear and renewable power generation leads to increased export volumes in the respective scenarios, driven by the reduced flexibility of energy production with these technologies. Consequently, to maintain balance in the United Energy System of Ukraine, electricity imports will also increase, albeit to a lesser degree than exports. As a result, all scenarios call for an expansion of the capacity of transborder transmission grids connecting Western Ukraine with its five neighboring countries.

Overall, the UKRAINE_EXPANSE model introduces a novel methodology for analyzing regional energy systems, with a particular emphasis on the electricity sector, its sustainable development, and the transition to green power. However, the focus on the electricity sector is an advantage of the study and, at the same time, its limitation. Other restraints include pre-war data used to build the model and the time horizon limited by 2035 that should be acknowledged when considering policy implications.

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