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ECONOMIC EFFICIENCY OF RENEWABLE ENERGY INVESTMENTS IN THE CONTEXT OF THE TRANSITION TO A GREEN ECONOMY

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Abstract. The article assesses the economic efficiency of renewable energy (RE) investments in Uzbekistan in the context of the transition to a green economy. The study uses official and analytical sources for 2024–2026 and reports of international organizations, and applies statistical-comparative analysis, calculation of specific capital intensity, sensitivity analysis of LCOE (levelized cost of energy), and methods for estimating the effect of displacing gas and CO2. According to the results, total capacity rose from 21.9 GW to 25.8 GW in 2025 (17.8%), and RE accounted for 31% of capacity; solar and wind power plants generated more than 9 TWh in January–October 2025, which, according to approximate calculations, displaced about 2.4 billion m³ of natural gas and 4.5 million t of CO2. However, because grid infrastructure and energy storage systems are insufficient, curtailment poses a serious risk to the efficiency of investments: when curtailment reaches 10%, the effective cost of energy rises by 11.1%. The article develops proposals for planning the investment portfolio in harmony with grid and storage capacities.

Keywords: renewable energy, green economy, investment efficiency, LCOE, solar and wind energy, curtailment, Uzbekistan.

1. Introduction

The transition to a green economy requires the energy sector to address economic and environmental issues simultaneously. For a long time, Uzbekistan relied on thermal power plants, mainly natural gas, for electricity generation. As of 2019, total installed capacity was 12.9 GW, of which 84.7% came from thermal power plants and 14.3% from hydropower plants, while the share of solar and wind was negligible [9]. After that the RE sector grew sharply: 2025 was declared the "Year of Environmental Protection and Green Economy" [8], and within the "Uzbekistan – 2030" strategy the goals are to add more than 17,000 MW of RE capacity by 2030 and to raise its share in generation to 54% [4; 5; 6].

Growth in the volume of investment does not by itself guarantee economic efficiency. RE projects require high initial capital, and output depends on the weather and is limited by grid connection and storage possibilities. Therefore, the efficiency of investments should be assessed not only by the size of capacity but together with cost, grid integration and external effects (gas savings, emission reductions).

The aim of the study is to propose a calculation framework based on open data for assessing the economic efficiency of RE investments in Uzbekistan and to analyze its results. The tasks are: (1) to determine the development dynamics of the RE sector; (2) to estimate the specific capital intensity of investments; (3) to quantify the effect of curtailment risk on efficiency; (4) to calculate the effect of displacing gas and emissions; (5) to develop policy recommendations.

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2. Theoretical framework and methods

The economic efficiency of energy projects is assessed through a system of financial and social indicators. Financial assessment uses net present value (NPV), internal rate of return (IRR), payback period and the levelized cost of energy (LCOE). LCOE is defined as follows:

LCOE = Σ [(I_t + O&M_t + F_t) / (1 + r)^t] / Σ [E_t / (1 + r)^t]

where I_t is capital expenditure in year t, O&M_t is operating expenditure, F_t is fuel expenditure (close to zero for RE), E_t is the energy produced, and r is the discount rate. If the share of curtailment (energy that was produced but could not be accepted by the grid) is c, the effective cost rises as follows:

LCOE_effective = LCOE / (1 − c)

Socio-economic efficiency also covers the climate and environmental externalities, in line with the approach of the Stern Review [1]. For international comparison, IRENA data were used: in 2023 the global weighted-average total installed cost of utility-scale solar PV projects was about USD 758/kW, and that of onshore wind projects about USD 1,274/kW [2].

The database consisted of official reports for 2025–2026, Enerdata, the IEA, the World Bank and sectoral analytical publications. Specific capital intensity (USD million/MW) was calculated by dividing the total cost of announced project portfolios by their capacity. The displacement of gas and CO2 was estimated under the following conditional assumptions: the efficiency of the displaced gas-fired plants is 40%, the net calorific value of gas is 34 MJ/m³, and the emission factor of gas is 56.1 kg CO2/GJ (the IPCC default value) [10]. These calculations are estimates in nature; precise results require operational data on the grid balance.

3. Results

3.1. Dynamics of capacity and generation

Table 1. Electricity capacity and generation indicators

Indicator	Value	Source
Total installed capacity, 2024 → 2025	21.9 → 25.8 GW (+17.8%)	[3]
RE capacity, end of 2025	8 GW (31%)	[3]
Electricity generation, 2025	86.7 TWh (+6%)	[3]
Plan for 2026 (generation)	90 TWh	[3]
Solar and wind generation, January–October 2025	> 9,000 GWh	[4]
Share of RE, July 2025 (in total generation)	27% (2.89 billion kWh)	[5]
Target to 2030	+17,000 MW; share 54%	[4; 6]

Source: compiled by the author based on the sources indicated. The growth of total capacity (17.8%) is the author's calculation.

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The table shows that total capacity increased by 3.9 GW in one year, and RE makes up almost one-third of the capacity structure. The composition of the 6.7 GW of new capacity planned for 2026 is: 2.8 GW solar, 2.5 GW thermal, 884 MW energy storage, 470 MW wind and 68 MW hydro [3]. Here the share of RE and storage systems is 4.222 GW, or 63.0% of the plan, and the share of thermal capacity is 37.3%. That is, thermal capacity is being retained to ensure the reliability of the energy system, but attention to storage systems is growing.

3.2. Specific capital intensity of investments

Sixteen solar, wind, thermal and hydro projects whose construction started on 5 December 2025 are valued at a total of USD 3.3 billion and have a total capacity of 3.5 GW [7]. This means a specific capital intensity of about USD 0.94 million/MW. For the more than 30 energy projects being implemented between Uzbekistan and China (total capacity close to 10 GW, value above USD 9 billion), the indicator is about USD 0.9 million/MW [7]. Since both portfolios have a mixed composition (thermal, hydro, storage, transmission), they cannot be compared directly with pure solar and wind projects; however, the fact that they lie between the global average for solar projects (about USD 0.76 million/MW) and for wind projects (about USD 1.27 million/MW) indicates that the portfolio is close to the international level [2]. The total volume of the investment package (clean energy investments attracted in recent years of about USD 35 billion) [6] shows the attractiveness of the sector to investors.

3.3. The effect of curtailment risk on efficiency

The main systemic problem in the sector is the grid's inability to accept the energy produced. According to a local researcher's estimate, curtailment of solar and wind energy in 2025 may exceed 3,000 GWh; storage capacities are not yet sufficient [4]. Table 2 calculates the effect of the curtailment share on the effective cost.

Table 2. Effect of the curtailment share on the effective cost of energy

Curtailment share (c)	Effective cost coefficient 1/(1−c)	Increase in cost
0%	1.000	0%
5%	1.053	+5.3%
10%	1.111	+11.1%
15%	1.176	+17.6%
20%	1.250	+25.0%

Source: author's calculations (based on the formula LCOE_effective = LCOE / (1 − c)).

The calculation shows that every 10% of curtailment raises the cost by more than 11%; that is, the effect on project profitability is not linear but grows rapidly at high curtailment. If investments in the grid and storage are delayed, the efficiency of every newly added unit of capacity declines.

3.4. The effect of displacing gas and emissions

Table 3. Approximate ecological and economic effect of solar and wind generation in January–October 2025

Indicator	Value	Note
Solar and wind generation	9.0 TWh	[4]

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Indicator	Value	Note
Required thermal energy (efficiency 40%)	22.5 million MWh	9.0 / 0.40
Natural gas displaced (34 MJ/m³)	≈ 2.4 billion m³	calculation based on assumptions
CO2 emissions avoided (56.1 kg/GJ)	≈ 4.5 million t	calculation based on assumptions

Source: author's calculations. The results are an approximate assessment based on conditional assumptions and should be checked against the official gas balance.

For comparison, the energy-saving measures planned by the Ministry of Energy provide for savings of 4.4 TWh of electricity and 2.84 billion m³ of natural gas [3]. That is, according to the calculation above, solar and wind generation alone appears to have delivered, within ten months, a result close to the volume of gas savings planned. This makes it possible for the displacement effect to turn into a gas reserve that can be directed to exports or other sectors.

4. Discussion

The results show that RE investments are economically justified for Uzbekistan: capital intensity is close to the international level, and the ecological and economic effect (saving gas and emissions) is significant. However, three factors limiting efficiency were identified. First, the pace of development of the transmission and distribution grid lags behind generation capacity; as a result curtailment appears and the effective cost rises (Table 2). Second, energy storage systems are limited to 884 MW in the 2026 plan, which may not be sufficient to smooth the variable nature of solar and wind [3; 4]. Third, tariff formation and market mechanisms must ensure stable returns for investors; otherwise the cost of capital (discount rate r) rises and LCOE increases.

From a scientific point of view, this is a practical confirmation of the Stern approach: when externalities are taken into account, the social efficiency of RE is higher than its financial indicators [1]. In practical terms, investment decisions need to shift from the criterion of "increasing the number of MW" to the criterion of "kWh effectively integrated into the grid." The fact that 37.3% of planned capacity is thermal means that faster investment in storage and grids is needed to reach the RE share target (54%).

Limitations of the study: (1) the capital intensity calculation relies on mixed portfolio values and is not broken down by technology; (2) calculating NPV and IRR requires project-level data on tariffs, the discount rate and the capacity factor, which are not fully available in open sources; (3) the local estimate of the volume of curtailment has not been officially confirmed; (4) the gas and CO2 calculation is based on conditional assumptions.

5. Conclusion and recommendations

RE investments are the main instrument of the transition to a green economy in Uzbekistan: in 2025 capacity grew by 17.8% and the RE share reached 31%. The main threat to economic efficiency is the lag of grid and storage systems, and 10% of curtailment raises the cost by 11.1%. The following proposals are made:

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– When approving new RE capacities, introduce conditions related to grid connection possibilities and storage capacity as mandatory requirements; plan capacity additions and grid investments within a single schedule.

– Create separate tariffs and incentive mechanisms for storage systems (batteries, pumped hydro).

– Publish official month-by-month statistics on the volume of curtailment and openly provide investors with cost sensitivity analysis.

– In assessing socio-economic efficiency, take gas savings and emission reductions into account in monetary terms; assess the possibility of directing the saved gas to exports or industry.

– Strengthen public oversight by publishing NPV, IRR and LCOE indicators for projects on the basis of a uniform methodology.

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