Renewable Energy as a Driver of ESG Transformation of the Energy Complex and Industrial Clusters in Uzbekistan

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Abstract

This article examines the role of renewable energy (RES) as a key driver of the ESG transformation of Uzbekistan's energy sector and industrial clusters. Based on data from international organizations and specialized analytical reviews, the electricity sector's high dependence on natural gas (approximately 76% of generation in 2023) heightens energy security and sustainability risks amid declining gas production and rising electricity demand. An integrated framework for ESG energy transition management (ESG KPIs + scenario-based effects model) is proposed as a methodological solution, focusing on industrial cluster chains (textiles, construction materials, chemicals/metallurgy, and agro-industrial processing). An assessment of the economic effects of replacing gas-fired power generation with RES is conducted under a scenario in which target benchmarks are achieved by 2030 (scaling RES to 21–27 GW and increasing the share of RES in the electricity supply). The results show that the introduction of renewable energy sources in combination with energy efficiency at the cluster level can provide a sustainable economic effect through the release of gas (alternative cost of fuel), a reduction in electricity costs and losses, an increase in investment attractiveness, and access to “green” financing in the logic of the national green taxonomy.

Keywords: Green growth; ESG; Renewable energy; Energy transition; Industrial cluster; Green finance; Uzbekistan

1. Introduction

Uzbekistan is undergoing an accelerated energy transition. Gas-fired power generation dominates at approximately 76% in 2023. At the same time, electricity demand is rising, some generating capacity is physically depreciating, and natural gas production is declining. This mix increases the energy sector's vulnerability and creates systemic risks to sustainable economic development [1-2]. Therefore, the gas sector's dynamics demand diversification of the energy mix, reduced gas intensity, and increased sustainability of energy supplies for industry and regional clusters.

In these circumstances, renewable energy is not only a technological response to the shortage of generating capacity. It is also a crucial governance mechanism for the ESG transformation of the energy sector and related industries. The environmental component of ESG (E) is realized through reductions in greenhouse gas emissions and local pollution. It also lowers water intensity in electricity generation compared to thermal generation. The social component (S) is reflected in increased energy supply reliability and quality of life, fewer accidents, and more jobs in the renewable energy value chain. The governance component (G) involves greater transparency and better investment management through expanded public-private partnerships, the adoption of non-financial disclosure standards, and the development of green financing instruments.

DOI: https://doi.org/10.54216/AJBOR.140103
Received: August 27, 2025 Revised: October 29, 2025 Accepted: December 19, 2025

Several sources describe government and analytical benchmarks for renewable energy development in Uzbekistan by 2030 as significantly ambitious. They set targets for increasing installed renewable capacity to about 21 GW, aiming for a 54% share of renewables in the electricity mix. Some sources suggest even higher goals, up to 27 GW of installed capacity [5] [8]. These benchmarks serve as framework parameters for green growth policy, guiding investments, electricity market reform, and infrastructure modernization.

The purpose of this article is to substantiate the role of renewable energy as a key driver of the ESG transformation of the energy complex and industrial clusters of Uzbekistan, and to assess the economic impact of replacing gas generation with renewable energy sources under specific scenarios analyzed through 2030.

To achieve this goal, this paper addresses: analysis of the initial conditions and structure of the energy complex; mechanics of an ESG-oriented transition (including tools, key indicators, institutional and financial mechanisms); development of a scenario model to assess the economic impact of renewables (gas conservation, CO_2 reduction, investment effects, cluster impacts); and practical measures for cluster-level implementation (project portfolio, management decisions, funding sources).

This article's scientific novelty lies in integrating an energy balance-based analysis of renewable energy with an ESG framework for managing industrial clusters. The article also presents the economic impact of the energy transition as a mix of the opportunity cost of natural gas, improved energy efficiency, and expanded access to green financing instruments. The study's practical significance comes from applying the proposed model to justify cluster development programs. It also helps prepare investment memoranda and develop regional roadmaps within the "renewable energy, energy efficiency, and ESG financing" framework.

2. Materials and methods

The study relied on open-source materials from international organizations and specialized think tanks on Uzbekistan's energy sector and green transition. Specifically, data from [1] was used to analyze electricity generation and assess the role of natural gas and renewables.

The assessment of the energy system's capacity, structure, and development prospects used analytical reports from the German Economic Team. These reports examine scenarios to ensure energy security and the balance between supply and demand for electricity in the medium- and long-term [2].

Targets for renewable energy development and directions for green investments were analyzed using materials from the OECD and International Energy Agency. This included strategic reviews and roadmaps for energy and climate transition [1] [5].

To support the institutional and financial aspects of ESG transformation, World Bank documents were used. These covered the creation of a national green taxonomy, sustainable finance, and non-financial information disclosure standards [4].

The analysis of industrial clusters and their role in Uzbekistan's green transformation used materials from the European External Action Service and the European Bank for Reconstruction and Development. These included reports and methodological recommendations for implementing energy-efficient and renewable solutions in industry [6-7].

The methodological basis of the study included structural-logical and comparative analysis, scenario modeling, and ESG decomposition. These methods enabled assessment of how renewable energy development impacts the sustainability of the energy complex and the economic efficiency of industrial clusters within green growth.

This article used a set of complementary research methods to examine the role of renewable energy in the ESG transformation of the energy sector and industrial clusters. The core tool was a structural and logical analysis. This helped identify key relationships between energy infrastructure development, the economic sector structure, and cluster-based industrial production organization.

To assess the sustainability and impact of the energy transition, we used an ESG decomposition method. We analyzed environmental (E), social (S), and governance (G) indicators separately at the energy system and industrial cluster levels. This approach linked changes in electricity generation technology to their institutional and socioeconomic effects.

A quantitative assessment of the effects of renewable energy development was conducted through scenario modeling of substituting gas-fired power generation with renewable energy sources. This approach calculated the annual volume of renewable energy produced (TWh) based on installed capacity and capacity utilization factors (CFU) for the main technologies. The volume of displaced natural gas (billion cubic meters per year) was determined using typical energy factors and average thermal power plant efficiencies. The reduction in carbon

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dioxide emissions (thousands of tons of CO_2 per year) was also assessed using standard emission factors for gas-fired power generation and the electricity equivalent.

The economic impact of the energy transition was assessed using a range approach to determining the economic value of the released natural gas. The calculations accounted for both domestic fuel savings and the opportunity cost of gas for potential export sales. This approach was considered a sensitivity analysis rather than a single "exact" indicator, allowing for uncertainty in pricing and institutional conditions.

It should be noted that this study is not a feasibility study for specific generation facilities. Calculations of economic and environmental impacts are presented at the macro- and mesoeconomic levels, covering the energy system as a whole and industrial clusters. Further details on regional load curves, grid constraints, long-term power purchase agreements (PPAs), capital and operating costs for specific sites, and the financing structure of individual investment projects are required for detailed project analysis.

3. Results

According to the International Energy Agency, natural gas remained the largest source of electricity generation in Uzbekistan in 2023, accounting for approximately 76% of total generation [1]. This energy balance structure indicates the electricity sector's high carbon and fuel dependence. Analytical estimates by the German Economic Team confirm the dominance of gas-fired capacity in installed generation: in 2024, it was estimated at approximately 14 GW out of almost 19 GW of total installed capacity, institutionally and technologically cementing the gas-fired model of energy supply in the country [2].

The main constraint on further energy sector development is declining natural gas production and the need to reduce its use in the power sector without slowing growth. Enerdata reports a steady drop in Uzbekistan’s gas production since 2021 [8]. Media sources note 2024 production at roughly 44.5 billion cubic meters [9]. Despite varying sources, the conclusion holds: options for affordable gas generation are narrowing. Renewable energy increasingly stabilizes and diversifies the system.

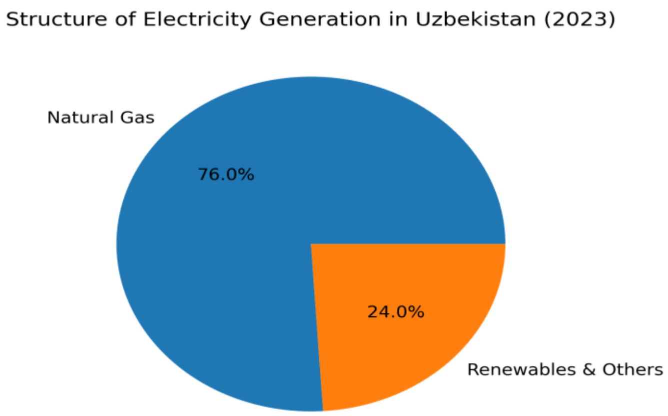

Figure 1. Structure of electricity production in Uzbekistan in 2023

Public strategic and analytical sources view the development of renewable energy in Uzbekistan as an accelerated process with a horizon extending to 2030. Specifically, reviews by the Organization for Economic Co-operation and Development indicate a target for increasing installed renewable energy capacity to approximately 21 GW, which could ensure that renewable energy sources account for approximately 54% of the country's electricity supply [5]. A number of analytical publications also offer a more ambitious interpretation of the target, suggesting that installed renewable energy capacity could reach 27 GW [5] [8]. In terms of technological structure, the International Energy Agency previously set a target for the development of solar generation at around 5 GW by 2030 [1], while for wind energy, a similar target of around 5 GW is mentioned in the materials of the US Department of Commerce [11].

The ESG logic of these targets is evident in their comprehensive impact on the economy and the energy system. The environmental component (E) is expressed in reducing the carbon intensity of electricity generation and decreasing dependence on natural gas. The social component (S) is realized through increased reliability of energy supply and the formation of new employment chains in the construction, installation, operation, and localization

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of renewable energy equipment. The governance component (G) focuses on strengthening project management, standardizing information disclosure, and expanding green financing practices.

Industrial clusters—especially the energy-intensive and export-driven cotton and textile sectors—are central to Uzbekistan's ESG transformation agenda. Reports emphasize that advancing these sectors means systematically improving energy efficiency and environmental performance [6]. As a result, adherence to ESG requirements is rapidly becoming essential for market access and financing within global supply chains.

Two basic renewable energy implementation architectures are applicable to industrial clusters. The first involves generating on-site or in close proximity to the site, including rooftop and canopy solar power plants, small wind turbines, and energy storage systems, which helps reduce peak loads and stabilize the energy supply. The second architecture is based on long-term off-site power purchase agreements (PPAs), which ensure large-scale decarbonization and tariff predictability. The institutional framework for green investments in the country is already being formed: the European Bank for Reconstruction and Development, through its GEFF program, supports energy efficiency and renewable energy projects in industry, including textile manufacturing, combining financial support with technical assistance [7].

To monitor the ESG transition, a practice-oriented set of key performance indicators has been proposed for integration into corporate reporting and regional development programs. It covers the share of renewable energy in electricity consumption, CO_2 emissions intensity, specific energy consumption of products, the share of green projects according to the national taxonomy, power supply reliability indicators (SAIDI/SAIFI), employment in the renewable energy supply chain, the prevalence of PPAs, and the presence of ESG policies and disclosures.

The financial framework for ESG transformation is largely determined by the development of a national green taxonomy and disclosure standards. World Bank guidance materials emphasize the need for a gradual implementation of disclosure requirements and the application of taxonomy practices, with state-owned banks considered key institutional anchors in this process [4].

A scenario-based approach, without reference to specific sites, was used to assess the macroeconomic effects of the energy transition. The calculations used typical installed capacity factors of 18–22% for solar generation, 30–40% for wind, and 35–45% for hydropower. It was assumed that 1 MWh of electricity generated by renewable energy sources displaces, on average, 1 MWh of gas-fired generation, without accounting for grid constraints or load curve characteristics. The economic value of the released gas was considered within a range reflecting domestic fuel savings and the alternative export value, which was used as a sensitivity analysis.

A scenario achieving 21 GW of installed renewable capacity by 2030—with a balanced portfolio—would deliver an estimated 50.3 TWh of additional electricity annually [5], underscoring the scale and ambition of Uzbekistan's transition strategy.

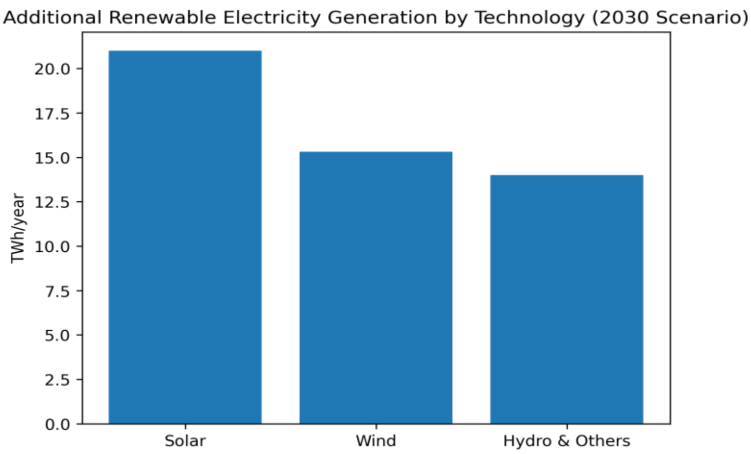

Figure 2. Additional generation of renewable energy by generation type (2030 scenario)

This volume is comparable in scale to the influence on gas generation. Its dominance in the current energy balance is significant [1].

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Based on typical energy coefficients, 1 billion m^3 of natural gas corresponds to approximately 4.7–5.5 TWh of electricity. Therefore, displacing approximately 50 TWh per year is equivalent to saving approximately 9–11 billion m^3 of gas annually. In terms of climate effects, taking into account the natural gas emission factor of approximately 56 kg CO_2/GJ and specific emissions from gas-fired power generation of 0.35–0.45 t CO_2/MWh, the potential emission reduction could amount to approximately 17–23 million t CO_2 per year. It should be emphasized that these estimates are approximate and require refinement during the transition to the project analysis.

The overall economic impact of the energy transition comes from three main components. First is the opportunity cost of freed natural gas. Savings of 9–11 billion cubic meters per year at a nominal price of $150–300 per 1,000 cubic meters yield an annual impact of $1.35–3.30 billion. Reducing gas production increases the importance of this impact for macroeconomic sustainability [8].

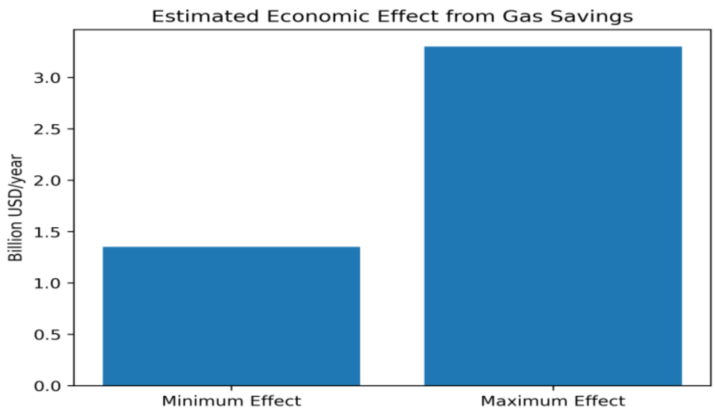

Figure 3. Range of annual economic effect from replacing gas generation with renewable energy sources

Reducing losses in industrial clusters is important, as power outages result in significant economic losses due to downtime and contractual breaches. Improving reliability with distributed generation and energy storage reduces these risks. Additionally, taxonomic projects and the development of ESG management help enterprises access preferential financing and lower capital costs. These effects arise from the national green taxonomy [4].

4. Discussion

Renewable energy is not just a technological expansion. It introduces new governance in energy and related sectors. Competitive and auction mechanisms, PPAs, banking covenants, non-financial disclosures, and carbon footprint systems all strengthen ESG governance (G-loop). These innovations make energy and industrial projects more transparent, predictable, and better managed for risk.

Industrial clusters play a key role in the practical implementation of the ESG agenda, transforming it from a declarative concept into measurable parameters of product cost and competitiveness. These parameters include specific energy consumption, the share of green electricity in the final product, compliance with global supply chain export requirements, and access to long-term financing. This transformation is particularly significant for the cotton and textile sector, as industry analyses emphasize the need for greener production and improved resource efficiency as prerequisites for maintaining market positions [6].

The sustainability of the energy transition in Uzbekistan is directly linked to accelerated infrastructure modernization and market reforms. In its country reviews, the International Energy Agency has repeatedly emphasized the need to improve the efficiency and reliability of energy supply, as well as to develop the institutional environment, as key factors for the successful implementation of renewable energy sources [1]. At the same time, the growing share of renewable energy sources objectively increases the requirements for energy system flexibility, the development of energy storage systems, the modernization of electrical grids, and improvements in dispatch control. Ignoring grid constraints can significantly reduce the actual impact of introducing new renewable energy capacity.

Greenwashing occurs when clusters claim ESG commitment but lack energy audits, management systems, or verifiable metrics. As investor and counterparty demands rise, this could erode trust and restrict access to financing and markets.

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ESG transformation creates financial risks through the need for long-term capital, currency risk management, and the setting of sustainable tariffs. The World Bank recommends a national green taxonomy and phased non-financial disclosure standards, both of which require mature reporting and strong financial institutions to build trust in green projects [4].

Given the identified challenges, achieving the ESG transformation goals of the energy sector and industrial clusters should be accomplished in stages. Immediate recommendations for the short term (6-18 months) are: conduct energy audits; implement digital energy monitoring systems aligned with ISO 50001; develop rooftop and industrial-site solar power generation; upgrade reactive power compensation; modernize energy-intensive equipment; and pilot energy storage systems for critical load areas. These actions deliver high-impact, measurable progress toward ESG objectives.

In the medium term (18–48 months), key recommended actions are: scale up cluster PPAs for green electricity supply; modernize thermal processes; implement energy recovery technologies; develop an ESG accounting system; and prepare enterprises for non-financial information disclosure to banks and investors. These steps consolidate initial successes and embed ESG principles in operations.

In the long term (up to 2030), the strategic focus should shift to the creation of regional renewable energy hubs combining solar and wind power plants with energy storage systems and modernized grids. Industry leaders and policymakers must act decisively and collaboratively to realize these advancements. Additional benefits will be achieved through the implementation of water- and resource-efficient technologies within the framework of a circular economy and the integration of Uzbekistan's industrial clusters into global green supply chains and export markets. It is imperative to seize this opportunity to position Uzbekistan as a pioneer of sustainable industry.

These measures can be financed through green financing mechanisms. This includes programs from the European Bank for Reconstruction and Development (GEFF) and similar commercial bank instruments. These programs, with technical assistance and standardized project solutions, can reduce transaction costs and investment risks [7]. All stakeholders should proactively engage with these mechanisms and prioritize project readiness to accelerate ESG transformation and ensure sustainable development in the energy and industrial sectors.

5. Conclusion

The study found that Uzbekistan's energy sector is currently characterized by a high structural dependence on gas-fired power generation, with gas accounting for approximately 76% of electricity production in 2023. Due to declining natural gas production and steadily growing electricity demand, this structure creates an elevated risk profile for the national economy and industrial sector, increasing the energy system's vulnerability to resource and price shocks [1] [8].

The analysis confirms that renewable energy is key to the ESG (Environmental, Social, and Governance) transformation of the energy sector and related industrial clusters. To fully realize these benefits, stakeholders should actively champion the development and adoption of renewables. The development of renewables improves environmental performance by reducing the carbon intensity of generation (E-component: Environmental). It also increases the sustainability and reliability of energy supply to industry and regions (S-component: Social). In addition, renewables facilitate the use of modern project and financial management methods, such as competitive bidding, long-term power purchase agreements (PPAs—contracts to buy electricity from specific sources for extended periods), and greater disclosure of non-financial information (G-component: Governance) [1].

A scenario-based assessment of the economic effects of the energy transition shows that scaling renewable energy capacity to approximately 21 GW by 2030 could generate an additional 50 TWh of "green" electricity per year. This, in turn, would allow for the displacement of approximately 9–11 billion cubic meters of natural gas annually, creating a significant macroeconomic benefit from the opportunity cost of the freed-up gas, increased energy security, and greater economic investment sustainability [5] [9].

At the industrial cluster level, the greatest socioeconomic and investment impact is achieved through a comprehensive approach integrating renewable energy, energy efficiency measures, ESG-oriented management, and green financing instruments [10]. Integrating this approach into key performance indicators and long-term cluster development roadmaps not only reduces production costs and carbon footprints but also enhances companies' competitiveness in international capital and product markets.

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Received: August 27, 2025 Revised: October 29, 2025 Accepted: December 19, 2025