UDC 620.91:338.2(574+575.1)
IRSTI 44.01.13
https://doi.org/10.48371/ISMO.2026.64.2.011

A COMPARATIVE ANALYSIS OF RENEWABLE ENERGY TRANSITION STRATEGIES IN UZBEKISTAN AND KAZAKHSTAN

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Abstract. This article compares renewable-energy transition strategies in Uzbekistan and Kazakhstan and examines how legacy energy systems, institutional capacity, investment models, and infrastructure readiness shape implementation. The study applies a structured qualitative comparison based on policy documents, official statistics, reports by international organizations, and peer-reviewed research. It identifies two distinct pathways. Uzbekistan follows an accelerated, investment-led model based on public-private partnerships, independent power producers, and large-scale solar and wind deployment. Kazakhstan follows an incremental, legacy-constrained model shaped by coal-fired generation, district heating, energy-intensive industry, and the social costs of structural adjustment. The comparison reveals different implementation gaps: Uzbekistan risks expanding generation faster than its grid, tariff system, off-taker, and domestic technical capacity can adapt, whereas Kazakhstan risks adopting advanced policy instruments without sufficient fossil-fuel displacement. The article argues that installed capacity and policy targets are insufficient indicators of transition progress. More meaningful evaluation requires attention to actual renewable generation, grid integration, fossil-fuel displacement, fiscal sustainability, and distributional effects.

Keywords: renewable energy transition, Uzbekistan, Kazakhstan, carbon lock-in, energy policy, Central Asia

Funding: This research paper was supported by Ministry of Science and Higher Education of the Republic of Kazakhstan under Grant «AP26103599 Challenges and opportunities for regional cooperation in sustainable water resources management in Central Asia»

Introduction

The transition to renewable energy has become a strategic priority for Uzbekistan and Kazakhstan, driven by rising electricity demand, aging infrastructure, climate commitments, and the need to reduce the economic risks of carbon-intensive development. Natural gas accounted for approximately 76% of electricity generation in Uzbekistan in 2023, while coal provided about 58% of Kazakhstan's electricity generation, illustrating the different fossil-fuel structures from which the two transitions begin [1; 2]. Although both countries have adopted renewable energy targets and market-oriented instruments, their pathways differ substantially. Uzbekistan is pursuing accelerated solar and wind deployment through foreign investment, public-private partnerships, and electricity-sector reform, whereas Kazakhstan follows a more gradual trajectory shaped by coal-fired generation, energy-intensive industries, and the wider economic importance of hydrocarbons [3; 4].

Existing studies have examined renewable resource potential, national climate commitments, and individual policy instruments in Central Asia. However, less attention has been paid to the implementation gap between formal targets and the institutional, infrastructural, and financial capacity required to achieve them. This gap is particularly important because growth in installed renewable capacity does not necessarily produce a proportional increase in renewable electricity generation. Its effect depends on grid flexibility, transmission capacity, storage, tariff design, and the ability of regulatory institutions to coordinate public and private actors. Moreover, national strategies must respond simultaneously to domestic supply pressures and regional climate commitments [5; 6].

The contrast between Uzbekistan and Kazakhstan illustrates two distinct transition models. Uzbekistan's strategy is driven by the need to expand electricity supply, reduce pressure on domestic gas availability, and attract external capital. Its utility-scale renewable program has been supported by institutional restructuring, independent power producers, and international financial institutions [4; 7; 8; 9]. Nevertheless, rapid capacity expansion may outpace transmission, storage, and balancing infrastructure and may increase exposure to foreign technologies, developers, and long-term contractual obligations. Uzbekistan's model should therefore be assessed not only through announced or commissioned capacity, but also through grid readiness, financial sustainability, and domestic technological absorption.

Kazakhstan faces a different form of transition constraint. Coal remained the country's largest source of electricity generation in 2023, accounting for approximately 58% of output, while coal-based electricity and heating infrastructure remains closely linked to industrial production and regional energy systems [2; 3; 10]. Kazakhstan has adopted a target of increasing the share of renewable energy to 15% by 2030 and aims to achieve carbon neutrality by 2060 [11; 12]. However, renewable support mechanisms coexist with regulated prices, legacy thermal assets, and the continued economic role of domestic coal. This creates a fundamental policy tension between decarbonization, energy affordability, industrial competitiveness, and the social costs of structural adjustment.

Both countries face common constraints. Aging power infrastructure, transmission and distribution losses, limited system flexibility, and the early stage of utility-scale storage deployment restrict the integration of variable generation and increase capital requirements [3; 8; 13]. In Uzbekistan, the World Bank has identified transmission and distribution modernization, utility financial reform, and cost-recovery tariffs as central conditions for reliable renewable integration [8; 13]. Regional electricity cooperation may improve balancing and cross-border exchanges, but interconnection cannot substitute for domestic reforms in tariff policy, utility governance, infrastructure investment, and technical capacity [1; 2].

Against this background, the article addresses the following research question: why have Uzbekistan and Kazakhstan adopted different renewable energy transition models, and how do their institutional structures, legacy energy systems, and investment frameworks affect the implementation of national decarbonization targets? The analysis compares the two countries across five dimensions: initial energy-system conditions, policy and regulatory instruments, investment models, infrastructure readiness, and implementation constraints. It distinguishes official targets from operational outcomes and evaluates the extent to which current policies address, rather than reproduce, existing structural dependencies.

The article argues that Uzbekistan represents an accelerated, investment-led capacity expansion model, whereas Kazakhstan follows an incremental, legacy-constrained model of structural adjustment. Neither pathway is inherently superior. Uzbekistan has achieved greater deployment momentum, but its approach remains vulnerable to grid limitations, external financial dependence, and weak domestic technological capacity. Kazakhstan possesses a more developed long-term policy framework, but continued support for coal-based generation and carbon-intensive industries limits the depth and speed of implementation. Multilateral financial institutions can reduce investment risks and support regulatory reform, but sustained progress ultimately depends on domestic institutional capacity, credible market rules, and technical expertise [5; 14]. The comparison therefore demonstrates that renewable energy targets alone are an insufficient measure of transition performance. The central issue is whether national institutions can convert capacity ambitions into financially viable, technically integrated, and socially sustainable energy-system transformation.

The article argues that Uzbekistan represents an accelerated, investment-led capacity-expansion model, whereas Kazakhstan follows an incremental, legacy-constrained model of structural adjustment. It makes three contributions. First, it develops a comparative typology that links transition speed to legacy fuel structures and institutional risk allocation. Second, it distinguishes between an integration-capacity gap in Uzbekistan and a fossil-fuel-displacement gap in Kazakhstan. Third, it proposes that transition performance should be evaluated through actual renewable generation, fossil-fuel displacement, grid adaptability, and institutional and social sustainability rather than installed capacity alone. Neither pathway is inherently superior; their effectiveness depends on whether policy ambition is converted into technically integrated, financially viable, and socially acceptable structural change.

Description of Materials and Methods

Energy transition in fossil-fuel-dependent economies is shaped not only by renewable resource potential and technology costs, but also by established infrastructure, institutions, industrial structures, and incumbent interests. The literature conceptualizes this persistence as carbon lock-in and path dependence, whereby previous investments and policy arrangements reinforce fossil-fuel systems and constrain alternative development pathways [15; 16]. Socio-technical transition research similarly emphasizes that technological substitution depends on changes in regulation, markets, infrastructure, and user practices rather than on technology costs alone [17]. Consequently, renewable capacity may expand without substantially reducing fossil-fuel generation.

This problem is particularly relevant to Kazakhstan and Uzbekistan, whose energy systems share a post-Soviet institutional legacy but differ in their dominant forms of fossil-fuel dependence. Natural gas accounted for approximately 76% of electricity generation in Uzbekistan in 2023, whereas coal supplied about 58% in Kazakhstan [1; 2]. These differences affect the pace of transition, the infrastructure that must be replaced or adapted, and the distribution of economic and social costs.

Research and policy assessments on Kazakhstan emphasize the contradiction between ambitious climate commitments and the continued structural importance of coal and hydrocarbons. Although the country has adopted green-economy and carbon-neutrality strategies, implementation remains constrained by aging thermal assets, regulated pricing, industrial dependence, and weaknesses in sector governance [3; 10]. Modernization of existing thermal facilities may improve efficiency, but without a credible retirement pathway it may also extend the life of carbon-intensive infrastructure and reinforce carbon lock-in.

Uzbekistan follows a more accelerated model driven by growing electricity demand and the need to diversify a gas-dominated power system. Foreign investment, public-private partnerships, independent power producers, and large-scale solar and wind projects have enabled rapid project development [4; 7; 9]. However, this model creates different vulnerabilities, including exposure to foreign-currency financing, imported technologies, long-term power-purchase obligations, and the capacity of the national grid to absorb variable generation.

Institutional capacity is therefore central to explaining transition outcomes. Renewable energy targets and legislation are insufficient unless supported by transparent procurement, effective tariff regulation, credible off-takers, grid access, utility reform, and coordination between public authorities and private investors. Uzbekistan's reforms have included sector unbundling, transmission modernization, and expanded private participation, while Kazakhstan has combined feed-in tariffs, auctions, carbon pricing, and long-term strategic planning [3; 4; 8]. The analytical issue is not simply whether market-oriented instruments exist, but whether they alter incentives and produce measurable structural change.

International financial institutions can reduce project risks, provide technical assistance, and mobilize capital. In Uzbekistan, World Bank Group operations have supported independent power producers, transmission reform, battery storage, and long-term power-purchase arrangements [4; 8; 9]. Nevertheless, foreign investment should not be treated as an indicator of transition success by itself. Its long-term contribution depends on technology transfer, local expertise, fiscal sustainability, domestic value creation, and the financial position of the electricity off-taker.

Infrastructure represents another major constraint. Uzbekistan's transmission and distribution networks require substantial modernization to meet growing demand and integrate renewable generation, while Kazakhstan's aging thermal and network assets reduce flexibility and reliability [3; 8; 13]. In Uzbekistan, renewable projects may be commissioned faster than transmission and balancing infrastructure can be upgraded. Kazakhstan faces additional spatial constraints because renewable resources and major industrial demand centers are unevenly distributed across a large national grid [18].

Regional electricity cooperation could improve balancing and facilitate cross-border trade because interconnected systems can offset differences in supply and demand as variable renewable generation increases [1; 2]. However, its effectiveness depends on compatible technical standards, transparent commercial arrangements, adequate metering, and modern national networks. Regional integration should therefore complement rather than replace domestic reform.

The social consequences of transition also differ. Kazakhstan must address the effects of coal reduction on industrial regions, heating systems, and employment, while Uzbekistan faces affordability risks associated with cost-recovery tariff reform and the financial obligations of an investment-led generation model [3; 13; 19]. A just transition therefore requires country-specific instruments rather than a uniform regional model [20].

Regional scholarship has expanded from resource-potential assessments toward institutional, geopolitical, and implementation questions. Djalilova (2021) examines the policy and socio-economic conditions shaping renewable deployment in Uzbekistan; Sulaimanova et al. (2023) show that Central Asian energy-transition research remains comparatively sparse and fragmented; Zabanova (2023) emphasizes the geoeconomic implications of transition for hydrocarbon-producing states; and Sabyrbekov et al. (2023) question whether regional climate pledges are consistent with national development trajectories. However, comparative work still rarely distinguishes announced targets, contracted projects, installed capacity, actual generation, and fossil-fuel displacement, or explains why similar instruments produce different outcomes under different institutional and energy-system conditions.

This article addresses this gap by comparing Kazakhstan and Uzbekistan through three analytical dimensions. The first is legacy energy dependence, including fuel structure, infrastructure, industrial specialization, and fiscal interests. The second is institutional and investment capacity, covering regulation, procurement, utility governance, tariff policy, and access to finance. The third is implementation capacity, defined as the ability to convert policy targets into technically integrated, financially sustainable, and socially acceptable structural change.

The article conceptualizes Uzbekistan as an accelerated, investment-led transition model and Kazakhstan as an incremental, legacy-constrained model. This distinction allows the analysis to evaluate not only renewable capacity growth, but also whether current policies reduce structural dependence on fossil fuels.

This study employs a comparative qualitative case-study design based on a structured, focused comparison of Kazakhstan and Uzbekistan. The countries were selected because they share a post-Soviet institutional legacy, strong state involvement in energy governance, aging infrastructure, substantial fossil-fuel resources, and increasing reliance on international investment. At the same time, they differ in their principal energy dependence: Uzbekistan relies primarily on natural gas, whereas Kazakhstan remains strongly dependent on coal. This variation makes it possible to examine how different legacy energy systems shape transition strategies and implementation outcomes.

The analysis combines a structured qualitative comparison with comparative policy analysis, qualitative content analysis, selected descriptive energy indicators, and chronological document analysis. Policy analysis is used to examine renewable energy targets, legislation, procurement mechanisms, tariff reforms, utility restructuring, and investment incentives. Qualitative content analysis is applied to government strategies, laws, reports by international organizations, and peer-reviewed studies. Selected indicators are used to contextualize differences in electricity generation, renewable deployment, and infrastructure conditions. Chronological document analysis distinguishes policy announcements from subsequent contracting, construction, commissioning, and institutional reform.

The empirical base includes national legislation and strategic documents, official statistics, reports by the OECD, World Bank, ADB, EBRD, IRENA, and United Nations agencies, documents issued by national energy institutions, and peer-reviewed publications. Primary and institutionally authoritative sources are prioritized when verifying targets and quantitative indicators. Secondary sources are used mainly to interpret institutional and political-economic developments.

The analysis covers the period from 2015 to 2025, during which both countries expanded renewable energy regulation, procurement mechanisms, and international investment. Earlier developments are considered where necessary to explain infrastructure and institutional path dependence.

The cases are compared across five groups of indicators:

fossil-fuel dependence and electricity-system structure;

renewable energy targets and regulatory instruments;

investment, procurement, and tariff mechanisms;

grid readiness and infrastructure constraints;

implementation outcomes and social costs.

Policy performance is evaluated at three levels: policy ambition, operational implementation, and structural transformation. This distinction prevents formal targets or contracted capacity from being treated as equivalent to actual generation or fossil-fuel displacement.

The study has several limitations. National statistics are not always directly comparable because sources use different definitions of installed capacity, generation, total energy consumption, and renewable energy. Government targets are also frequently revised. In addition, information on power purchase agreements, sovereign guarantees, and project risk allocation is often incomplete. Several projects remain under construction, which prevents a definitive assessment of their long-term contribution. Finally, the research is based primarily on documentary evidence and does not include stakeholder interviews.

Results

Comparative Energy and Policy Indicators

Table 1. Comparative energy and policy indicators

Indicator	Uzbekistan	Kazakhstan	Source
Dominant electricity source, 2023	Natural gas: approximately 76%	Coal: approximately 58%	[1; 2]
2030 renewable-policy objective	At least 25% of electricity generation under the 2019 strategy; later plans revised upward	15% of electricity generation	[7; 12]
Core procurement model	Project-specific tenders, PPPs, IPPs and long-term PPAs	Competitive auctions following feed-in-tariff support	[3; 21; 22]
Key reform milestone	Renewable-energy and PPP laws adopted in 2019; electricity-sector unbundling	Renewable auctions introduced in 2018; carbon-neutrality strategy adopted in 2023	[3; 7; 8; 11]
Grid and flexibility priority	Transmission and distribution modernization; battery storage at an early deployment stage	Renewal of aging assets, interregional transmission and flexible balancing	[3; 8; 9; 13]
Long-term climate orientation	Renewable expansion and lower carbon intensity under evolving national targets	Carbon neutrality by 2060	[6; 11]

Table 2. Comparative analytical framework

Analytical dimension	Uzbekistan	Kazakhstan
Primary transition driver	Electricity-demand growth and diversification of a gas-dominated system	Decarbonization and renewal of a coal-dependent electricity and heating system
Transition model	Accelerated, investment-led expansion	Incremental, legacy-constrained adjustment
Principal implementation gap	Generation investment may outpace grid, tariff, off-taker and technical capacity	Formal policy instruments may not produce sufficient coal displacement
Main financial risk	Foreign-currency, contractual and off-taker exposure	Policy uncertainty and delayed structural adjustment
Main social risk	Affordability effects of cost-recovery tariffs	Concentrated costs in coal-dependent industrial and heating regions
Priority for structural transformation	Grid integration, utility solvency and domestic technological absorption	Credible coal-reduction pathway, heat modernization and just-transition policy

Uzbekistan: Gas Dependence and Capacity Expansion

Uzbekistan’s electricity system remains dominated by natural gas, which accounted for approximately 76% of electricity generation in 2023 [1]. This concentration has supported a centralized thermal power system but has also increased exposure to rising demand, supply pressures, and inefficient energy use. Earlier IEA assessments identified natural gas as providing more than 85% of electricity in 2019, indicating that diversification has begun but the system remains strongly gas-dependent [7].

The government has responded by prioritizing solar and wind energy as instruments of both diversification and supply expansion. Uzbekistan has substantial solar potential, and national policy has increasingly linked renewable deployment to energy security, private investment, and electricity-sector modernization [4; 7]. The transition is therefore driven not only by climate commitments but also by the need to meet growing electricity demand without proportionally increasing gas-fired generation.

Since 2017, the government has introduced legal and institutional reforms intended to attract private investors. The Law on the Use of Renewable Energy Sources and the Law on Public-Private Partnership were adopted in 2019, establishing a legal basis for renewable support and private participation [7; 21; 22]. Electricity-sector restructuring subsequently separated key generation, transmission, and distribution functions, while international development partners supported institutional reform and the modernization of the national transmission company [8].

These measures have facilitated independent power projects, competitive tenders, and long-term power-purchase agreements for utility-scale solar, wind, and battery-storage projects. World Bank Group operations have supported project preparation, financing, and risk allocation, including a 25-year power-purchase agreement for a solar-plus-storage project developed by a private investor [4; 9]. Uzbekistan has consequently expanded both contracted and commissioned renewable capacity, although installed capacity and actual generation should be assessed separately.

However, the expansion model remains exposed to several risks. Official targets have been revised over time and do not always use consistent definitions of installed capacity, electricity generation, and the broader energy mix [7]. Rapid growth in contracted capacity may also outpace investment in transmission, distribution, storage, and balancing infrastructure [8; 13]. Dependence on foreign financing and imported equipment may limit domestic value creation, while long-term contracts create contingent payment and foreign-currency exposure whose scale is not always publicly disclosed.

Electricity tariff reform represents an additional challenge. The World Bank identifies the transition toward separate cost-recovery transmission and distribution tariffs as a priority for sector development and financial sustainability [13]. However, higher tariffs may create affordability pressures for vulnerable households. Reform should therefore combine improved cost recovery with targeted social protection rather than generalized price suppression.

Overall, Uzbekistan's transition is characterized by rapid capacity expansion supported by centralized decision-making and foreign investment. Its principal challenge is no longer the absence of renewable projects, but the ability to integrate them into a financially viable and technically flexible electricity system.

Kazakhstan: Coal Dependence and Structural Inertia

Kazakhstan's transition begins from a more carbon-intensive baseline. Coal supplied approximately 58% of electricity generation in 2023 and remains deeply embedded in the country's power and heating systems [2]. Coal-based generation is closely connected to mining, metallurgy, district heating, and regional industrial activity, making rapid reduction economically and politically complex [3; 10].

Kazakhstan has substantial wind and solar resources, and renewable electricity has expanded through feed-in tariffs and competitive auctions. The country introduced renewable auctions in 2018 and has adopted a target of increasing the share of renewable energy to 15% by 2030, alongside a commitment to carbon neutrality by 2060 [3; 11; 12]. Auctions have strengthened price competition, although the effect of lower bids depends on project completion, grid connection, and sufficient balancing capacity.

Nevertheless, the policy framework contains significant contradictions. Renewable energy is promoted through auctions and investment incentives, while coal-fired generation continues to benefit from established infrastructure, domestic fuel availability, and regulated electricity and heat prices [3; 23]. These conditions weaken incentives for early thermal-asset retirement and may extend the operational life of coal-based generation.

The physical condition of the power system further constrains transition. OECD assessments identify aging generation and network infrastructure, governance weaknesses, and the need for substantial investment to improve security of supply and energy efficiency [3]. Aging assets contribute to losses, outages, and limited operational flexibility. Integrating variable renewable energy therefore requires investment not only in generation but also in transmission, dispatch systems, storage, and flexible balancing resources.

Geography creates an additional challenge. Kazakhstan's wind and solar resources are distributed across a large territory, while major industrial demand is concentrated in historically coal-supplied regions. IEA analysis identifies extensive wind potential across the country, but greater renewable penetration requires stronger interregional transmission and coordination between resource-rich areas and demand centers [18].

Kazakhstan's emissions trading system provides a formal carbon-pricing mechanism, but policy assessments indicate that its price signal and coordination with wider energy-sector reform require strengthening [3; 24]. Best Available Techniques may reduce industrial pollution and improve efficiency, yet efficiency measures alone are unlikely to deliver the structural decline in coal use required for deep decarbonization [10].

The social dimension is particularly important. Coal use is linked to industrial activity and heating, and coal combustion remains a major source of urban air pollution in Kazakhstan [10; 19]. An accelerated phase-out without regional diversification, worker retraining, and heat-sector modernization could concentrate economic costs in particular communities. Gradualism may therefore reduce short-term disruption, but it also risks postponing structural reform unless accompanied by a credible and measurable coal-reduction pathway.

Kazakhstan's transition can consequently be characterized as a state-managed process of incremental adjustment. Its main challenge is not the absence of renewable energy policy, but the persistence of institutional and economic arrangements that protect coal-based generation.

Regulatory and Investment Frameworks

Uzbekistan and Kazakhstan have introduced market-oriented instruments to expand renewable energy, but their implementation models differ. Uzbekistan relies primarily on centralized procurement, public-private partnerships, and government-coordinated agreements with foreign developers [4; 21; 22]. Kazakhstan has developed a broader framework combining feed-in tariffs, competitive auctions, strategic planning, and emissions regulation [3].

Uzbekistan's institutional reforms have facilitated the development of utility-scale renewable projects. The 2019 renewable-energy and public-private-partnership laws established a legal basis for private participation, while electricity-sector restructuring separated key functions and strengthened the role of the national transmission company [7; 8; 21; 22]. The government and international development partners subsequently supported independent power projects and long-term power-purchase agreements [4; 9].

The main strength of the Uzbek model is its capacity to mobilize international capital and implement large projects rapidly. The World Bank Group and other development institutions have supported project preparation, contractual design, transmission reform, and investment-risk mitigation [4; 8; 9]. This support has accelerated deployment, although its long-term developmental effect depends on domestic institutional learning and technology transfer.

However, this investment-led model presents financial and institutional risks. Dependence on foreign developers, imported technologies, and external financing may restrict domestic value creation. Long-term power-purchase agreements may also generate payment and foreign-currency exposure for the off-taker, particularly where retail and network tariffs do not recover sector costs. The sustainability of this model therefore depends on tariff reform, utility solvency, transparent contingent-liability management, and domestic technical capacity [13].

Kazakhstan has placed greater emphasis on competitive procurement. Renewable energy auctions were introduced in 2018 and have strengthened price competition among developers [3]. However, auction outcomes do not in themselves demonstrate structural transformation. Their effect depends on project completion, timely grid connection, predictable procurement volumes, and sufficient transmission and balancing capacity.

The effectiveness of Kazakhstan's renewable policy is also limited by weak coordination with the economics of incumbent generation. Coal-fired plants retain advantages derived from domestic fuel, existing infrastructure, and regulated electricity and heat prices [3; 23]. Renewable support therefore coexists with arrangements that preserve conventional generation, weakening incentives for thermal-asset retirement and prolonging carbon lock-in.

The comparison indicates that Uzbekistan prioritizes implementation speed through centralized coordination, whereas Kazakhstan relies more heavily on competitive selection and gradual market reform. Uzbekistan's approach has accelerated project delivery but increased exposure to external financial and technological dependence. Kazakhstan's model provides stronger formal competition, yet its transformative effect remains limited by the continued protection of coal-based generation.

Tariff Policy and Market Distortions

Electricity tariffs are a central constraint in both transition models. Below-cost or administratively regulated prices can support short-term affordability and industrial production, but they also weaken incentives for efficiency and limit the revenues available for infrastructure investment. World Bank assessments identify tariff reform and stronger utility finances as central to electricity-sector modernization in Uzbekistan and Kazakhstan [13; 23].

In Uzbekistan, tariff reform is necessary to improve the financial sustainability of transmission, distribution, and long-term obligations to private generators. The World Bank identifies separate cost-recovery transmission and distribution tariffs as a priority, while also emphasizing the protection of vulnerable consumers [13]. Reform should therefore combine gradual cost recovery with targeted social support.

In Kazakhstan, regulated electricity and heating prices and the low cost of domestic coal reduce incentives for rapid fuel switching. Recent tariff reforms may create additional financing for needed investment, but price increases must be coordinated with heat-sector modernization and social protection [23]. The pricing system thus remains a key link between renewable policy, infrastructure investment, and the continued competitiveness of coal-based generation.

Kazakhstan's emissions trading system could strengthen this price signal by raising the cost of carbon-intensive production. However, OECD assessments indicate that the system's coverage, price signal, and integration with wider climate and energy policy require further strengthening [3; 24]. Effective decarbonization therefore requires coordination among renewable procurement, carbon pricing, tariff regulation, and industrial modernization.

In both countries, tariff reform involves a trade-off between financial viability and social affordability. Maintaining artificially low prices restricts infrastructure investment, while rapid increases may intensify energy poverty and undermine public support for reform. The effectiveness of tariff policy should therefore be assessed not only through price liberalization, but also through the design of targeted protection for vulnerable consumers.

Grid Modernization and System Integration

The expansion of renewable capacity requires parallel investment in transmission, storage, balancing, and digital system management. Uzbekistan's transmission and distribution systems require major modernization to meet growing demand and integrate renewable projects, while Kazakhstan's aging generation and network assets constrain flexibility and reliability [3; 8; 13].

Uzbekistan faces a potential sequencing problem. Solar, wind, and battery projects are being developed alongside major transmission and distribution reforms, indicating that grid readiness is a recognized constraint [8; 9; 13]. If network and balancing investments lag behind project commissioning, capacity growth may increase congestion, curtailment risk, or dependence on thermal balancing. Renewable deployment should therefore be evaluated through actual generation and system absorption rather than installed capacity alone.

Kazakhstan faces both technical and geographical constraints. OECD assessments identify aging infrastructure and substantial investment needs, while IEA analysis points to large but geographically dispersed renewable resources [3; 18]. Their integration requires stronger interregional transmission, modern dispatch systems, and flexible generation or storage capacity.

Utility-scale battery storage is beginning to enter Uzbekistan's project portfolio, but remains at an early stage of deployment; Kazakhstan likewise requires additional flexibility as renewable penetration increases [3; 9]. Digital dispatch, forecasting, demand response, and smart-grid technologies can improve system management, but they cannot compensate for inadequate transmission capacity or inconsistent market rules.

Regional interconnection may provide additional flexibility by enabling cross-border balancing and electricity trade. The IEA notes that direct interconnections can help balance supply and demand as variable renewable generation grows [1; 2]. Nevertheless, regional cooperation depends on modern national networks, compatible technical standards, transparent pricing, and enforceable contractual arrangements.

Technology Transfer and Domestic Capacity

Both countries depend substantially on imported renewable equipment, engineering services, project finance, and specialized expertise. This dependence can accelerate deployment but may limit domestic value creation and increase exposure to supply-chain and foreign-currency risks. In Uzbekistan, the prominent role of foreign independent power producers illustrates both the mobilizing effect of external capital and the need for domestic technical absorption [4; 9].

Uzbekistan's foreign-investment-led model creates opportunities for technology transfer, but such transfer is not automatic. Large-scale projects may remain technologically dependent on external developers if domestic participation is limited to construction and low-value services. Long-term benefits require the development of local engineering, maintenance, grid-management, and research capabilities.

Kazakhstan has a broader industrial base that could support selected renewable energy supply chains. However, domestic production requires predictable long-term demand, stable procurement volumes, and access to international technologies. Irregular auction schedules and uncertain market growth may discourage investment in local manufacturing.

Human-capital development is therefore essential in both cases. Specialized education and vocational training are required in renewable engineering, storage, digital dispatch, energy economics, and project management. This is an analytical implication of the documented reliance on foreign developers, technologies, and technical assistance rather than evidence that capacity-building policies are already sufficient.

Infrastructure and Operational Constraints

The main implementation challenge in both countries is the mismatch between ambitious renewable-energy objectives and the technical capacity of existing power systems. Uzbekistan requires extensive transmission and distribution modernization, while Kazakhstan must renew aging assets and improve system flexibility [3; 8; 13].

In Uzbekistan, rapid project development creates a sequencing problem. New renewable capacity may be commissioned faster than transmission lines, substations, balancing mechanisms, and storage facilities can be modernized. This increases the risk of congestion, curtailment, and continued reliance on gas-fired plants to stabilize the system. Consequently, growth in installed capacity should not be interpreted automatically as evidence of a proportional increase in renewable electricity consumption.

Kazakhstan faces a more complex technical constraint because its power system remains dominated by aging and relatively inflexible coal-fired generation. A substantial share of generation and heating infrastructure has operated for several decades, while depreciation levels remain high [3]. The geographical separation between renewable-rich regions and major industrial demand centers further increases the need for long-distance transmission and interregional balancing.

Limited storage and flexibility remain common constraints, although Uzbekistan has begun to introduce battery systems through privately financed projects [9]. Without storage, flexible generation, demand response, and stronger interconnections, higher shares of variable electricity may increase operational risks. Digital dispatch and forecasting can improve system management, but their effectiveness depends on physical infrastructure and market reform.

Financial and Institutional Risks

Both transition models depend on external capital, but the distribution of financial risk differs. Uzbekistan has attracted private investment through public-private partnerships and long-term power-purchase agreements, including projects backed by World Bank Group guarantees and financing [4; 9]. This model accelerates implementation but may create contingent payment and foreign-currency obligations for the state-owned off-taker.

These risks are particularly important where tariffs and utility revenues do not fully recover system costs. World Bank assessments identify cost-recovery tariff reform and financial strengthening of electricity companies as priorities in Uzbekistan [13]. If utility revenues remain insufficient, contractual and network-investment costs may be transferred to the state through subsidies, guarantees, or accumulated debt.

Kazakhstan's investment risks are more closely related to policy inconsistency. Auctions support renewable procurement, while regulated prices and the continued role of coal weaken incentives for structural change [3]. Investors may therefore face uncertainty concerning future procurement volumes, grid investment, and the pace of thermal-asset retirement.

Institutional fragmentation also affects both countries. Market-oriented instruments coexist with strong state control over utilities, tariffs, and investment decisions. Incomplete restructuring can limit competition and obscure the allocation of financial responsibilities. Therefore, the adoption of auctions or public-private partnerships should not be equated with full market liberalization.

Social and Political Constraints

The distributional consequences of decarbonization differ significantly between the two cases. In Kazakhstan, coal is embedded in electricity generation, heating, and industrial activity, concentrating transition costs in particular regions and communities [3; 10; 19]. Without retraining, regional diversification, and heat-sector modernization, accelerated decarbonization could generate resistance and deepen territorial inequalities.

This explains, but does not fully justify, Kazakhstan's gradual transition strategy. A phased approach can reduce short-term disruption, yet it may also provide political justification for postponing structural reforms. The critical issue is whether gradualism is accompanied by a credible timetable for reducing coal use or merely preserves the existing energy structure.

Uzbekistan faces a different social challenge. The financial sustainability of its investment-led model depends partly on cost-recovery electricity tariffs, but tariff increases may reduce affordability for vulnerable households and small firms. World Bank policy documents therefore link tariff reform with targeted social protection [13].

In both countries, the transition requires a just-transition framework, but its content must reflect national conditions. Kazakhstan needs policies for coal-dependent workers and regions, whereas Uzbekistan requires stronger protection against the regressive effects of tariff reform.

Regional Cooperation as a Supporting Mechanism

Regional electricity cooperation could improve the flexibility and reliability of renewable integration. Cross-border interconnections can help offset differences in supply and demand and become more valuable as solar and wind generation increase [1; 2].

However, regional cooperation is frequently presented too broadly in policy discussions. Its effectiveness depends on compatible grid codes, transparent pricing, reliable metering, data exchange, and enforceable commercial agreements. Political declarations alone cannot resolve national infrastructure deficiencies or utility insolvency.

Regional integration should therefore be treated as a supporting mechanism rather than the central solution to domestic transition problems. Its main contribution lies in improving balancing and resource utilization once national systems have achieved sufficient technical and institutional readiness.

Discussion

The comparison demonstrates that renewable-energy transition in Central Asia is mediated by legacy fuel structures rather than determined by resource potential alone. Uzbekistan's gas-dominated system creates pressure for rapid diversification as electricity demand grows, whereas Kazakhstan's coal dependence is more deeply embedded in fixed generation assets, district heating, industrial geography, and regional employment. The result is not simply a difference in policy ambition, but two distinct configurations of path dependence [15; 16; 25].

Uzbekistan's accelerated, investment-led model shows how centralized procurement, sector restructuring, and multilateral risk mitigation can mobilize utility-scale investment despite underdeveloped domestic capital markets [4; 8; 9; 14]. Its main implementation gap lies between the speed of generation investment and the capacity of the grid, tariff system, off-taker, and domestic technical base to absorb that investment. Foreign capital is therefore an accelerator, but not a substitute for institutional consolidation or system flexibility.

Kazakhstan's incremental, legacy-constrained model reflects the concentrated social and industrial costs of reducing coal use. Auctions, carbon pricing, and long-term climate strategies broaden the formal policy framework, but their transformative effect remains limited while regulated pricing, aging thermal infrastructure, and coal-dependent heating retain structural advantages [3; 11; 12; 24]. Gradualism is credible only when it is linked to measurable coal reduction, heat-sector modernization, and transition policies for affected regions.

These findings explain why similar instruments produce different outcomes. Competitive procurement, private investment, tariff reform, and grid modernization operate through different institutional environments and distribute risks differently. Uzbekistan accepts greater exposure to external finance, imported technology, and long-term contractual obligations in exchange for implementation speed. Kazakhstan reduces short-term disruption through gradual adjustment, but risks transferring decarbonization costs into the future.

The article makes three contributions. First, it distinguishes accelerated investment-led transition from incremental legacy-constrained adjustment. Second, it identifies different implementation gaps: integration capacity in Uzbekistan and fossil-fuel displacement in Kazakhstan. Third, it argues that transition performance should be assessed through actual renewable generation, fossil-fuel displacement, grid adaptability, and institutional and social sustainability rather than installed capacity alone. This framework complements regional research showing that Central Asian energy-transition scholarship remains fragmented and that national climate pledges are difficult to evaluate without attention to implementation capacity [5; 6].

Regional interconnection can support balancing and cross-border trade, but its contribution remains conditional on domestic grid modernization, financially viable utilities, compatible technical standards, and enforceable market rules [1; 2]. The broader implication is that renewable expansion becomes transformative only when procurement, transmission, tariffs, utility governance, fossil-fuel phase-out, and social policy are sequenced as a coordinated reform package.

Conclusion

This study explains the divergence between renewable-energy transition strategies in Uzbekistan and Kazakhstan through the interaction of legacy energy dependence, institutional and investment capacity, and implementation constraints. Uzbekistan follows an accelerated investment-led pathway, while Kazakhstan pursues incremental adjustment within a coal-dependent electricity, heating, and industrial system.

Uzbekistan has mobilized private and multilateral capital rapidly, but the durability of this model depends on transmission and distribution modernization, cost-recovery reform, off-taker solvency, technology transfer, and domestic technical capacity. Kazakhstan has developed a broader set of formal instruments, but their effectiveness depends on whether auctions, carbon pricing, and infrastructure investment are linked to a credible reduction in coal use and a socially managed transformation of heating and industrial regions.

Neither model is inherently superior. Uzbekistan's principal risk is expansion without sufficient system integration; Kazakhstan's is policy ambition without adequate fossil-fuel displacement. Renewable targets and installed capacity are therefore incomplete indicators of progress. Actual generation, grid absorption, displacement of fossil fuels, fiscal sustainability, and distributional effects provide a more meaningful basis for evaluation.

The analysis is limited by inconsistent national statistics, revised targets, incomplete disclosure of contractual risk allocation, and the ongoing construction of several major projects. Future research should combine documentary comparison with project-level data and interviews with regulators, utilities, investors, workers, and affected communities.

Overall, renewable-energy expansion becomes transformative only when it is coordinated with grid development, tariff reform, utility restructuring, fossil-fuel phase-out, domestic capacity building, and social protection. Without such coordination, renewable energy may remain an additional source of electricity rather than a foundation for structural decarbonization.

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ӨЗБЕКСТАН МЕН ҚАЗАҚСТАННЫҢ ЖАҢАРТЫЛАТЫН ЭНЕРГИЯ КӨЗДЕРІНЕ КӨШУ СТРАТЕГИЯЛАРЫ: САЛЫСТЫРМАЛЫ ТАЛДАУ

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Аңдатпа. Мақалада Өзбекстан мен Қазақстанның жаңартылатын энергия көздеріне көшу стратегиялары салыстырылып, олардың іске асуына қалыптасқан энергетикалық жүйе, мемлекеттік институттардың мүмкіндігі, инвестиция тарту тетіктері және инфрақұрылымның жай-күйі қалай ықпал ететіні қарастырылады. Зерттеу саяси-құқықтық құжаттарды, ресми статистиканы, халықаралық ұйымдардың есептерін және рецензияланған ғылыми еңбектерді салыстыра талдауға негізделген. Талдау екі түрлі бағыттың қалыптасқанын көрсетеді. Өзбекстан мемлекеттік-жекешелік әріптестікке, тәуелсіз энергия өндірушілерге және күн мен жел энергетикасын жедел дамытуға сүйенетін инвестициялық үлгіні ұстанып отыр. Қазақстанның бағыты көмір электр станцияларына, орталықтандырылған жылумен қамту жүйесіне, энергияны көп қажет ететін өнеркәсіпке және құрылымдық өзгерістердің әлеуметтік салдарына тәуелді болғандықтан, біртіндеп жүзеге асырылуда. Екі елдегі негізгі қиындықтар да әртүрлі. Өзбекстанда жаңа қуаттардың іске қосылу қарқыны электр желілерінің, тарифтік жүйенің, электр энергиясын сатып алушы ұйымның және отандық техникалық мамандардың бейімделу мүмкіндігінен озып кетуі ықтимал. Қазақстанда заманауи реттеу тетіктері енгізілгенімен, көмір мен басқа да қазба отындарының үлесін нақты азайту баяу жүруі мүмкін. Зерттеу нәтижелері орнатылған қуат пен ресми мақсаттар энергетикалық өзгерістердің шынайы нәтижесін толық көрсете алмайтынын аңғартады. Сондықтан бағалау кезінде жаңартылатын көздерден өндірілген нақты электр көлемін, оның ұлттық желіге қосылу деңгейін, қазба отындарын алмастыру ауқымын, қаржылық тұрақтылықты және әлеуметтік салдарды қатар ескеру қажет.

Тірек сөздер: жаңартылатын энергия, энергетикалық өзгеріс, Өзбекстан, Қазақстан, көміртекке тәуелділік, энергетикалық саясат, Орталық Азия

Қаржыландыру: Бұл ғылыми мақала Қазақстан Республикасы Ғылым және жоғары білім министрлігінің AP26103599 «Орталық Азиядағы су ресурстарын орнықты басқару саласындағы өңірлік ынтымақтастықтың сын-қатерлері мен мүмкіндіктері» гранты аясында дайындалды.

СТРАТЕГИИ ПЕРЕХОДА К ВОЗОБНОВЛЯЕМОЙ ЭНЕРГЕТИКЕ В УЗБЕКИСТАНЕ И КАЗАХСТАНЕ: СРАВНИТЕЛЬНЫЙ АНАЛИЗ

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Аннотация. В статье сопоставляются стратегии перехода к возобновляемой энергетике в Узбекистане и Казахстане. Основное внимание уделено тому, как сложившаяся структура энергетики, возможности государственных институтов, механизмы привлечения инвестиций и состояние инфраструктуры влияют на реализацию заявленных целей. Исследование основано на структурированном качественном сравнении нормативно-правовых и программных документов, официальной статистики, отчетов международных организаций и рецензируемых научных публикаций. Выявлены две различные модели энергетических преобразований. Узбекистан развивает инвестиционно ориентированную модель, основанную на государственно-частном партнерстве, участии независимых производителей электроэнергии и быстром расширении солнечной и ветровой генерации. Казахстан движется более постепенно, поскольку сохраняет высокую зависимость от угольной энергетики, централизованного теплоснабжения и энергоемкой промышленности, а также вынужден учитывать социальные последствия структурных преобразований. Различаются и основные трудности реализации. В Узбекистане ввод новых генерирующих мощностей может опережать модернизацию электрических сетей, тарифной системы, единого закупщика электроэнергии и подготовку национальных технических кадров. В Казахстане внедрение современных инструментов регулирования не всегда сопровождается заметным сокращением использования угля и других видов ископаемого топлива. Результаты исследования показывают, что установленная мощность и официальные целевые показатели не отражают в полной мере фактические результаты энергетических преобразований. Более точная оценка должна учитывать реальный объем выработки электроэнергии из возобновляемых источников, ее интеграцию в энергосистему, замещение ископаемого топлива, финансовую устойчивость и социально-экономические последствия.

Ключевые слова: возобновляемая энергетика, энергетический переход, Узбекистан, Казахстан, углеродная зависимость, энергетическая политика, Центральная Азия

Финансирование: Данная научная статья подготовлена при поддержке Министерства науки и высшего образования Республики Казахстан в рамках гранта AP26103599 «Вызовы и возможности регионального сотрудничества в области устойчивого управления водными ресурсами в Центральной Азии».

Received / Мақала түсті / Статья поступила: 08.05.2026.
Accepted / Жариялауға қабылданды / Принята к публикации: 26.06.2026

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