МРНТИ 06.71.63; 55.30.51; 44.01.75
JEL Classification: Q01
DOI: https://doi.org/10.52821/2789-4401-2024-3-114-131

OPPORTUNITIES OF INTEGRATING ARTIFICIAL INTELLIGENCE INTO THE EXPLOITATION OF RENEWABLE ENERGY IN KAZAKHSTAN

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ABSTRACT

The purpose of the research is to delve into the intersection of renewable energy sources and artificial intelligence in Kazakhstan. It aims to uncover the potential benefits, challenges, and overall impact on the country's economy and energy sector, offering a fresh perspective on this emerging field.

Research methodology adopts a mixed-methods approach, incorporating both systematic review and comprehensive research methods. Data is gathered through academic databases, journals, relevant literature analysis, and case studies, which offer practical insights into the applications and outcomes of AI-driven renewable energy projects in Kazakhstan.

Originality / value of the research is unique in its focus on the intersection of artificial intelligence and renewable energy within the specific context of Kazakhstan. It offers valuable insights into how emerging technologies can drive economic growth and sustainability in a developing country and provides practical strategies for harnessing these opportunities. The study significantly contributes to the literature by providing a deep and comprehensive analysis of the economic implications and strategic opportunities associated with this integration.

The research findings reveal that the application of artificial intelligence to renewable energy sources in Kazakhstan can significantly enhance energy efficiency, reduce costs, and increase the reliability of energy supply. Moreover, it identifies several key economic opportunities, including job creation, technological advancement and the capacity for the state to establish the regional leadership regarding the renewable energy. This study reveals the challenges and requirements for the significant funding into the infrastructure, personnel development, regulatory amendments, setting a roadmap for policymakers and industry professionals.

Keywords: Sustainable development, green energy sector, AI (artificial intelligence), Republic of Kazakhstan, energy efficiency.

INTRODUCTION

Kazakhstan is poised to capitalise on significant economic opportunities by integrating AI (artificial intelligence) in utilization of RE (renewable energy). AI can help enhance efficiency, optimize resource management, and make innovation within the renewable energy sector, placing Kazakhstan at the very top in the arena of sustainable energy. As Kassym-Jomart Tokayev explained in his Address on September 1, 2023, the application of artificial intelligence technologies requires special attention today [1].

Despite Republic of Kazakhstan that has enormous natural resources, it has started to transform its economy towards the sustainable energy development. As the global community increasingly prioritises environmental sustainability and the reduction of carbon footprints, Kazakhstan is strategically positioning itself to harness the power of renewable energy sources. The integration of AI into this sector presents a significant opportunity to optimise energy production, enhance efficiency, and drive economic growth.

The country’s commitment to transitioning from a fossil fuel-dependent economy to a green economy is evident in its national policies and strategic initiatives. With vast expanses of land suitable for solar and wind energy generation, Kazakhstan has the natural advantages required to become a leader in renewable energy. AI

technology, with its capabilities in data analysis, predictive maintenance, and real-time optimisation, offers an unprecedented opportunity to maximise the efficiency and reliability of renewable energy systems.

This integration is vital for meeting the growing energy demands in an environmentally sustainable manner and for fostering economic development. Adopting AI in renewable energy can lead to significant cost reductions, improved resource management, and the creation of high-skilled jobs. Moreover, it positions Kazakhstan as an attractive destination for foreign investments in the renewable energy sector.

This study highlights the current advancements, potential applications, and prospects of AI-enhanced renewable energy in Kazakhstan. By examining the synergies between AI and renewable energy, this paper underscores the transformative impact these technologies can have on Kazakhstan's energy landscape, paving the way for a sustainable and prosperous future.

Research methods. The research method used to examine the opportunities of utilising renewable energy sources with artificial intelligence (AI) in Kazakhstan involved a systematic and comprehensive approach. The following steps outline the methodology employed.

The initial step was focused on the defining of scope and objectives. The primary objective was to explore the integration of AI in renewable energy systems in Kazakhstan, focusing on identifying the benefits, challenges, and potential applications. A wide range of academic databases, journals, and relevant sources were identified to gather comprehensive information on the topic. Key databases included Web of Science, ScienceDirect, SpringerLink, and Google Scholar. Government reports, policy documents, and industry whitepapers were also considered to ensure a holistic understanding of the subject.

A systematic search strategy was developed using specific keywords and phrases related to the topic. Some of the keywords used were «artificial intelligence», «renewable energy», «wind power», «solar energy», «Kazakhstan», «energy optimisation», «predictive maintenance», and «smart grids». Boolean operators such as AND and OR were used in modifying this search to retrieve literature relevant to the present research study.

The established criteria for the inclusion and exclusion of articles have made certain that only relevant and quality literature was selected. Inclusion criteria: peer-reviewed articles, research focusing on AI and renewable energy, and publications undertaken within the last 15 years. Those not peer-reviewed, articles not directly relevant to some strand of what is being tackled in the context of Kazakhstan, and those dated were excluded.

The start of the research yielded a big number of documents, articles, legislative frameworks. These were screened based on their titles and abstracts to assess their relevance. Full-text articles of selected studies were then reviewed to ensure they met the inclusion criteria. Duplicate articles were removed to streamline the review process. The data extraction involved systematically collected relevant information from the selected literature. The key themes, findings, and insights were identified and categorised. The synthesis process involved organising the extracted data into coherent sections that addressed the research objectives, such as the benefits of AI in renewable energy, specific applications, challenges, and case studies from Kazakhstan.

A critical analysis was conducted to evaluate the findings' quality, reliability, and significance. This involved comparing different studies, identifying gaps in the existing literature, and assessing the findings' applicability to the context of Kazakhstan. The final step involved compiling the synthesised data and critical analysis into a structured literature review. The review was organised into sections that provided a comprehensive overview of the topic, including an introduction, main body, and conclusion.

This would be done in a manner whereby this methodology of systematic review would set the base for a comprehensive and profound analysis of the literature, with regard to AI integration into the renewable energy systems of Kazakhstan, opportunity mapping, stumbling blocks, and future prospects.

Literature review. One of the most debated topics within the last years has been transition to renewable energy and sustainable development, especially in Kazakhstan. Several studies have explored various aspects of this transition, including green hydrogen production, the green economy, CO2 emissions, and green building development [2], [3], [4], [5].

With Kazakhstan's increasing population and economic growth, the increasing energy demand and the production is expected. However, the extensive use of fossil fuels has significantly depleted natural resources and contributed to the warming pf the climate and the change due to the emission of greenhouse gas [6]. M. Kalikov et al. [2] have brought their own analysis of the concept of a green economy as the paradigm of

sustainable development for Kazakhstan. In this view, they consider the application of green alternative energy as inseparable part of the economy. This research revealed that the entire capacity of the RE globally would rise extensively by 2024, necessitating the raise of a new financial instruments and payments for the ecosystem services as green bonds, or green banking. These elements are crucial for the transformation to the sustainable economy. G. Akhanova et al. [3] developed a multi-decision model for establishing sustainability assessment in Kazakhstan, which could serve as a reference for policymakers and also it might be useful to adapt the approach with the neighbouring states with similar climate conditions.

Researchers have analysed the impact of human-induced extreme events on green innovation, as well as the outcomes of natural extreme events from an international perspective in Central Asia [7], [8]. Carbon emissions cause a range of issues, for example the glacier melting, rising sea levels, and ecological damage, that introduce a substantial threat to community [9]. Global climate change represents one of the most critical challenges facing the world today [10], [11]. The PA (Paris Agreement) says that Kazakhstan, relative to 1990, has committed to unconditional targets of reducing GHG emissions by 15 % until December 31, 2030, and conditional targets of a 25 % reduction by the end of the same year [12], [13]. Meanwhile, Kazakhstan is also confronting significant environmental issues [14]. Kazakhstan's CO2 emissions have been closely analysed, especially in the period following the Kyoto Protocol. X. Wang et al. [4] constructed production based CO2 footprints inventories in Kazakhstan during four years 2012-2016. Their study indicated that though Kazakhstan's footprints are relatively minor compared to major emitters like China and the US, the country still has considerable pressure to reduce emissions and promote green development. The study suggested that both technological and policy actions are necessary for effective emissions control.

Renewable energy is seen as a modern solution to climate change issues and embodies the future of energy development [15]. As Z. Xin-gang and Z. You [16] noted, renewable energy includes sources such as wind, hydro, geothermal, biomass and solar. It offers clear benefits over fossil fuels, including being green, clean, and renewable and having a low carbon footprint [4].

AI technology is set to transform traditional corporate innovation models significantly. Enhancing the efficiency of green innovative technologies enables energy companies to more swiftly comply with environmental protection standards. This improvement also reduces the costs associated with developing green patents and boosts the production of green products [17]. AI technology acts as a catalyst, motivating energy companies to pursue the development of more green patents. As AI technology progresses and permeates different industries and sectors [18], energy companies are increasingly captivated by its potential.

AI holds the potential to boost company profits, improve employment rates, and enhance operational efficiency. Advocates emphasize the beneficial impacts of AI technology on corporations; however, critics, as noted by N. Grashof and A. Kopka [19], argue that alongside its advantages, AI could also negatively affect innovation efficiency. Consequently, companies need to develop a more comprehensive AI innovation management model to adequately address the challenges associated with using AI technology, including concerns about AI replacing parts of the workforce [20]. Nevertheless, the initial implementation costs, such as higher employee salaries, can be substantial. Despite these initial expenses, the overall profit gains generally exceed the costs of adopting AI technology [21].

The intermittent, unpredictable, and random characteristics of renewable energy can impact the strength as well as consistency of the PS (power system) while integrated on a big size into the distribution network [22]. As a result, improving the accuracy of renewable energy predictions is crucial for power system stability [23]. Various techniques have been developed to enhance the precision of renewable energy forecasts [24], [25].

Synthetic intelligence techniques are widely utilized in renewable energy prediction for their capability to manage nonlinear and complex data structures [24], [26]. When applied effectively and appropriately, these methods lead to the development of sophisticated and valuable systems that exhibit enhanced performance and unique characteristics not achievable with traditional approaches [27]. The domain of Artificial Intelligence in Renewable Energy (AI&RE) has seen rapid growth recently [28]. AI-based technologies are increasingly used to tackle challenges associated with integrating renewable energy into power systems, including forecasting for solar and wind energy.

Nonetheless, several challenges and bottlenecks persist, particularly in the scope and accuracy of renew-

able energy predictions and the impact of specific geographical climates on these forecasts. Additionally, the proliferation of publications in this field necessitates a comprehensive summary of the existing research. J. Xu et al. [29] discussed the challenges and prospects of wind power generation in Kazakhstan, highlighting the environmental benefits and the need for policy support to incentivise the transition to greener technologies. Additionally, R. Mukhamediev et al. [5] developed a support for the decision in optimising the placement of the renewable energy generators using geospatial data, demonstrating the high potential for RE development. Moreover, A. Nurgissayeva et al. [30] discuss the increasing significance of the private ownership in public-private partnerships aimed at achieving sustainable development goals for the city. They explain that these partnerships enhance the quality and efficiency of services typically provided by the government while alleviating the state budget's financial burden.

These recommendations should concentrate on addressing the present challenges and fostering future advancements in this evolving sector. As energy companies explore the incorporation of AI technologies with renewable energy (RE), we suggest the following research inquiries: What are the potential effects of implementing AI on RE within energy companies? Furthermore, how can the rate of AI adoption be measured to more accurately reflect the use of AI technology in environmentally focused companies?

The literature on renewable energy and sustainable development in Kazakhstan indicates a strong focus on green hydrogen production, the green economy, CO2, footprints decrease and green building development. The studies reviewed suggest that while there are significant challenges, including technical, economic, and policy-related barriers, there is also substantial potential for progress. Continued research and the development of supportive policies will be crucial for Kazakhstan to achieve its sustainable development goals.

THE MAIN PART

Transition to a Green Economy in Kazakhstan. For the Republic of Kazakhstan over the past three decades, the creation of one of the most advanced economies in this region has been successful. Now, this is being furthered by a strategic displacement of an oil-dependent economy to a «green economy». The rationale for the transformation to the green economy is described in Table 1.

Table 1 – The rationale and main reasons for transformation to RE in Kazakhstan

Reasons for the transformation	Description
Exhaustion of Conventional Energy Sources	The traditional sources of energy—oil, gas, and coal—are finite and will run out within just a few years. New, more sustainable energy sources must be developed in order to achieve a stable energy future.
Adverse Environmental Impact of Traditional Sources of Energy	A huge volumes of greenhouse gases emissions are related to the production of energy from coal and oil, which determine climatic changes and air pollution. In this regard, solar and wind renewable energies bring less harm to the environment compared to large volumes of greenhouse gases that are emitted during the production of energy by coal and oil.
Technological Progress	Advancements in artificial intelligence and other cutting-edge technologies allow for efficient management and control of energy production processes, which can increase efficiency and market competitiveness.
Economic Benefits	Renewable energy sources are becoming increasingly competitive with traditional ones, especially considering the declining costs of production and the development of new technologies.
Political Support	Many governments around the world actively support, fund the improvement of RE sources and recognise their potential to reduce dependence on energy imports and promote more sustainable development.
Note – compiled by the author	

Table 2, titled Dynamics of Renewable Energy Capacity Growth in Kazakhstan», provides a snapshot of the extension RE infrastructure in Kazakhstan over a five-year period from 2018 to 2022. The data includes the number of renewable energy facilities and their total megawatts (MW) capacity each year.

Table 2 – Dynamics of renewable energy capacity growth in Kazakhstan

Year	Number of Objects	Total Capacity (MW)	Stage
2018	67	531	Rapid Expansion
2019	90	1,050	
2020	116	1,685	
2021	134	2,010	Consolidation and Optimisation
2022	142	2,021	
Note – compiled by the author based on [31]			

In 2018, the number of renewable energy facilities was 67. This increased to 90 in 2019, marking a growth of 23 facilities, which is approximately a 34 % increase from the previous year. In 2022, the number of facilities reached 142, adding 8 more, which is about a 6 % increase from 2021. In 2018, the total capacity was 531 MW. It nearly doubled to 1,050 MW in 2019, an increase of 519 MW, representing a 97 % growth from the previous year. In 2022, the total capacity slightly increased to 2,021 MW, adding 11 MW, which is a marginal increase of about 0.5 % from 2021.

From 2018 to 2020, there has been a massive increase not only in terms of the number of renewable energy facilities but also in total capacity. Going more than double from the 2019 capacity of 531 MW to 1,050 MW and the massive increase to 1,685 MW in 2020 gives an indication of the strong push toward enhancement in renewable energy infrastructure. This rapid growth is likely driven by strategic national policies and increased investment in the sector. From 2021 onwards, the expansion of quantity of facilities continued but at a slower pace compared to the previous years. The total capacity growth also slowed down significantly, especially in 2022, where the increase was minimal. This could indicate that the initial phase of rapid expansion has transitioned to a phase of consolidation and optimisation substantial increase in the early years suggests the effective implementation of supportive policies. The slower growth in later years may reflect the saturation of easily deployable projects and the onset of more complex integration challenges.

The deceleration in capacity growth highlights potential challenges, such as the need for enhanced grid infrastructure, storage solutions, and regulatory adjustments to support further expansion. However, it also presents opportunities to focus on improving the efficiency and integration of existing renewable energy capacities.

Table 3 – Investments for implementing the Green Economy Transition Concept in Kazakhstan

Period	**2020-24**	**2025-29**	**2030-39**	**2040-49**
Funding Needs as % of GDP	1.79	0.77	0.59	0.61
Average Annual Funding Needs (USD billion, 2010 prices)	5.5	3.0	3.0	3.8
Total Funding Over Period (USD billion, 2010 prices)	27.5	15.0	30.0	38.0
Note – compiled by the author from [32]				

The data in Table 3 reveals a phased approach to investment in Kazakhstan's green economy transition. The initial years (2014-2017) focus on foundational investments, which ramp up significantly during 2018-2024 with the implementation of major projects. Post-2024, the investment stabilises, indicating a shift from heavy initial investments to sustaining and optimising existing projects while still growing in the long term to meet ongoing and future needs. This comprehensive investment strategy reflects the long-term commitment required for transitioning to a sustainable green economy.

The key enabling legislations have been enacted, and most of the strategic documents at the national level and sectoral policies and plans have been developed over the past decade. Crucial legislative steps in this direction include the following: Law on Support for Renewable Energy Sources No. 2009, establishing a support scheme for promotion and development of RES in the country. Challenges in the Sphere of Energy Saving and Energy Efficiency Improvement: The Law on Energy Saving and Energy Efficiency Improvement has to enhance energy conservation and improve energy efficiency in various areas of activities. The Concept for Transition to a Green Economy provides an overall view of the strategy toward transition to green economy with prospects for development of the green economy and with prospective targets of 15 % of share in electricity generation by renewable energy up to 2030 and up to 50 % by 2050 including alternative energy sources.

The Concept for Kazakhstan's Transition to a Green Economy is particularly significant as it establishes clear goals for the integration of renewable energy sources (RES) into the national energy mix. By the year 2030, the country has a target of 15 % of renewable energy in electricity production and, long-term, a target of 50 % by the year 2050. Such goals underline Kazakhstan's aspiration to decrease the contribution of fossil fuel to its energy balance and reduce negative environmental consequences. Nowadays, a Strategy for Transition to Carbon Neutrality by 2060 will be elaborated in Kazakhstan. This strategy envisions a further increase in the renewable energy supply within electricity generation and heat production. This holistic approach underscores the importance of renewable energy in achieving broader sustainability goals.

Support for renewable energy facilities in Kazakhstan is primarily facilitated through an auction mechanism. This mechanism plays a critical role in exerting downward pressure on the price of renewable energy, thereby making it more competitive. Additionally, it regulates the volumes of capacity introduction by considering the availability of flexible capacities, the electrical grid infrastructure, and the possibilities for integrating renewable energy into the power system. Another limitation is that renewable energy investments remain unappealing to investors due to the low energy prices. While energy prices in Kazakhstan are not directly subsidized, they remain low due to a regulatory system that fails to fully incorporate maintenance, replacement costs, and the external environmental and climatic impacts. This pricing structure makes renewable energy sources less economically appealing compared to coal, which is both abundant and cheap (Kazakhstan possesses the world's largest coal reserves). As a result, coal accounts for over 70 % of energy production and more than 20 % of final energy consumption. However, Kazakhstan's reliance on outdated, inefficient, and highly polluting coal-fired power plants ranks it among the top ten countries in terms of energy intensity [33].

The existing approach mandates the coordination of capacity delivery schemes for renewable energy facilities that are introduced outside the auction support mechanism. This coordination requires the inclusion of storage capacities to compensate for the variable nature of electricity production. Such a requirement will help not to exceed the limits of renewable energy capacities, providing the reliable work of the Unified Power System of Kazakhstan and avoiding the risk of tariff deficits. The continuous policy on the promotion of renewable energy is further supported by the declining costs of constructing renewable energy stations. This cost reduction is provided by continuous technological development, growing demand from investors, and economies of scale. These factors all combine to provide great impetus to the development of renewable energy in Kazakhstan.

Supporting the creation of AI startups and innovation hubs is vital to encourage entrepreneurial ventures in the AI sector. Innovation hubs can serve as incubators for new ideas, providing resources, mentorship, and networking opportunities for budding AI entrepreneurs. By fostering an environment that encourages experimentation and innovation, these hubs can significantly contribute to the growth and dynamism of the AI landscape. Providing funding and incentives for startups and companies working on cutting-edge AI solutions is crucial for the sustained growth of the AI sector. Financial support can come in the form of grants, loans, and tax incentives, which can lower the barriers to entry for new players and support the development of groundbreaking technologies. Incentives can also be tailored to encourage research and development, fostering a competitive edge in the global AI market.

Also, international collaboration is essential to harnessing AI technologies' full potential. Countries can benefit from shared knowledge and resources by building strong partnerships and participating in global initiatives. Fostering international collaborations with leading AI research institutions and technology companies

is vital for exchanging knowledge and expertise. These partnerships can facilitate joint research projects, technology transfers, and the sharing of best practices. By collaborating with global leaders, countries can accelerate their own AI development and stay at the forefront of technological advancements.

It is important to understand that public awareness and engagement are key to ensuring that AI developments are transparent, inclusive, and aligned with societal values. Launching public awareness campaigns is essential to educate citizens about AI's benefits and potential risks. These campaigns can help demystify AI technologies, highlighting their practical applications and addressing common misconceptions. By providing clear and accessible information, awareness campaigns can foster a more informed and supportive public. Engaging with communities to gather feedback and ensure that AI developments align with societal needs and values is crucial. Community engagement can take various forms, such as public consultations, workshops, and town hall meetings. By actively involving citizens in the conversation, policymakers and developers can better understand public concerns and priorities, leading to more socially responsible AI implementations.

Building a robust innovation ecosystem, fostering international collaboration, and promoting public awareness and engagement are essential components of a comprehensive strategy to harness the potential of AI technologies. It is in these key areas that countries can ensure inclusivity, sustainability, and alignment of AI development with greater societal goals. These priority areas, if heeded to, undoubtedly will spur the effective development of artificial intelligence in Kazakhstan, offering it the special treatment its applications so deserve. Thereby, this multidimensional approach will chart the roadmap for the country to wield AI as leverage toward sustainable development with an improved quality of life for its people.

Example of AI application in Wind Power Utilization. Globally, the application of AI in the RE, especially in wind power is not new. The optimisation of wind power utilisation through artificial intelligence (AI) is being undertaken by a diverse range of stakeholders, including tech companies such as Siemens Gamesa, GE Renewable Energy, IBM, and Enel. Siemens Gamesa did not stop at just providing wind turbines; it has incorporated AI into predictive maintenance and dynamic optimization of its wind turbines. On the other side, GE uses AI to enhance efficiency and reliability for their wind farms by using high-accuracy wind forecasting and operational optimization software. IBM provides AI-driven solutions for energy management, including wind power optimisation. Enel Green Power, the Italian multinational, utilises AI to enhance the performance of its renewable energy assets, including wind farms.

Another example, among the research institutions, is the National Renewable Energy Laboratory (NREL), based in the United States. It conducts extensive research on integrating AI with renewable energy technologies, including wind power [31]. Also, the Fraunhofer Institute for Wind Energy Systems (IWES), a German research institute, focuses on applying AI to improve wind energy systems' performance and reliability.

The European Union funds many projects relating to the integration of AI with renewable energy systems, including wind power, under programs such as Horizon 2020. The China National Energy Administration comes up with initiatives and research funding in applying artificial intelligence in renewable energy, particularly wind farm optimization. Global Wind Energy Council (GWEC) works with industry leaders to promote the use of AI in wind energy, enhancing the sector's efficiency and sustainability. The IEA (International Energy Agency) collaborates with various stakeholders to explore and promote AI applications in renewable energy, including wind power [34]. These entities collectively contribute to the advancement and implementation of AI technologies in wind power optimisation, driving forward the transition to more efficient and sustainable energy systems.

By harnessing AI's power, Kazakhstan can enhance its renewable energy capabilities and set a precedent for regional leadership in the sustainability. This strategy aligns with international trends, establishing the country as an innovative leader in the energy sector [35]. The integration of AI with renewable energy sources presents a transformative opportunity for Kazakhstan. By focusing on efficiency, economic growth, and environmental sustainability, the country can leverage AI to maximise the potential of its renewable energy sector, driving both innovation and sustainable development.

For example, LLP «First Wind Power Plant» is the first project in Kazakhstan in the field of alternative energy development since 2013. The establishment of LLP «First Wind Power Plant» marked a significant milestone in Kazakhstan's energy sector, representing the country's initial foray into RE development. This project

was initiated as part of Kazakhstan's broader strategic goals to diversify its energy mix and reduce reliance on fossil fuels, in line with national policies aimed at fostering sustainable development [36].

As the pioneer project in Kazakhstan's renewable energy sector established in 2011, LLP's «First Wind Power Plant» set a precedent for subsequent renewable energy initiatives. It demonstrated the feasibility and benefits of wind energy, encouraging further investment and development in the sector. In 2013 Eurasian Development Bank (EDB) has provided a loan of 14.2 billion KZT for 10 years [36]. The project's success garnered recognition both domestically and internationally, highlighting Kazakhstan's commitment to sustainable energy solutions and its potential as a leader in renewable energy in the region. The deployment of wind energy technology through LLP «First Wind Power Plant» introduced advanced renewable energy solutions to Kazakhstan. This technological advancement contributed to the country's knowledge base and expertise in managing and optimising wind energy resources. Economically, the project helped to diversify Kazakhstan's energy portfolio, providing a stable and RE that complements the country's traditional energy resources. This diversification is crucial for enhancing energy security and achieving long-term sustainability.

However, the LLP «First Wind Power Plant» stands behind the technology of AI implementation, and as the landmark project in Kazakhstan's renewable energy, it to explore the development of AI. Its establishment and success have paved the way for future renewable energy projects, solidifying Kazakhstan's position in the global shift towards sustainable energy.

Results. We systematically reviewed the documents and legislation and developed the following framework for the transition to the green economy (Figure 1). The suggested steps will help to develop the Innovation Ecosystem for fostering the usage of AI to boost the green economy. The innovation ecosystem is critical for fostering a thriving environment where artificial intelligence (AI) can flourish.

Regarding the implementation of AI algorithms, it can analyse vast amounts of data to predict energy production and consumption patterns, leading to better resource allocation and reduced waste. Additionally, AI can anticipate equipment failures and schedule maintenance proactively, minimising downtime and extending the lifespan of renewable energy assets. AI can enhance the functionality of smart grids by balancing supply and demand in real-time, ensuring stability and reliability in energy distribution. The AI will optimise the use of the energy storage systems so that all the excess energy they have generated from renewable sources is stored efficiently and used in a form appropriate to the needs at hand.

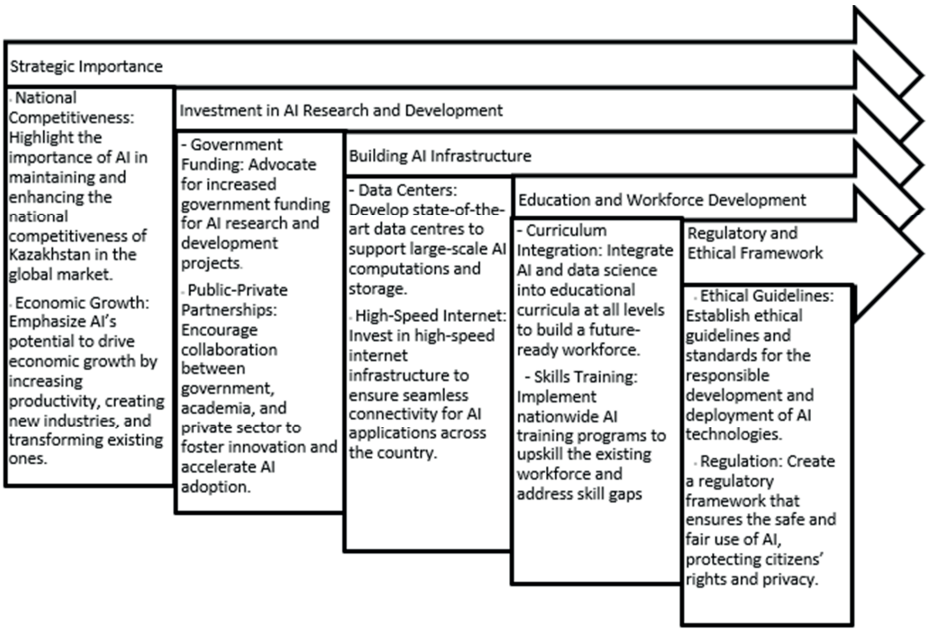

Figure 1 – Scopes to transitioning to green technologies in AI

Note – compiled by the author

We underline four main scopes and direction in the policy: Strategic Importance, Investment in R&D, Building AI Infrastructure, and Education and Workforce Development (Figure 1). National competitiveness and economic growth are main strategic orientations to succeed in a long-term prospect. Regarding the investment, we suggest government funding and (public-private partnership) PPP. It is crucial to develop an appropriate infrastructure like data centers, including data storage, high speed and available internet. The data analytics, data science and other related fields of studies should be imbedded into the education curriculum to prepare workforce for utilization of big data and machine learning. The ethical usage of the AI tools is important to create safe and legal environment (Figure 1).

The Kazakh government is interested in the development of renewables due to its long-term desire to diversify its energy mix. This is well illustrated by critical legislative measures, one of them being the Law on Support for Renewable Energy Sources in 2009. Among others, it had set up a variety of measures to create a supporting system for launching projects within this sector. The Concept for Transition to a Green Economy, 2013, reiterated the need for renewable energy and set ambitious goals associated with the output of renewable sources in the country's energy mix. The example of establishment of LLP «First Wind Power Plant» aligned with these policy objectives [36].

The Concept of Kazakhstan's transition to a «green» economy and the «Strategy Kazakhstan-2050» set forth bold and ambitious targets for transforming the nation's energy landscape. These plans aim to dramatically boost the proportion of alternative and renewable energy sources in Kazakhstan's energy mix, with milestones set at 3 % by 2020, a substantial increase to 15 % by 2030, and a remarkable leap to 50 % by 2050 [37].

The sector is seeing the rapid development. Recently, by Government Decree No. 342, dated April 27, 2024, titled «On Certain Issues of the Ministry of Digital Development, Innovations, and Aerospace Industry of the Republic of Kazakhstan», the Republican State Enterprise «Committee for Artificial Intelligence and Innovation Development of the Ministry of Digital Development, Innovations, and Aerospace Industry of the Republic of Kazakhstan» (the «Committee») was established. The Committee is set to oversee the implementation of the Artificial Intelligence Development Program for 2024-2029. This draft ruling, published on legalact.egov.kz for public consideration until April 4, outlines that the share of public services provided with the help of AI is expected to increase from 0 % this year to 20 % by 2029. Also it is planned to educated 80 000 citizens in the area of AI. Furthermore, the government plans to gradually double the funding allocated for promoting AI, from $4.4 million this year to $8.8 million by 2029 [38; 39].

Additionally, we generated a framework that illustrates the practical benefits – 4Bs – in implementing AI in RE (Figure 2). There are four main beneficial characteristics of AI – Proactivity, Efficiency, Economic Growth, and Environmental Impact.

AI can anticipate equipment failures and schedule maintenance proactively, minimising downtime and extending the lifespan of renewable energy assets. AI can enhance the functionality of smart grids by balancing supply and demand in real-time, ensuring stability and reliability in energy distribution. Furthermore, AI can optimise the use of energy storage systems, ensuring that excess energy generated from renewable sources is stored efficiently and utilised when needed. The development and deployment of AI in the renewable energy sector can create high-skilled jobs in data science, engineering, and technology. Demonstrating advanced capabilities in renewable energy can attract foreign investment and partnerships, boosting Kazakhstan's economic growth. By optimising renewable energy production, AI can help reduce reliance on fossil fuels, leading to lower greenhouse gas emissions. AI-driven renewable energy initiatives support Kazakhstan's commitment to sustainable development goals, promoting environmental stewardship.

The development and deployment of AI in the renewable energy sector can create high-skilled jobs in data science, engineering, and technology. Demonstrating advanced capabilities in renewable energy can attract foreign investment and partnerships, boosting Kazakhstan's economic growth. By optimising renewable energy production, AI can help reduce reliance on fossil fuels, leading to lower greenhouse gas emissions. AI-driven renewable energy initiatives support Kazakhstan's commitment to sustainable development goals, promoting environmental stewardship.

Renewable energy sources are those that are replenished naturally and are considered more sustainable compared to fossil fuels. The main types of renewable energy are described in table 4 below.

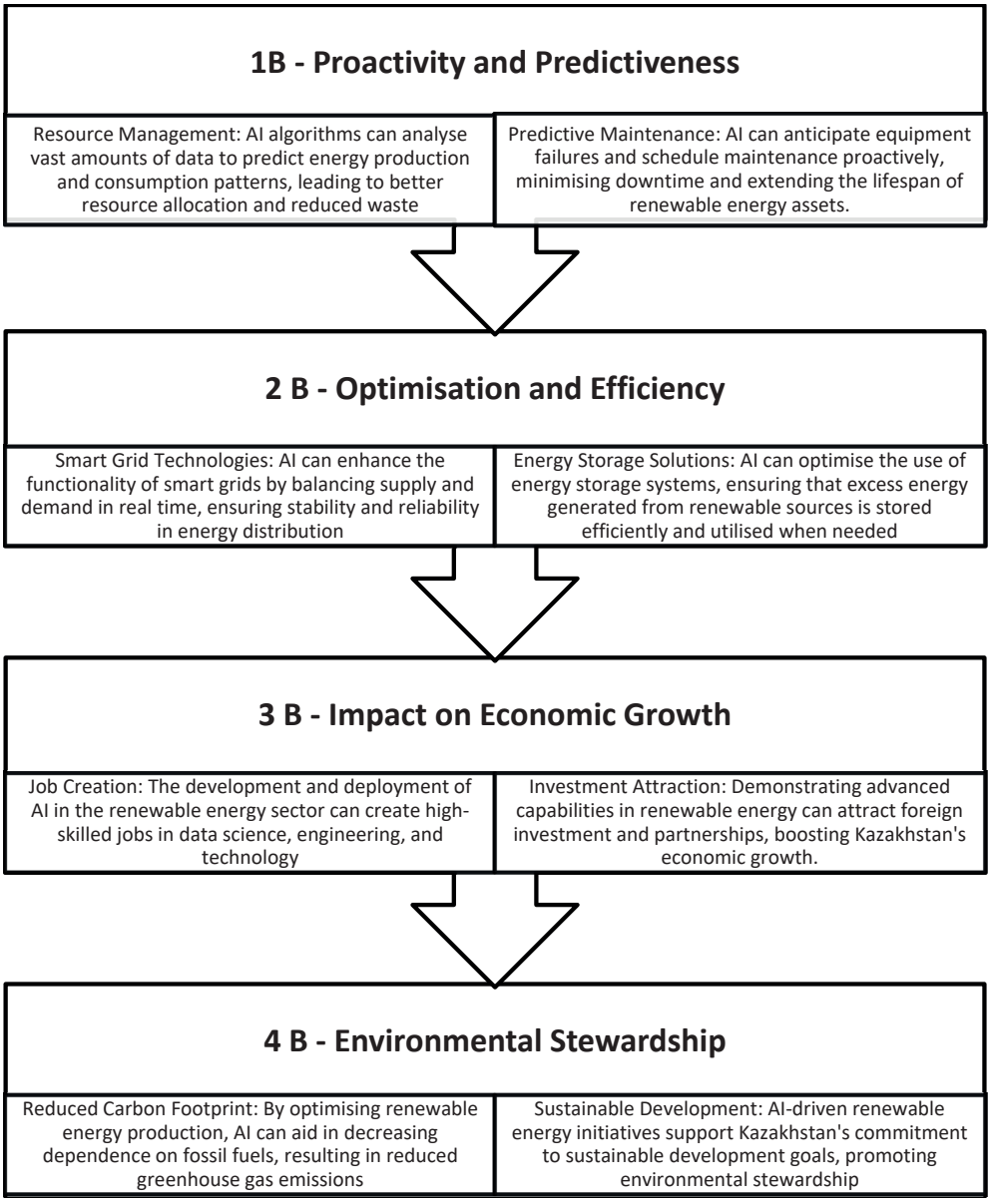

Figure 2 – 4 Bs - Benefits of Artificial Intelligence applied to Renewable Energy
Note – compiled by the author

Table 4 – Types of Renewable Energy (RE)

Type of RE	Description	AI application
Solar Energy	Photovoltaic (PV) Convert sunlight directly into electricity using solar cells. Concentrated Solar Power (CSP): Uses mirrors or lenses to concentrate sunlight onto a small area to produce heat, which is then used to generate electricity.	AI can optimize energy conversion rates, manage shading issues, and predict weather patterns to enhance efficiency [40].
Wind Energy	Onshore Wind Farms: Wind turbines installed on land. Offshore Wind Farms: Wind turbines installed in bodies of water, typically on the continental shelf.	AI can improve turbine efficiency, predict wind patterns, and reduce downtime through predictive maintenance [41].

Hydropower	Dams with large reservoirs that generate significant amounts of electricity	AI can manage water flow and energy storage more effectively, ensuring a stable supply and demand balance [42].
Ocean Energy	Harnesses energy from tidal movements Captures energy from surface waves. Ocean Thermal Energy Conversion (OTEC): Uses temperature differences between surface water and deep water to generate electricity.	AI algorithms can predict tidal patterns with high accuracy, optimizing the timing of energy capture and storage [43].
Biomass Energy	Derived from organic materials like wood, agricultural residues, and animal waste. Biofuels: Liquid fuels like ethanol and biodiesel derived from biomass.	AI can optimize the parameters of biomass conversion processes, such as temperature and pressure, to maximize energy output and minimize waste [44]
Geothermal Energy	Uses geothermal reservoirs to provide direct heating. Geothermal Power Plant: Uses steam from geothermal reservoirs to drive turbines and generate electricity.	AI can analyse geological data to identify potential geothermal hotspots, reducing the time and cost of exploration [45].
Note - compiled by the author		

By addressing these specific methodologies, the integration of AI into renewable energy can be managed comprehensively, ensuring that all critical aspects are considered. This holistic approach helps to maximize the benefits of AI, such as improved efficiency and reliability, while mitigating potential challenges related to regulation, funding, and organizational management.

Table 5 – Approaches aimed at integrating artificial intelligence into RE

Approaches	AI application
Organizational	Establish dedicated bodies within energy companies to oversee the integration of AI into renewable energy systems. Develop frameworks for the collaboration between AI experts and renewable energy professionals to ensure seamless integration.
Economic	Implement economic incentives, such as subsidies or tax breaks, to encourage the adoption of AI technologies in the renewable energy sector. Facilitate public-private partnerships to fund AI-driven renewable energy projects.
Legal	Develop clear regulatory guidelines that address the use of AI in renewable energy, focusing on data privacy, cybersecurity, and liability issues. Ensure that regulatory frameworks are flexible enough to adapt to the rapid advancements in AI technology.
Technological	Invest in research and development to enhance AI algorithms tailored for renewable energy applications. Promote the development of AI-driven predictive maintenance and real-time optimization tools to improve the efficiency of renewable energy systems.
Note – compiled by the author	

The application of Artificial Intelligence, combined with renewable energy sources, is very promising for transforming the environment of this country. From the utilization front, Kazakhstan can bring AI technologies into the use of those aiming at the optimization of efficiency, reliability, and sustainability in renewable energy systems based mainly on wind and solar power. This technological synergy addresses the growing energy demands and aligns with global sustainability goals, reducing reliance on fossil fuels and mitigating environmental impacts.

CONCLUSION

The research concludes that the application of artificial intelligence (AI) to renewable energy sources in Kazakhstan can significantly enhance energy efficiency, reduce costs, and increase the reliability of energy

supply. The integration of AI presents several key economic opportunities, including job creation, technological advancement, and the potential for Kazakhstan to establish regional leadership in renewable energy. However, this integration also poses challenges, such as the need for significant investment in infrastructure, personnel development, and regulatory amendments.

Kazakhstan's strategic initiatives and national policies have laid a strong foundation for this transformation. The support for renewable energy development and the adoption of advanced AI technologies positions the country as a leader in transforming to the sustainable future. The benefits are multifaceted: enhanced energy efficiency, significant cost reductions, improved resource management, and the creation of high-skilled jobs. Moreover, Kazakhstan's increasing attractiveness as a destination for foreign investment in the renewable energy sector underscores the economic potential of this integration.

This study underscores the critical role of AI in maximizing the potential of renewable energy sources in Kazakhstan. It highlights the need for a comprehensive approach that includes organizational, economic, legal, and technological strategies to ensure successful integration. By addressing these aspects, policymakers and industry professionals can develop a robust framework that supports the sustainable development of the renewable energy sector. The findings emphasize that ongoing innovation, investment, and international collaboration will be essential to fully realize the benefits of integrating AI into renewable energy, thereby contributing to Kazakhstan's commitment to a sustainable and prosperous energy future.

Kazakhstan's regulatory approach aligns with global standards and involves active participation in international forums. The government also focuses on educational initiatives to raise public awareness about the opportunities and risks associated with cryptocurrencies, fostering a more informed and engaged citizenry. As Kazakhstan continues to advance its renewable energy capabilities with AI, it contributes to global efforts in combating climate change and secures a sustainable and prosperous energy future for its citizens. The findings of this study underscore the critical role of AI in maximising the potential of renewable energy sources, highlighting a pathway towards a resilient, efficient, and sustainable energy system in Kazakhstan. The continued focus on innovation, investment, and international collaboration will be essential in realising this integration's full benefits, driving the nation's commitment to sustainable development.

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ҚАЗАҚСТАНДАҒЫ ЖАҢАРТЫЛАТЫН ЭНЕРГИЯ КӨЗДЕРІН ПАЙДАЛАНУҒА ЖАСАНДЫ ИНТЕЛЛЕКТІНІ ИНТЕГРАЦИЯЛАУ МҮМКІНДІКТЕРІ

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АҢДАТПА

Зерттеу мақсаты – Қазақстанда жаңартылатын энергия көздерін пайдалану кезінде жасанды интеллектінің мүмкіндіктерін зерттеу, осы салада әлеуетті артықшылықтарды, ел экономикасы мен энергетикалық секторына әсерлерін анықтау және дамып келе жатқан бұл салаға жаңа көзқарас ұсыну. Осы зерттеу жүйелі шолуды да, кешенді зерттеу әдістерін де қамтитын аралас әдісті қолданады. Деректер академиялық деректер базалары, журналдар, әдебиеттерді талдау және Қазақстандағы жасанды интеллект басқаратын жаңартылатын энергия жобаларының қолданылуы мен нәтижелерін практикалық түсінуді ұсынатын кейс-зерттеулер арқылы жиналды.

Әдіснамасы. Бұл зерттеу Қазақстан контекстінде жасанды интеллект пен жаңартылатын энергияның қиылысуына баса назар аударуымен бірегей. Ол жаңа технологиялардың дамушы елдегі экономикалық өсуді және тұрақтылықты қалай ынталандыра алатыны туралы қорытындылар ұсынады және осы мүмкіндіктерді пайдалану үшін практикалық стратегияларды ұсынады. Зерттеу осы интеграциямен байланысты экономикалық салдарлар мен стратегиялық мүмкіндіктердің терең және жан-жақты талдауын ұсына отырып, әдебиетке елеулі үлес қосады.

Зерттеу нәтижелері. Зерттеу нәтижелері Қазақстанда жаңартылатын энергия көздеріне жасанды интеллектті қолдану энергия тиімділігін айтарлықтай арттырып, шығындарды азайтып, энергиямен жабдықтаудың сенімділігін арттыра алатынын көрсетеді. Сонымен қатар, зерттеу жұмыс орындарын құру, технологиялық инновациялар және Қазақстанның жаңартылатын энергия саласында өңірлік көшбасшы болу әлеуетін қоса алғанда, бірнеше негізгі экономикалық мүмкіндіктерді анықтайды. Дегенмен, зерттеу инфрақұрылымға инвестиция салу, оқыту және реттеуші қолдаудың қажеттілігі сияқты қиындықтарды да атап көрсетеді, саясаткерлер мен салалық мамандарға арналған практикалық жол картасын ұсынады.

Түйін сөздер: Жаңартылатын энергия, жасанды интеллект (ЖИ), экономикалық мүмкіндіктер, Қазақстан, энергия тиімділігі, тұрақты даму, жасыл энергия секторы.

ВОЗМОЖНОСТИ ИНТЕГРАЦИИ ИСКУССТВЕННОГО ИНТЕЛЛЕКТА В ИСПОЛЬЗОВАНИЕ ВОЗОБНОВЛЯЕМЫХ ИСТОЧНИКОВ ЭНЕРГИИ В КАЗАХСТАНЕ

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АННОТАЦИЯ

Цель данного исследования – изучить возможности искусственного интеллекта при использования возобновляемых источников энергии в Казахстане, выявить потенциальные преимущества, влияния на экономику страны и энергетический сектор, предлагая новый взгляд на эту развивающуюся область.

Методология исследования. Данное исследование использует смешанный метод, включающий как систематический обзор, так и комплексные исследовательские методы. Данные собраны через академические базы данных, журналы, анализ литературы и кейс-исследования, которые предлагают

практическое понимание применения и результатов проектов по возобновляемой энергии, управляемых искусственным интеллектом в Казахстане.

Оригинальность/ценность исследования. Это исследование уникально своим фокусом на пересечении искусственного интеллекта и возобновляемой энергии в контексте Казахстана. Оно предоставляет выводы о том, как новые технологии могут стимулировать экономический рост и устойчивость в развивающейся стране, и предлагает практические стратегии для использования этих возможностей. Исследование вносит значительный вклад в литературу, предоставляя глубокий и всеобъемлющий анализ экономических последствий и стратегических возможностей, связанных с этой интеграцией.

Результаты исследования показывают, что применение искусственного интеллекта к возобновляемым источникам энергии в Казахстане может значительно повысить энергоэффективность, снизить затраты и увеличить надежность энергоснабжения. Более того, исследование выявляет несколько ключевых экономических возможностей, включая создание рабочих мест, технологические инновации и потенциал Казахстана стать региональным лидером в области возобновляемой энергии. Однако, исследование также подчеркивает вызовы, такие как необходимость инвестиций в инфраструктуру, обучение и регуляторную поддержку, предоставляя практическую дорожную карту для политиков и профессионалов отрасли.

Ключевые слова: Возобновляемая энергия, искусственный интеллект (ИИ), экономические возможности, Казахстан, энергоэффективность, устойчивое развитие, сектор зеленой энергии.

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