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Green energy in Azerbaijan (types and development prospects)

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Aim of the article. The global shift towards renewable energy sources (RES) is an inevitable consequence of the depletion of fossil fuel reserves. As countries seek to mitigate the environmental impact of traditional energy production, the transition to "green energy" becomes a critical factor in sustainable development.
The novelty of this article. The author provides a comprehensive exploration of Azerbaijan's transition to green energy, with a particular focus on the country's distinctive use of hydropower, solar, wind, and tidal energy solutions.
Methodology and methods. The methodology employed includes a comprehensive review of the existing literature, analysis of energy policy documents, and evaluation of renewable energy projects implemented in Azerbaijan. Additionally, comparative analysis is applied to understand the distinctive approaches Azerbaijan has taken in advancing green energy compared to other countries in the region.
Main results. The results indicate that Azerbaijan is making substantial progress in utilizing green energy resources. Key initiatives include the expansion of hydropower projects, significant investments in solar and wind energy infrastructure, and the exploration of tidal energy potential in the Caspian Sea. Notably, the country has also prioritized the rehabilitation of territories liberated from occupation, integrating green energy solutions into the reconstruction process. Author concludes by highlighting the crucial role of green energy in Azerbaijan's economic development and environmental sustainability. The study emphasizes the importance of enhancing the regulatory and legal framework to foster further growth of renewable energy. The findings suggest that Azerbaijan's experience may offer valuable insights for other countries, particularly in regions with similar energy challenges. Author also provides a roadmap for the future of green energy in Azerbaijan, underscoring the need for continuous innovation, investment, and international collaboration.
Key words: *energy production, renewable energy sources (RES), energy transition, green energy, advantages of green energy, challenges of RES utilization, RES development.*

Introduction. One of the key directions of human societal development is closely linked to the energy transition, which entails the gradual replacement of fossil fuel-based energy with alternative energy sources, primarily through the use of renewable and environmentally friendly resources.

As is well known, the concept of the "green" economy, which envisions a gradual transition to renewable energy sources (RES) for the sustainable development of human society, was first formulated and introduced by British economist M. Jacobs in his work *Green Economy: Environment, Sustainable Development, and Future Policy* [1]. However, M. Jacobs' ideas gained widespread recognition only after the global economic crisis of 2008. During this period, the green economy began to be viewed as an important tool for global economic recovery. Issues related to green energy started to gain significant international relevance. Consequently, the concept of the green economy was incorporated into the United Nations Environment Programme (UNEP) and was recognized as a means of "enhancing human well-being and social equity while significantly reducing environmental risks and ecological deficits."

In the modern era, the significance of green energy for the further development of human society is becoming paramount. Among the key objectives of sustainable development outlined in the *2030 Agenda for Sustainable Development* adopted by the United Nations, the transition to green energy is considered one of the most crucial goals, as its achievement will facilitate progress toward all other sustainable development objectives. This document was adopted at the Sustainable Development Summit, held from September 25–27, 2015 [2].

As evident, green energy, by gradually replacing traditional energy sources, has the potential to become a fundamental mechanism for restructuring the global economy and a key instrument for mitigating various global challenges.

Many countries, particularly economically developed ones, are taking concrete steps toward transitioning their economies to renewable energy sources. For instance, the United States plans to transition to an economy that is 100% reliant on clean energy and to achieve carbon neutrality no later than 2050. Similarly, the European Union is taking decisive action in this direction. On December 11, 2019, the European Commission adopted the so-called *European Green Deal*. This initiative aims to achieve complete greenhouse gas neutrality by 2050 by transitioning away from fossil fuels to renewable energy sources [3].

At the same time, the study of RES development processes in various countries, particularly in the post-Soviet space, presents significant scientific

interest. In this regard, examining the development and utilization of RES in the Republic of Azerbaijan is of particular relevance from the perspective of gaining insights and conducting research in this field.

The significance of global energy consumption. One of the key characteristics of human societal development is the continuous increase in global energy consumption. Although traditional industries and the service sector are becoming increasingly energy-efficient, factors such as population growth, rising demands for electricity and thermal energy, advancements in science and various industries, as well as the emergence of new sectors, contribute to the overall increase in energy consumption.

According to the International Energy Agency, global energy consumption in 2015 amounted to 20.76 trillion kWh. Although it experienced a temporary decline due to the COVID-19 pandemic, it has since resumed a steady upward trajectory. In line with economic trends, global energy consumption growth in percentage terms slowed significantly in 2022 (from +4.9% in 2021, reaching 23.7 trillion kWh, to +2.1% in 2022). However, this remained above the average annual growth rate of 1.4% observed from 2010 to 2019. Overall, between 2018 and 2022, the total capacity of alternative energy sources increased by 21% compared to traditional energy sources [4]. Projections indicate that global energy consumption will reach approximately 33.4 trillion kWh by 2030 and could rise to 41.3 trillion kWh by 2050.

It is well known that fossil fuel reserves are finite and will eventually be depleted. The world must prepare for the so-called energy transition, which will inevitably follow the depletion of fossil fuel reserves. As a result, increasing global emphasis is being placed on the utilization of renewable energy sources (RES). To describe these energy sources, terms such as “renewable” or “regenerative” energy are commonly used. However, in scientific research, international legislation, and public discourse, the term “green energy” is being increasingly adopted in reference to renewable energy sources.

Green energy and its global development. Green energy refers to energy derived from natural sources that replenish more quickly than they are consumed. Examples include solar energy, wind energy, and other renewable resources capable of generating substantial amounts of electricity. To meet the growing global demand for energy, fundamental changes in this field are necessary. Green energy is essentially derived from renewable, or inexhaustible, sources. The core principle of green energy utilization lies in harnessing energy from continuous natural processes or renewable organic resources over time.

Green energy is obtained from natural resources such as sunlight, various water flows (hydropower), oceanic tides, wind, and, to some extent, geothermal energy – all of which are renewable in nature. Additionally, green energy is produced from various types of biofuels, including wood, vegetable oil, and ethanol. In 2010, renewable energy sources accounted for 16.7% of global energy consumption. By 2015, renewable energy sources supplied approximately 19.3% of the world’s final energy consumption [5]. According to the International Energy Agency, in 2019, renewable energy sources provided 26.8% of global energy consumption, with hydropower constituting the largest share (16%), followed by wind energy (5.3%), solar energy (2.6%), biofuels and other waste (2.4%), and geothermal energy (0.5%) [6].

According to some estimates, by 2050, up to 80–90% of the world’s electricity will be sourced from renewable energy. Efficient and reliable renewable energy technologies will help create a system that is less vulnerable to macroeconomic and political challenges [7]. The leading countries in the production of energy from non-traditional sources include Iceland (geothermal energy), Denmark (20.6%, wind energy), Portugal (18%, wave, solar, and wind energy), Spain (17.7%, solar energy), and New Zealand (15.1%, geothermal and wind energy).

In Germany, renewable energy sources accounted for 38% of electricity production in 2018. However, by 2023, renewables provided a record share of approximately 60% of Germany’s total clean electricity production. Brazil has implemented one of the world’s largest renewable energy programs, focused on producing ethanol fuel from sugarcane. Ethanol accounts for 18% of the country’s automotive fuel supply [8]. As a result, Brazil, which previously had to import most of the oil required for domestic consumption, has achieved full self-sufficiency in oil production [9]. Ethanol fuel is also widely used in the United States.

Development of green energy in Azerbaijan. Azerbaijan is endowed with abundant traditional energy resources, such as oil and gas, which not only fully meet the country’s energy consumption needs but also constitute a significant portion of its exports. Nevertheless, increasing attention is being directed toward the development and utilization of various types of renewable energy sources. This shift is driven by objective factors. According to some estimates, Azerbaijan’s state-owned oil company, SOCAR, aims to achieve decarbonization within the next decade. However, other projections suggest that this transition may take longer, given the country’s substantial natural gas reserves and the potential discovery of additional oil fields. Regardless, the global transition to renewable energy is inevitable, as fossil fuels are finite resources. The world is gradually entering a new phase of the energy transition, marked by the widespread adoption of renewable energy sources and the gradual displacement of fossil fuels.

Azerbaijan possesses significant natural resources for the development of alternative energy sources. The country has the potential to utilize various types of renewable energy, including hydropower, solar energy, wind energy, tidal energy, biomass energy, and geothermal energy. Moreover, research is underway on the production and transportation of hydrogen through the Trans Adriatic Pipeline (TAP), including the generation of green hydrogen via electrolysis of Caspian Sea water using electricity from offshore wind turbines, as well as the production of blue hydrogen from natural gas extracted from the Caspian shelf [10].

The establishment of a green energy zone in the Republic of Azerbaijan has been designated as a strategic objective. In this regard, the Presidential Decree of the Republic of Azerbaijan on the approval of the "National Priorities for Socio-Economic Development: Azerbaijan 2030," issued on February 2, 2021, enshrines the formation of a "Clean Environment and Green Growth Country" as one of the five national priorities for the country's socio-economic development until 2030 [11]. These national priorities play a crucial role in fulfilling commitments outlined in the United Nations document "Transforming Our World: The 2030 Agenda for Sustainable Development".

Furthermore, the available resources have the capacity to address key objectives, such as enhancing the reliability of electricity supply, establishing reserve capacities, compensating for losses, ensuring energy provision to remote areas, and exporting surplus energy abroad.

In this context, Azerbaijan is preparing for the implementation of the so-called Green Energy Corridor project. This corridor will connect the Caspian Sea with Europe through a deep-sea cable laid along the seabed of the Black Sea.

The feasibility study for this Green Energy Corridor project from Azerbaijan to Europe is expected to be completed by the end of 2024. In general, the process of conducting an international tender, obtaining the necessary approvals for financing, and concluding contracts for project execution may take approximately another year. Preliminary estimates suggest that the project will require an investment of between €2 billion and €2.5 billion. The construction phase could take up to three years. Thus, the Green Energy Corridor is projected to become operational around 2028. To regulate activities in the field of alternative and renewable energy sources, Azerbaijan established the State Agency for Renewable Energy Sources, which has been operating under the Ministry of Energy of Azerbaijan since September 22, 2020.

It is noteworthy that by the autumn of 2023, the share of renewable energy in Azerbaijan's total electricity production had already reached 8%. According to government forecasts, the share of renewable energy in Azerbaijan's installed electricity generation capacity is expected to reach 30% by 2030.

One distinctive feature of energy production development in Azerbaijan's wind and solar power sectors is that these fields are expanding exclusively through foreign investment. It is essential to emphasize that large-scale green energy projects have already been launched in Azerbaijan in collaboration with foreign partners as part of the country's energy transition. In 2024 alone, the total installed capacity of wind and solar energy projects will amount to 1,300 MW.

Numerous contracts have been signed with foreign companies for the implementation of these renewable energy projects. For example, a wind power plant with a capacity of 240 MW is being constructed by ACWA POWER (Saudi Arabia), with construction having commenced in January 2024 [12]. A 230 MW solar power plant, built by MASDAR (United Arab Emirates), was commissioned on October 20, 2023. Additionally, a 240 MW solar power plant is under development by BP (United Kingdom), with design work ongoing for the "Shafag" solar power station in Jabrayil. These projects are being implemented in accordance with the Presidential Decree of the Republic of Azerbaijan "On Measures for the Implementation of Pilot Projects Using Renewable Energy Sources," issued on December 5, 2019.

Development of green energy in Azerbaijan: Challenges and prospects. It should also be noted that the rapid development of green energy allows for savings in domestic natural gas consumption. This, in turn, creates an additional opportunity to export these natural gas resources.

Undoubtedly, the issue of using renewable energy sources (RES) is also linked to the problem of environmental cleanliness and preservation. In this regard, Azerbaijan is taking practical measures to combat climate change and ensure the planet's environmental well-being. By decree of the country's president, 2024 has been declared the "Year of Solidarity for a Green World" in Azerbaijan. Karabakh, East Zangezur, and the Nakhchivan Autonomous Republic have been designated as green energy zones. Overall, Azerbaijan plans to reduce emissions from industrial activities by 35% by 2030 and by up to 40% by 2050. Several examples can be cited. One of the priority areas during the restoration and reconstruction of territories liberated from Armenian occupation is the overall restoration of the ecosystem of these lands, as well as environmental protection. Notably, real steps are being taken to turn these territories into a net-zero emissions zone by 2050, with plans for the complete transition of the Karabakh and East Zangezur economic regions of Azerbaijan to renewable energy sources.

Following a study of the hydro-energy potential of the Karabakh and East Zangezur economic regions, the Joint-Stock Company "Azerenergy" (the primary

entity in the energy sector) prepared and presented a report on the restoration of hydroelectric power plants (HPPs) destroyed during the occupation, as well as the construction of new HPPs in compliance with environmental standards. According to the report, 72 small HPPs with a total capacity of 467 MW will operate in the region.

In our view, attracting leading foreign producers of electrical energy equipment, including from Ukraine, could play a significant role in the implementation of these projects, given the friendly and strategic nature of relations between Ukraine and Azerbaijan. Ukrainian companies could potentially participate in the construction of new or reconstruction of small HPPs in the East Zangezur economic region of Azerbaijan. Overall, the total power generation from existing plants in the region is expected to reach 270 megawatts (MW) by the end of 2024. By 2027, the total HPP capacity will reach 500 MW. Naturally, this will be an important contribution to Azerbaijan's transition to green energy.

It is particularly noteworthy that, for the first time in Azerbaijan's energy system history, the electricity needs of the Karabakh and East Zangezur regions are now 100% met by green energy [13]. Moreover, the surplus electricity is supplied to the national grid. If we consider both current and planned projects, the total expected renewable energy capacity in the Karabakh and East Zangezur economic regions will reach 1100 MW, which is approximately 12–15 times their current energy needs. It is crucial to highlight that the adoption of green energy technologies and the increase in its share in the overall electricity supply system allows for a gradual reduction in reliance on traditional energy sources such as oil, petroleum products (e.g., fuel oil), and natural gas. Azerbaijan has already ceased using oil and petroleum products for electricity generation, and the volume of gas used for this purpose is also steadily decreasing. This enables the country to redirect the freed-up resources for export. It is believed that this experience could also be applied in Ukraine after the de-occupation of its territories and the country's economic development in the near future.

It is also particularly noteworthy that, for the first time in the post-Soviet space, Azerbaijan hosted the COP29 conference in the fall of 2024. Among other topics, the conference addressed the further development of green energy worldwide in connection with environmental protection issues.

Conclusion. The challenges facing countries worldwide and the anticipated structural transformations in the global energy balance have set forth key tasks, such as increasing sustainable and clean energy capacities in the region and identifying new energy routes. Azerbaijan as one of the key players in ensuring global and, to a greater extent, regional energy security, is implementing sustainable projects, particularly in the development of green energy. The country also maintains close integration with the energy systems of neighboring states such as Georgia, Iran, and Turkey.

Summarizing this study, we can conclude that the prospects for developing green energy are determined by the following key points:

A clear and steady trend towards increasing the production and consumption of green energy within the overall energy generation and consumption system is evident. Although oil and gas will remain among the primary energy sources for at least the next two decades, renewable energy generation is an essential direction for the future of the energy sector.

The energy transition is inevitable. However, it must be carried out gradually, without disrupting existing economic ties, while also considering environmental protection issues.

Green energy aims to ensure the efficient consumption of depletable resources (such as fossil fuels – oil and gas) and the rational use of inexhaustible resources, including solar, wind, hydro, and tidal energy.

The Republic of Azerbaijan, despite its abundant oil and gas resources, is making serious efforts to transition to renewable energy sources. At the same time, it is necessary to take appropriate measures to improve the regulatory and legal framework supporting the development of renewable energy, primarily through the adoption of a law on RES.

Thus, one of the main directions of Azerbaijan's future economic development is closely linked to the use of environmentally friendly technologies, clean energy sources, waste recycling, and measures for the rehabilitation of polluted areas.

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Зелена енергія в Азербайджані (типи та перспективи розвитку)

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Мета статті. Глобальний перехід до відновлюваних джерел енергії (ВДЕ) є неминучим наслідком вичерпання запасів викопних видів палива. Оскільки країни прагнуть зменшити екологічний вплив традиційного виробництва енергії, перехід до «зеленої енергії» стає критичним фактором сталого розвитку.

Новизна цієї статті. Автор надає всебічне дослідження переходу Азербайджану до зеленої енергії, з особливою увагою до унікального використання гідроенергії, сонячної, вітрової та приливної енергії в контексті країни.

Методологія та методи. Використовувана методологія включає всебічний огляд існуючих наукових праць, аналіз енергетичних політик та оцінку реалізованих проектів відновлюваної енергетики в Азербайджані. Крім того, застосовується порівняльний аналіз для розуміння унікальних підходів, які Азербайджан використовує для розвитку зеленої енергії порівняно з іншими країнами регіону.

Основні результати. Результати показують, що Азербайджан робить суттєвий прогрес у використанні ресурсів зеленої енергії. Основні ініціативи включають розширення проектів гідроелектростанцій, значні інвестиції в інфраструктуру сонячної та вітрової енергії та дослідження потенціалу приливної енергії в Каспійському морі. Важливою є також пріоритетність відновлення територій, звільнених від окупації, з інтеграцією рішень з зеленої енергії в процес реконструкції. Автор підсумовує, підкреслюючи вирішальну роль зеленої енергії у економічному розвитку Азербайджану та забезпеченні екологічної сталості. Дослідження акцентує на важливості посилення регуляторної та правової бази для сприяння подальшому розвитку відновлюваних джерел енергії. Знайдені результати свідчать, що досвід Азербайджану може бути корисним для інших країн, зокрема в регіонах із подібними енергетичними проблемами. Автор також пропонує дорожню карту для майбутнього розвитку зеленої енергії в Азербайджані, підкреслюючи необхідність постійних інновацій, інвестицій та міжнародної співпраці.

Ключові слова: *виробництво енергії, відновлювальні джерела енергії (ВДЕ), енергетичний перехід, зелена енергія, переваги зеленої енергії, проблеми використання ВДЕ, розвиток ВДЕ.*