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Assessment of the Modern Territorial Organization and Development Priorities of the Transition to Green Energy in the East Zangezur Economic Region

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Abstract. *The transition to green energy in the East Zangezur economic region represents a strategic shift in Azerbaijan's national energy policy, promoting efficient use of renewable resources, sustainable economic growth, environmental restoration, and international cooperation. Green energy projects generate significant socio-economic benefits by creating jobs, enhancing local employment, strengthening human capital through high-tech infrastructure, and diversifying energy production to ensure market stability and economic independence. Environmentally, this policy reduces carbon emissions—small hydropower plants alone prevented 225,000 tons of CO_2 emissions in 2024—while minimizing ecological risks and supporting biodiversity. The integration of solar and hydropower further improves grid stability, making green energy transition a comprehensive model of technological, social, and ecological development. Thus, the green energy transition in the East Zangezur economic region is a multidimensional development model encompassing technological innovation, social welfare, ecological restoration, and international integration.*

Keywords: *East Zangezur economic region, green energy zone, renewable energy sources, solar energy potential*

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Şərqi Zəngəzur iqtisadi rayonunda yaşıl enerjiyə keçidin müasir ərazi təşkilinin və inkişaf prioritetlərinin qiymətləndirilməsi

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Xülasə. *Şərqi Zəngəzur iqtisadi bölgəsində yaşıl enerjiyə keçid, bərpa olunan mənbələrdən səmərəli istifadəni, davamlı iqtisadi artımı, ətraf mühitin bərpasını və beynəlxalq əməkdaşlığı təşviq edərək, Azərbaycanın milli enerji siyasətində strateji bir dəyişikliyi təmsil edir. Yaşıl enerji layihələri iş yerləri yaratmaqla, yerli məşğulluğu artırmaqla, yüksək texnologiyalı infrastruktur vasitəsilə insan* *kapitalını gücləndirməklə və bazar sabitliyini və iqtisadi müstəqilliyi təmin etmək üçün enerji istehsalının şaxələndirilməsi ilə əhəmiyyətli sosial-iqtisadi faydalar yaradır. Ekoloji cəhətdən bu siyasət karbon emissiyalarını azaldır - təkcə kiçik su elektrik stansiyaları 2024-cü ildə 225.000 ton CO_2 emissiyasının qarşısını alıb - eyni zamanda ekoloji riskləri minimuma endirir və biomüxtəlifliyi dəstəkləyir. Günəş və su elektrik stansiyalarının inteqrasiyası şəbəkə sabitliyini daha da yaxşılaşdırır, yaşıl enerjiyə keçidi texnoloji, sosial və ekoloji inkişafın hərtərəfli modelinə çevirir. Beləliklə, Şərqi Zəngəzur iqtisadi bölgəsində yaşıl enerjiyə keçid texnoloji innovasiyanı, sosial rifahı, ekoloji bərpanı və beynəlxalq inteqrasiyanı əhatə edən çoxölçülü inkişaf modelidir.*

Açar sözlər: *Şərqi Zəngəzurun iqtisadi bölgəsi, yaşıl enerji zonası, bərpa olunan enerji mənbələri, günəş enerjisi potensialı*

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Introduction

The transition to green energy in the East Zangezur economic region is of particular importance as one of the strategic priorities of Azerbaijan's national energy policy. Eastern Zangezur holds great potential (Isbılen, 2025). This initiative combines renewable energy integration with a vision for sustainable growth, environmental balance, and human resource development. In general, green energy infrastructure, in addition to ensuring sustainable electricity production, strengthens the energy security of economic regions and becomes one of the main pillars of climate-adapted development (Pegels et al., 2018).

Globally, green energy policy is recognized as the leading direction of energy transformation (Kilinc-Ata & Proskuryakova, 2024; Le et al., 2025). Many countries around the world prioritize the transition to renewable energy sources in order to build sustainable energy systems, reduce carbon emissions, and comply with international climate commitments (Wojtaszek, 2025). Azerbaijan, joining this trend, aims to transition from the carbon intensity of oil and gas resources to a diversified energy portfolio (Imamverdiyev, 2026). Within the framework of the national energy strategy, it is planned to increase the share of renewable energy in the total energy balance to 30% by 2030, which is directly related to the status of the East Zangezur region as a “green energy zone”.

The contribution of the East Zangezur economic region to these goals is not limited to meeting domestic energy needs. The region also plays a strategic role in terms of forming the export potential of electricity, strengthening competitiveness in regional energy markets and ensuring long-term sustainable development. Based on decisions taken at the state level, the East Zangezur and Karabakh economic regions have been declared “green energy zones”. This status implies the reconstruction of the restored territories formed on environmentally friendly energy sources, the introduction of high-tech infrastructure and the role of the region as a pilot area in energy production.

The energy potential of the region is quite large: 7200–10000 MW for solar energy, about 2000 MW for wind energy, and small hydropower sources are already producing practical results. In 2024, the 32 SHPs operating prevented approximately 225,000 tons of carbon emissions, which is a significant contribution to the fight against climate change. These indicators, in addition to strengthening the diversification of Azerbaijan's energy balance, create conditions for achieving environmental advantages.

At the same time, the green energy projects of East Zangezur also serve to expand regional cooperation and economic integration. For example, the energy produced through the Jabrayil Energy Hub can be transmitted to the Turkish and European markets, opening a new stage in Azerbaijan's energy exports and strengthening the region's strategic position on the international energy map (Ministry of Energy 2025). Thus, the transition to green energy in the East Zangezur economic region is a strategic turning point in Azerbaijan's energy policy, acting as a complex concept serving to strengthen national energy security, sustainability of socio-economic development, restoration of ecological balance and expansion of international cooperation.

The priorities of the transition to green energy in the East Zangezur economic region are focused on complementary directions such as strengthening the energy security of the region as a whole, achieving environmental benefits, increasing economic diversification and export potential, promoting socio-economic development and innovations, as well as expanding regional and international cooperation. These priorities, formed in interaction within the framework of a single strategic concept, serve both to sustainably meet domestic energy demand and to strengthen Azerbaijan's position in global energy markets. Therefore, the green energy policy for East Zangezur applies technological innovations while serving as a broader development model that restores ecological balance, improves social well-being, and strengthens international integration.

Materials and Methods

The main objective of this study is to scientifically analyze the strategic importance, socio-economic and environmental impacts of the transition to green energy in the East Zangezur economic region. The aim is to assess the technical potential of renewable energy sources and to demonstrate how they contribute to the region’s sustainable development, energy security, ecological restoration, and international cooperation. This context is consistent with the goal of transitioning from carbon-intensive resources to a diversified energy portfolio in Azerbaijan's national energy policy and is directly related to the status of East Zangezur as a "green energy zone".

The material base of the research is the following sources:

- Official government documents and strategies: Azerbaijan's national energy strategy, which aims to increase the share of renewable energy to 30% by 2030.
- Statistics: 7,200–10,000 MW of potential for solar energy, approximately 2,000 MW for wind energy; 32 small hydroelectric power plants operating in 2024 to prevent 225,000 tons of CO_2 emissions.
- Regional development programs: State decisions on declaring the East Zangezur and Karabakh economic regions as "green energy zones".
- Scientific and analytical sources: International and local research on energy security, environmental sustainability, and economic diversification.
- Infrastructure projects: Energy export opportunities to Turkish and European markets through the Jabrayil Energy Hub.

The methodological approaches used in the study include the analytical-synthetic method - comparative analysis and generalization of data collected from various sources; assessment of geographical-energy potential - scientific assessment of the region's solar, wind and hydropower resources based on statistical indicators; socio-economic impact analysis - study of the impact of green energy projects on employment, social welfare and regional economic integration; ecological assessment - study of the ecological consequences of reducing carbon emissions and complying with climate commitments; strategic comparison - analysis of the compliance of Azerbaijan's energy policy with global trends. The study indicates that moving to green energy in East Zangezur is a diversification of energy production and a strategic approach to sustainability, ecology, and international collaboration.

Results and Discussion

Our research area, the East Zangezur economic region, was established in 2021 as one of the new economic and geographical divisions of Azerbaijan and covers an area of 7,448 km². The region includes the Jabrayil, Kalbajar, Lachin, Gubadly, and Zangilan districts. Figure 1 shows the geolocation of the economic region within Azerbaijan.

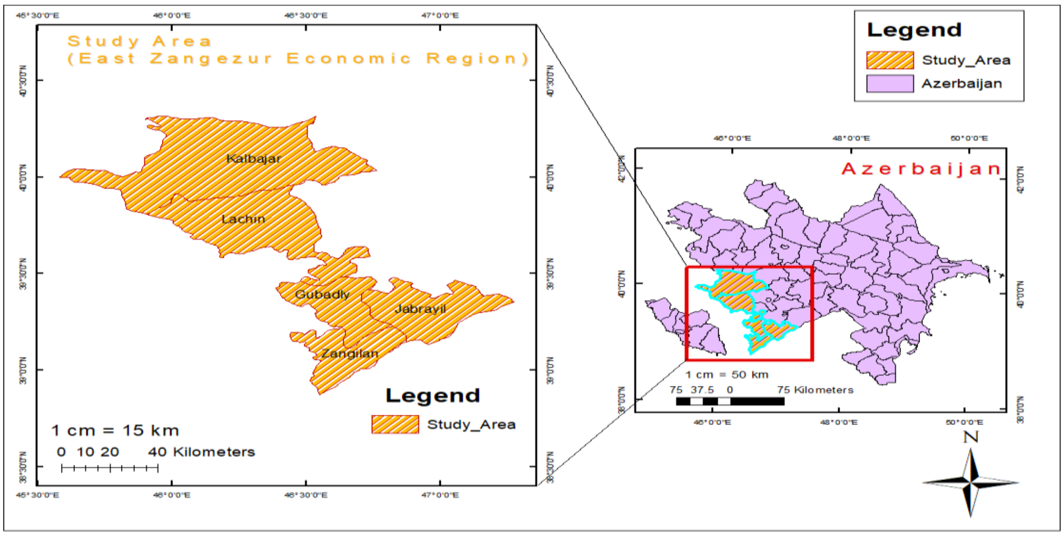

Figure 1
Location map of East Zangezur economic region

Source. Prepared by author.

The geographical position of the region is characterized by strategic advantages. East Zangezur has a state border with Armenia in the west, Iran in the south, and establishes internal relations with the Karabakh economic region in the east. This border configuration brings the region to an important position both at the intersection of the South Caucasus transit networks and in the energy and transport strategy of Azerbaijan. Currently, large-scale reconstruction and reintegration programs are being implemented in the region (Hajiyeva & Karimli, 2021, p. 73).

In 2025, the total production of electricity in Azerbaijan increased by 262.3 million kWh or 0.9% compared to the previous year and reached 28657.5 million kWh. According to official data from the Ministry of Energy, the main part of electricity was produced in thermal power plants during the reporting period, and this indicator amounted to 24823.4 million kWh. The volume of electricity produced in hydroelectric power plants was 2842.5 million kWh. Production from other sources was recorded at a total level of 991.6 million kWh, of which 169.7 million kWh fell to wind power plants, 599.8 million kWh to solar power plants, and 222.1 million kWh to the Solid Waste Incineration Plant.

These data show that traditional thermal power plants still form the basis of energy supply. However, the share of BEM in total generation, including small HPPs, Solar and Wind power, is gradually increasing (Ministry Of Energy, 2025). The total installed electricity capacity of the country for 2024 is 8415.6 MW, of which TPP: 6623.0 MW (78.7%); HPP: 1406.6 MW (16.7%); Solar Power Plants (SPP): 278.0 MW (3.3%); Wind Power Plants (WPP): 63.62 MW (0.75%); Bioenergy and Hybrid Plants: 44.4 MW (0.5%). The share of BEM (HPS, GPP, HPP, bioenergy) in total capacity is approximately 21.3% (1792.64 MW). This figure is a positive trend, given Azerbaijan's goal of increasing the share of renewable energy sources to 30% by 2030. In particular, the projects implemented within the framework of the concept of creating a "Green Energy Zone" in areas undergoing restoration (installation of more than 3,000 kW of solar panels, operation of 32 hydroelectric power stations) are an important step in this direction.

The EU plans to continue the Green Economy, reduce carbon emissions worldwide to zero, and increase the share of Green energy to 60-80% by 2050 through international and regional measures, especially through the widespread use of renewable energy. According to statistics for 2023, 2.5% of GDP in the European Union countries was allocated to the development of the Green Economy, and 2.5% of the total economically active population worked in this field.

As a result of our research, it was determined that (according to the analysis of materials for 2024) the share of alternative sources in energy production in the European Union countries was 47%. The share of various sources in renewable energy was 39.1% from wind, 29.9% from water, and 22.4% from the Sun. According to the Green Deal agreement, EU countries have set a goal of switching to practically 100% alternative energy sources by 2050. According to the energy indicators for 2025, the share of alternative energy in electricity production in Norway was 99%, in Denmark 88.7%, in Sweden 70.6%, in Finland 52.2%, in Iceland 100%, in the United Kingdom of Great Britain and Northern Ireland 49.7%, in Germany 50%, in France 28%, in Italy 45.7%, in the Netherlands 50%, in Switzerland 66.4%, in Spain 53%, in the Czechia 16%, in Hungary 27.4%, and in Poland 28% (Irena Report 2025; REN 21 2025; Pashayev 2025).

In terms of alternative energy, East Zangezur is one of the territories of Azerbaijan declared a "green energy zone". The region has a special strategic position in Azerbaijan's energy policy. The geographical location of the region creates significant advantages in terms of both the richness of natural resources and regional integration opportunities. The terrain of the area, rich in mountains and valleys, creates favorable conditions for solar and wind energy, while the river systems allow for the construction of small hydroelectric power stations. In addition, East Zangezur's border position – its proximity to access routes to Turkish and European markets – is a strategic advantage for energy exports.

The socio-economic impact of the transition to green energy is reflected in the formation of a sustainable development model for the region. Firstly, renewable energy projects create conditions for the creation of new jobs, increasing the employment level of the local population and increasing social welfare. Secondly, the introduction of high-tech infrastructure requires the strengthening of the national human resource potential, which opens up new opportunities in the field of education and specialization. Thirdly, the diversification of energy production increases the economic independence of the region and ensures the stability of the internal market.

From a strategic perspective, green energy strengthens the function that East Zangezur plays on Azerbaijan's energy map. Energy production in the region aims to cover local needs and at the same time build export capacity. The transmission of electricity generated through the Jabrayil Energy Hub to the Turkish and European markets increases Azerbaijan's competitiveness in regional energy markets and expands opportunities for international cooperation. This serves to reduce dependence on oil and gas resources and strengthen the renewable energy portfolio, in line with the strategic diversification goals of the country's energy policy.

Environmental impacts are one of the most important outcomes of green energy policies. The implementation of solar, wind and hydropower projects significantly reduces carbon emissions, enabling the fulfillment of national commitments in the fight against climate change. The prevention of 225,000 tons of CO_2 emissions from small hydroelectric power plants operating in the region in

2024 is a clear example of this. This process creates conditions for the restoration of the ecological balance of the restored areas, the production of clean energy and the protection of the environment.

The portfolio of small hydropower plants (SHPs) in the East Zangezur economic region is forming as an important pillar of the regional energy transition and exhibits a systematic structure in terms of both spatial distribution, technical-power configuration, and phased operation dynamics. The overall picture shows that the SHPs that have been successively commissioned, built and prepared for operation, and are under construction in the Lachin, Kalbajar, Zangilan, and Gubadly regions together form a regional hydropower cluster that ensures sustainable electricity supply. Its strategic function involves satisfying local demand, contributing to renewable energy balance, strengthening grid reliability, and opening pathways for future exports.

Table 1
Small hydropower plants located in the East Zangezur economic region

Small Hydropower Plant	Location	Commissioning date	Power (MW)	Status
Aghbulag-1 HPP	Lachin	2026*	14.7	Built
Aghbulag-2 HPP	Lachin	2026*	14.25	Built
Jahangirbeyli HPP	Zangilan	2023	10.5	Working
Sayif HPP	Zangilan	2024	10.5	Working
Sarigişlag HPP	Zangilan	2024	10.5	Working
Zangilan HPP	Zangilan	2024	10.5	Working
Nadirkhanli SHP	Kalbajar	2025	8.8	Working
Lower Vang SHP	Kalbajar	2024	8.6	Working
Chirag-1 SHP	Kalbajar	2023	8.3	Working
Mishni SHP	Lachin	2023	8.25	Working
Gulebird SHP	Gubadly, Lachin	2021	8.0	Working
Qamishli SHP	Kalbajar	2023	6.3	Working
Alkhasli SHP	Lachin	2023	6.0	Working
Soyujbulag SHP	Kalbajar	2023	5.3	Working
Kalbajar-1 SHP	Kalbajar	2022	4.4	Working
Zar SHP	Kalbajar	2024	4.3	Working
Silent SHP	Lachin	2024	4.0	Working
Garigishlag SHP	Lachin	2024	4.0	Working
Chirag-2 SHP	Kalbajar	2023	3.6	Working
Mirik SHP	Lachin	2025	3.5	Working
Meydan SHP	Kalbajar	2023	3.4	Working
Zabukh SHP	Lachin	2024	2.8	Working
Upper Malibeyli SHP	Lachin	2025	4	Built
Lower Malibeyli SHP	Lachin	2025	3.1	Built
Zeynalli SHP	Lachin	2025	5	Built
Minkend SHP	Lachin	2025	2.1	Built
Galaja SHP	Lachin	2025	3.1	Built
Upper Vang SHP	Lachin	2025	22.5	Built

Planned for commissioning

Source. Ministry of Energy - List of independent and operating power plants in the energy system of Azerbaijan (until 2025).

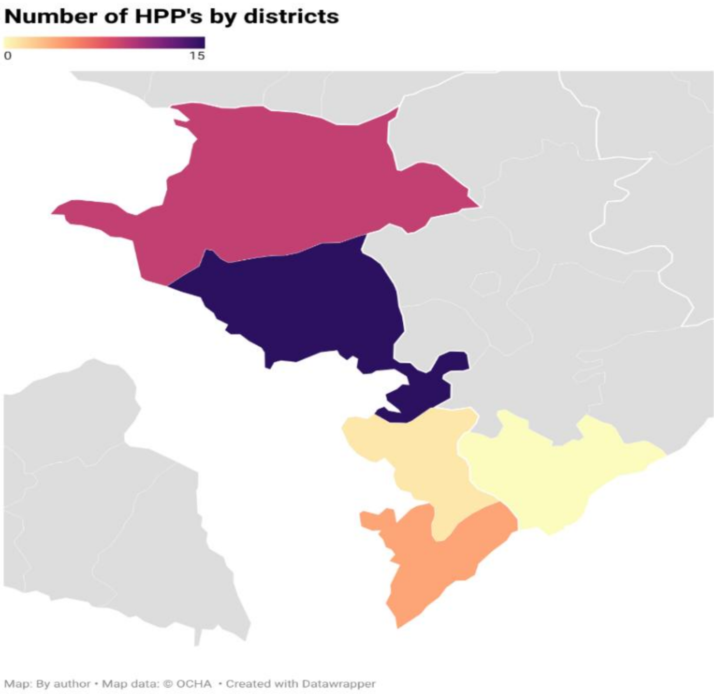

Figure 2
Distribution of hydroelectric power plants by region

When we look at Table 1 and Figure 2, it is noticeable that there is inequality in the distribution of power stations in the area. There are 15 stations in Lachin, 9 in Kalbajar, 4 in Zangilan, and 1 in Gubadly. There is no station in Jabrayil. This is also related to the terrain of the area.

The current power profile shows that the total capacity of the SHP currently in operation is approximately 131.55 MW. This category includes four stations with a capacity of 10.5 MW in the Zangilan region (Jahangirbeyli, Sayifli, Sarıgışlag, "Zangilan HPP"), nine stations in Kelbajar with capacities in the range of 8.8–3.4 MW (Nadirkhanli, Lower Veng, Chirag-1, Qamishli, Soyugbulag, Kalbajar-1, Zar, Chirag-2, Meydan), and seven stations in the Lachin-Gubadly chain with capacities in the range of 8.25–2.8 MW (Mishni, Gulabird, Alkhasli, Sus, Garigishlag, Mirik, Zabukh). In addition, the Aghbulag-1 (14.7 MW) and Aghbulag-2 (14.25 MW) stations in Lachin, which have been completed but are scheduled for commissioning, form a "built" category of 28.95 MW; once these stations are connected to the grid, the renewable power base of the region will expand further. The portfolio of projects under construction in the Lachin region consists of the Yukhari Malibeyli (4 MW), Ashagi Malibeyli (3.1 MW), Zeynalli (5 MW), Minkand (2.1 MW), Galaja (3.1 MW) and Yukhari Veng (22.5 MW) stations; the total capacity of this group is approximately 39.8 MW. Thus, the total portfolio capacity of SHPs in operation, ready for operation, and under construction reaches approximately 200.3 MW, which confirms the significant share of hydropower in the renewable energy-based model of Eastern Zangezur.

Table 2
Modern energy potential of Jabrayil district

Power Plants	Power(MW)	Commissioning date
Khudaferin	200 MW	2024
Giz Galasi	80 MW	2024
Shafag PV	240 MW	2027*

Source. Ministry of Energy - List of independent and operating power plants in the energy system of Azerbaijan (until 2025).

As can be seen from Table 2, Jabrayil district is one of the regions of strategic importance in Azerbaijan's energy policy. During the current recovery period of the study area, this region has become the focus of large-scale reconstruction and development programs. Its geographical location, water resources, and solar radiation profile make Jabrayil a region with high potential in terms of both hydropower and solar energy. The largest projects in the region's energy portfolio are the Khudaferin and Giz Galasi hydropower plants. The Khudaferin Hydroelectric Power Plant has a capacity of 200 MW and was commissioned in 2024. This facility is considered a strategic centre that will not only meet the energy supply needs of Jabrayil but also strengthen Azerbaijan's overall energy balance. The Giz Galasi Hydroelectric Power Plant has a capacity of 80 MW and was also commissioned in 2024. This plant, together with Khudaferin, forms an important part of the hydropower complex created on the Araz River. Thus, these two projects together increase the hydropower capacity of the Jabrayil region to 280 MW, which represents a significant share in Azerbaijan's renewable energy portfolio.

The geographical location and climatic conditions of the region also create favorable opportunities for solar energy. The Shafag Solar Power Plant project is designed to realize this potential. The technical parameters of the project are being finalized, but the solar radiation profile of Jabrayil will allow this plant to operate with high efficiency. The implementation of energy projects has a number of socio-economic consequences in the Jabrayil region. The creation of new jobs during the construction and operation stages, the restoration of infrastructure, and the strengthening of economic diversification have a significant impact on the social well-being of the region. Energy production supports the development of agricultural and industrial sectors, increasing the economic independence of the region. Strategically, the energy potential of the Jabrayil region is directed toward domestic consumption and export. The energy produced by the Khudaferin and Giz Galasi Hydroelectric Power Plants can be transmitted to the Turkish and European markets through the Jabrayil Energy Hub. This amplifies Azerbaijan's competitiveness in regional energy markets and strengthens the country's energy security.

In the context of the Jabrayil region, the integration of hydro and solar potential is of additional strategic importance. The power indicators presented here for the Khudaferin hydropower plant of 200 MW and for the Giz Galasi of 80 MW, if verified, could dramatically strengthen the overall energy configuration of the region; the phased commissioning of these facilities, both in terms of power scale and grid stability, would increase the transmission capacity on the interconnectors and turn export trajectories into a real sector opportunity. Although the indicators for the Shafag SPP need to be clarified, the solar-hydro synergy in the Jabrayil region creates a rational hybrid model in terms of balancing the daytime-late-night load profile and smoothing peaks due to hydro reserves during seasonal periods with high water volume.

In terms of space, the distribution of SHP is based on important geographical advantages. The mountainous-valley relief and multi-water river systems provide a favorable hydromorphology for stations built on the principle of small-power, sequential cascade (Imanov et al. 2021, p. 142). On the one hand, this morphology creates opportunities for more flexible hydrological regulation, and on the other hand, it minimizes the ecological and social risks of large reservoirs and ensures that local impacts can be managed with small-scale facilities. The cascading arrangement in Lachin and Kalbajar provides the topological advantage of proximity to the distribution network, intensive connection with lines and reduced losses; the Zangilan line simplifies operational management by creating stable blocks with 10.5 MW modular power units.

The socio-economic impacts are multi-layered. First, the SHP portfolio forms a sustainable production base in the region by ensuring rapid diversification of renewable energy infrastructure, which both increases the level of local consumption and has a positive impact on price stability. Second, new employment opportunities are created for qualified and re-qualified personnel throughout the construction, installation, operation and maintenance phases; this leads to the strengthening of local personnel potential based on practical skills, and the increase of applied competencies in the fields of vocational education and engineering. Third, the spatial distribution of small-power hydropower plants increases the continuity of energy supply for the agricultural and processing sectors, creating a reliable infrastructure environment for electrified irrigation, cold chain and small processing enterprises. Fourth, the modular nature of the portfolio facilitates the sharing of project risks, allows for flexible packaging in terms of capitalization and financing; this encourages the functional expansion of private-investor participation and access to the grid of local producers.

Strategic implications deepen the role of the “pilot green zone” in the energy map of East Zangezur. With approximately 131.55 MW of base capacity in operation, 28.95 MW of units to be commissioned in the near future, and 39.8 MW of units under construction, the region’s renewable energy portfolio is gradually expanding, making the load management of the electricity grid more flexible, and providing backup capacity. facilitates planning and brings it closer to the stability criteria required for exports. The approval and phased connection of large hydro facilities along the Jabrayil line strengthens access to the Turkish and European markets through interconnectors. This process combines two main goals in terms of Azerbaijan's energy security: reducing hydrocarbon dependence and strengthening renewable energy bases. As a result, the country's energy policy gains new opportunities in the direction of both sustainability and diversification.

In the context of environmental impacts, the role of SHPs should be particularly emphasized (Arabatzis & Myronidis, 2011). Small hydropower plants, in addition to directly contributing to the reduction of carbon emissions, provide a more flexible framework for the localization and management of environmental risks. The use of small reservoirs and intakes allows for the maintenance of measurable and compensable impacts on biodiversity, the preservation of ecosystem services, and the planning of ecological flows. In addition, the integration of hydropower modules with solar and wind power reduces the share of carbon-containing reserve capacities, supports the frequency stability of the network due to the ability of hydropower units to quickly respond to peak loads, and lowers the overall emission profile of the system.

Consequently, the SHP and associated PV portfolio in the East Zangezur economic region is a complex model aimed at building a sustainable energy system with a phased power growth strategy that effectively uses geographical advantages. Consolidation of existing capacities, timely integration of projects ready for operation into the network, and completion of facilities under construction in accordance with quality indicators ensure the parallel strengthening of both socio-economic stability, strategic energy security, and environmental sustainability. In the event of approval of large power projects along the Jabrayil line, the energy map of the region will move one step closer to a renewable-based export model, which will strengthen East Zangezur as a practical example of Azerbaijan's green transformation vision and a reliable hub for regional energy integration.

The East Zangezur economic region is one of the regions of strategic importance in terms of renewable energy resources of the Republic of Azerbaijan. The assessment of the solar, wind and geothermal energy potential of the region is of particular importance in terms of diversification of electricity production and formation of a sustainable energy strategy. For this purpose, international and national databases were used during the study, including the “Global Solar Atlas”, “Global Wind Atlas”, Solargis solar resource maps, Agroclimatic and Geographic Atlases of the Republic of Azerbaijan, as well as NASA's MERRA-2 and GMAO-5 satellite observation data (1981–2019) (Global Solar Atlas, 2021; Global Wind Atlas, 2021; Agroclimatic Atlas, 1993; Geographic Atlas, 2018).

In order to assess the solar energy potential of the East Zangezur economic region, the areas were divided into three groups based on annual solar radiation indicators. In areas with weak solar potential, annual solar radiation varies in the range of 976–1400 kWh/m². These areas mainly cover the Gubadly and Lachin regions, covering an area of approximately 5.6 thousand km² and equal to

33% of the total area of the region (Global Solar Atlas, 2021). In zones with medium solar potential, the annual radiation amount varies between 1400–1500 kWh/m²-year, and these areas cover 39% of the region (6.7 thousand km²). In areas with high solar potential, the radiation indicator is in the range of 1500–1607 kWh/m²-year, mainly located in the mountainous parts of the Kalbajar and Gubadly regions, and the total area is approximately 0.7 thousand km². These areas are considered the most favorable zones for the placement of photovoltaic power plants and The total solar energy potential is estimated at 300–400 MW (Ministry of Energy, 2021).

According to the Agroclimate Atlas, the maximum solar radiation in the region is observed in the Kalbajar and Lachin regions due to the increase in altitude above sea level, and this indicator rises to 1667 kWh/m² (Agroclimate Atlas 1993). Approximately 70% of the annual solar radiation falls on the months of April-September, and 30% on the months of October-March. The approximately 10% differences observed between different sources are explained by the lack of stationary meteorological observations in the region over the past 30 years, which indicates the importance of continuous monitoring in the future. One of the important factors affecting the efficiency of solar energy use is the annual number of sunny hours. In East Zangezur, the annual number of sunny hours varies between 2000 hours on average in the Kalbajar-Gubadly zone and 2200–2400 hours in other parts of the region. The least sunny month is December, during which the number of sunny hours is 120 hours in the Istisu area and 130–250 hours/month in the Lachin region (Geographic Atlas, 2018).

The energy production efficiency of photovoltaic panels is also affected by climatic factors, including precipitation regime, temperature conditions and duration of the frost-free period. The amount of precipitation in the region increases from 400 mm to 1000 mm from east to west, and the maximum indicators are recorded in the Kalbajar and Lachin regions (Agroclimatic Atlas, 1993). The duration of the frost-free period varies between 100–225 days and decreases with increasing altitude. The number of days with daily air temperatures above 15°C is 50–150 days, and the number of days with maximum temperatures above 35°C is 5–15 days. The number of days with continuous snow cover is on average 80 days/year in the Kalbajar–Lachin low-mountain zone (Geographical Atlas, 2018).

Choosing the optimal inclination angle of solar panels plays an important role in increasing energy production. According to the calculations, the optimal inclination angle of the panel in the East Zangezur region takes maximum values at the winter solstice (66–67°), and minimum values at the summer solstice (6–7°). The developed analytical method Its application allows to increase the annual energy production of photovoltaic systems located in complex terrain conditions by 7–10% (Gardashov et al., 2020, pp. 316–317).

The wind energy resources of the East Zangezur economic region are considered to be mainly of medium potential. The average annual wind speed varies in the region within the range of 2.5–8.7 m/s, and the number of days with wind speeds exceeding 15 m/s per year is recorded in the regions between 5–52 days (Agroclimate Atlas, 1993). According to the Global Wind Atlas, 4618 km², which constitutes 62% of the region, have an average annual wind speed of 0.1–2.0 m/s and are considered weak wind zones (Global Wind Atlas, 2021). Areas with medium wind speeds (2.1–4.0 m/s) cover 2160 km² and 29% of the region, and are mainly suitable for the installation of small-power wind turbines. Zones with high wind potential (≥4.1 m/s) account for only 819 km² or 11% of the area and are mainly located in the western part of the Kalbajar region. The complex terrain and poor infrastructure of these areas limit the economic feasibility of building wind power plants (Sun et al., 2023; Alam et al., 2025).

The region's geothermal energy resources are mainly concentrated in the Kalbajar region. The Istisu and Bagirsag areas are considered the main thermal water sources of East Zangezur (Taghiyev et al. 2001, p. 101). The water temperature at a depth of 100 m in the Baghirsag area is 80°C, in the Istisu area it is 62°C at a depth of 70 m, and at a depth of 300–350 m it is 75°C (Mukhtarov et al., 2015, pp. 54-55). The temperature of thermal waters in the region is estimated at 30–74°C, and the total daily flow is 4171 m³. The total energy potential is determined at 771 MW, provided that the water is cooled to 20°C (Tahmazov, 2013, p. 102). These resources have high prospects for energy production, as well as for treatment and health tourism purposes.

In the East Zangezur economic region, it is considered a priority to realize the potential for "green" energy exports in the region by 2030 by utilizing international cooperation. In this context, foreign investments in the transition to green energy in East Zangezur in 2026–2030 will mainly come from BP from the United Kingdom, Chinese state corporations (China Energy Overseas Investment, China Datang, PowerChina), Masdar from the UAE and ACWA Power from Saudi Arabia, as well as is built on expanding cooperation with other European companies and partners. These partnerships are of strategic importance for increasing Azerbaijan's renewable energy potential, accelerating technology transfer, and achieving its 2030 goals. Also, European influence in the renewable energy space of Eastern Zangezur has so far been mainly based on institutional cooperation, standardization and financial support. The volume of direct investment by European companies is still small compared to Spain and other large investors, however high-level cooperation agreements (e.g. Memorandum of Understanding with WindEurope) and financial support from the European Bank for Reconstruction and Development (EBRD)/European Investment Bank (EIB) are actively integrating the European side's strategy in this direction and expanding the possibilities of technical assistance (Khanayev et al., 2025, pp. 803–805).

Our analyzes show that it is advisable to implement the alternative energy potential formed in the territory of Azerbaijan along three main technical-geographical routes for export after internal integration. The first and currently most realistic route is the Azerbaijan-Georgia-Turkey line. This route is dependant on the existing transmission infrastructure and is being gradually strengthened. The energy from East Zangezur is first transmitted to the western regions via the domestic main network, and from there to the Turkish energy system via Georgia. Turkey plays the role of a transit country on this route for access to both consumer and European markets.

The second main route is the East Zangezur-Nakhchivan-Turkey route. This route is of particular strategic importance because, in addition to strengthening the energy supply of Nakhchivan, it creates a new energy integration between the continental part of Azerbaijan and Nakhchivan and, in the medium term, forms the opportunity for direct access to European energy markets via Turkey.

The third and long-term strategic route is the Central Asia-Caspian-Azerbaijan-Europe green energy corridor. This model envisages the transmission of renewable energy produced in Kazakhstan and Uzbekistan across the Caspian basin to Azerbaijan, and from there to Europe via Georgia and the Black Sea. Among the three routes mentioned, the second—the strategic East Zangezur–Nakhchivan–Turkey line—has priority in the transport and logistics sector, carrying significance for the region, the country, and the wider South Caucasus.

Conclusion

As a result of the conducted comprehensive research, it was determined that the East Zangezur economic region is one of the areas with high potential for the diversified development of renewable energy sources. The mainstay of the green energy system in the region should be SHP and PV. The mountainous terrain of the economic region and the density of the river network create favorable conditions for the development of small hydroelectric power stations (SHP). Lachin and Kalbajar regions are the most favorable areas for the development of hydropower cascades. The abundant river systems and mountainous-valley terrain allow for the construction of small powerful hydroelectric power stations on the principle of sequential cascade. Existing and prospective hydropower nodes located on Tartar, Hakari and their tributaries are considered priority areas for the construction of SHP. However, the territorial organization of SHP in the regions belonging to the region differs significantly from each other. For example, the sequential formation of modular HPP blocks in the

Zangilan region plays a distinctive role in the regional energy system. Here, the parallel operation of several stations with a capacity of 10.5 MW simplifies operational management and creates stable energy blocks . This model strengthens uninterrupted power supply for the agricultural and processing sectors and creates technical stability for connection to the export grid.

In the Gubadly district, the Gulabird HPP and other small hydro facilities are the mainstays of energy supply to agricultural areas. The joint use of HPPs along the Gubadly-Lachin line allows for minimizing network losses and more efficient organization of energy supply. Jabrayil region is distinguished by its large hydropower complexes and solar-hydro hybrid model. The phased connection of Khudaferin (200 MW) and Giz Galasi (80 MW) HPPs strengthens the energy map of the region and enables export-oriented energy production. These facilities increase Azerbaijan's competitiveness in regional energy markets by ensuring energy transmission to Turkish and European markets through the Jabrayil Energy Hub.

The mountainous and foothill areas of the Kalbajar, Gubadly and Lachin regions with high and medium solar radiation act as the main priority zones for the placement of large-scale solar power plants (SPPs). The high annual number of sunny hours in these areas, the relatively low suitability of the land cover for agriculture, and the possibility of connecting to power transmission lines make it possible to efficiently organize photovoltaic stations on the territory. When organizing solar energy on the territory, the differentiation of the optimal inclination angles of the panels by relief and altitude zones, as well as the selective application of tracking systems, are of great importance in terms of increasing energy production.

Wind energy should play a supporting role in the green energy balance in the East Zangezur economic region. The limited area of areas with high wind potential in the region and the presence of complex mountainous terrain limit the construction of large wind power plants (WPPs) from an economic point of view. Nevertheless, it is considered advisable to install small and medium-power wind turbines in the high mountainous areas located in the western part of the Kalbajar region and along separate watersheds. These turbines should be considered mainly as an integral part of local energy supply, electrification of mountainous settlements and hybrid (solar-wind) energy systems.

Geothermal energy resources are of particular strategic importance in the territorial organization of green energy in the East Zangezur economic region. The Istisu and Bagirsag thermal fields located in the Kalbajar region should be used as low and medium temperature geothermal resources mainly for thermal energy production, greenhouse farms, sanatorium-resort infrastructure and municipal heating systems.

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