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EVALUATION OF THE ECONOMIC EFFICIENCY OF THE PRODUCTION OF RENEWABLE ENERGY SOURCES IN AZERBAIJAN

Abstract

The main goal of assessing the economic efficiency of the production capacity of green energy resources is to reveal the price difference and prospects of renewable energy plants planned to be built in the country and traditional plants. The study was carried out by analyzing the terms of levelized cost per unit of energy (LCOE), initial capital expenditure (CAPEX), operating expenditure (OPEX), net present value (NPV), capacity factor, and feed-in tariff. The profitability of installing the plant was assessed by comparing the results obtained separately with the help of statistical methods and a unified approach. It was determined that the cost per unit of energy during the installation and operation of renewable energy-based plants (solar and wind) is higher than that of traditional energy resources. The decisive way this is to develop them in accordance with state subsidies to fulfill the international obligations of the state in the fight against climate change. In this study, the cost-benefit factor in the construction of renewable energy plants was analyzed, and the feasibility of investment for investors was determined. This also plays a fundamental role in decarbonization, preventing global warming, and diversifying energy sources, which are among the country's energy policy priorities.

Keywords: *renewable energy resources, energy policy, economic efficiency, LCOE, feed-in tariff, investment.*

1. INTRODUCTION

Globally, energy security and sustainable development have become of the top priorities of countries around the world. Problems such as depletion of oil and gas resources, carbon dioxide emissions from their use, global warming, and increasing droughts have led to a review of energy strategies (Grammatico, 2023). The most effective way to prevent these problems is to improve the use of renewable energy sources (RES). To implement such power plants, it is necessary to prove on scientific grounds that electricity production from them is economically efficient.

Countries around the world have prioritized the development of renewable energy sources with the principle of minimum investment and maximum benefit in the energy transition process. The attraction of investment and its efficient use directly depend on the economically correct assessment of the resources in the area. Because, for these projects to be effective, the initial capital expenditure (CAPEX) is high, the investment requires a long payback period, and it is related to variable natural factors depending on local climatic conditions. Although there are works on this topic in scientific research, a comparative analysis of renewable energy sources with each other and with hydrocarbon-based plants based on a single methodology has not been developed in detail. The

main purpose of this study is to find a gap in solving the problem and to conduct a comparative analysis of the economic assessment methods of solar and wind energy projects for the country.

2. MATERIALS AND METHODS

2.1. Classification of renewable energy technologies

The article analyzes the country's solar and wind energy potential to determine the economic efficiency of RES production capacity. The evaluation indicators are mainly capital and production costs (CAPEX and OPEX), high solar radiation and wind speed of the area, and the continuity of the energy produced (Wall Street Prep., 2021). Most solar and wind power stations use concentrated solar energy, photovoltaic panels (polycrystalline), and onshore and offshore turbines. In particular, with the annual solar radiation for the country at the level of 1500-1650 kWh/m², it is efficient to build these systems in the Absheron, Kur-Aras, and Nakhchivan regions (Geographic Atlas of Azerbaijan, 2018). There has been a downward trend in the prices of these technologies over the last 10 years, which has minimized their capital costs. The reduction in prices for panel cleaning and maintenance, which are operating costs, also makes the construction of these stations cost-effective.

2.2. Economic efficiency indicators

In general, the most commonly used indicator when conducting economic comparisons of different technologies is the Levelized Cost of Energy (LCOE). It measures the average cost of producing a unit of energy over the life of the plants. The calculation methodology takes into account factors such as initial capital investment (CAPEX), annual operation and maintenance costs (OPEX), and the life of the project (BP, 2024). Considering the Azerbaijani market, the annual interest rates applied by local financial institutions between 10%-15% can be considered as a realistic discount rate reflecting the risk profile of the project and the opportunity cost of the investment. Although LCOE does not take into account price differences in the energy market, it allows comparing energy projects and sources of different sizes and technologies.

2.2.2. Dynamic indicators (NPV, IRR, payback period)

Dynamic indicators based on the time value of cash flows invested in renewable energy projects provide investors with a more accurate analysis. Net Present Value (NPV) indicates the current value of the income that the project will generate during its operation. In the obtained indicators, a positive NPV indicates that the project is financially viable, and a negative NPV indicates that it will result in a loss (Ross, Westerfield, & Jaffe, 2019). The Internal Rate of Return (IRR), which is the effective rate of return of the project and is higher than the minimum rate of return required by the investor (MARR), indicates that the investment is profitable (Brealey, Myers, & Allen, 2022). The payback period calculates how long it will take to repay the initial investment. Although this indicator is useful for assessing the riskiness of the project, it is considered inadequate because it does not take into account the income after the payback period of the investment.

2.3. Factors affecting the assessment

Three main factors play a significant role in the decline in energy production prices for RES: competitive energy supply, state incentive policy and continuous adaptation to technological development. As a result of the development of alternative energy technologies in the world, the price of produced electricity has decreased significantly compared to the beginning of the century. In 2010-2021, the price of one kWh of electricity obtained from industrial-scale solar panels decreased 9 times (from 0.40 to 0.046 US dollars) (IRENA, 2022). The economic assessment of projects for RES is a complex process which reflects the influence of various factors. They can be classified into four groups:

1. Natural-geographical factors: Wind speed (optimal 6-7 m/sec), solar radiation intensity of the area (1500-1650 kWh/m²), land use, infrastructure conditions, proximity to housing and the power grid, etc.

2. Technological factors: Equipment (turbine, panel, generator) efficiency (solar - 12-22%, wind turbines 35-45% KPD), service life (25 years), prices, technology development rate and price decline (LCOE has decreased by 80% in the last 10 years).

3. Financial factors: Cost of capital, financial risk, currency value and inflation. Interest rates of 10-15% set by local banks directly affect the financial weight of the project and its LCOE indicator.

4. Legislative framework: State subsidies, preferential tariffs (0.08-0.12 USD/kWh), carbon tax, tax breaks, antitrust, etc. These are included in the calculation as the main influencing factors in the implementation of the project and investment. Although the use of this system for individual consumers up to 10 kWh is allowed, the application of preferential tariffs is necessary for the development of industrial-scale projects.

These factors together shape the economic efficiency and investment attractiveness of RES projects. In addition, solar radiation in an area with high intensity provides a low LCOE when combined with technologically efficient panels, but high interest rates and lack of government support prevent this advantage (Mustafayev, Kulawczuk, & Orobello, 2022).

3. RESULTS AND DISCUSSION

3.1. Comparative Analysis: Comparison of Technologies Based on LCOE

Analysis of energy sources and conventional fuels for 1 kW of electricity generation shows that the LCOE of renewable energy equipment, especially solar (PV) and wind energy, has decreased significantly recently (table). In fact, in many regions, it has become competitive with traditional coal and gas fuels. To clarify, the table below displays the average LCOE values (USD/MW) of various energy technologies.

Table 1

Comparison of LCOE of different energy technologies

Energy Source	CAPEX (USD/kWh)	OPEX (USD/kWh/year)	LCOE (USD/MWh)	Notes
Coal (conventional)	3000-4000	30-40	65 - 150	Excluding carbon tax
Natural gas (conventional)	1000-1200	20-35	45 - 100	Depends on fuel price
Solar PV (Azerbaijan)	800-1200	5-15	40 - 70	Considering high radiation (1500-1650 kW/h/m²-year)
Wind (Onshore)	1300-1800	20-30	35 - 55	For areas with average wind speed above 7 m/s
Hydropower	2000-5000	15-25	50 - 100	Although it requires high CAPEX and specific geographical conditions, it requires low OPEX

3.2. Comparison of prices

It is possible to reveal by comparing the LCOE values of the various energy technologies studied with each other. As can be seen, RES is already competitive with hydrocarbon fuels, which is why the LCOE values of wind (onshore) and solar (PV) energy are already in the range of traditional coal and natural gas plants. This has become possible in the reality of technological development and decreasing equipment prices (CAPEX) (Wall Street Prep, 2021). The LCOE indicator of a solar power plant to be installed in accordance with the high solar radiation potential (1500-1650 kWh/m²) in the country is close to the lower limit of the range of 35-80 USD/MWt (35-50 USD/MWt), which brings it closer to the level of direct competition with local natural gas-based plants (Mustafayev, Kulawczuk, & Orobello, 2022). For example, this indicator is 50-85 USD/MWh for solar PV in Turkey and 35-60 USD/MWh in China (IRENA, 2023). Since hydrocarbon prices

are mainly based on variable costs (fuel purchases), RES costs are mainly based on initial capital investment. As we have noted, this also reveals the need for initial investment and a long-term payback period. In 2024, the cost of solar PV projects worldwide was 670 million USD. It is predicted that it will decrease to 0.04–0.06 USD/kWh by 2027, which is in line with global trends (Eurostat, 2025). For Azerbaijan, local financing rates (10-15%) should be taken into account in more realistic calculations of LCOE. This is because interest rates are high compared to developed countries, which increases local LCOE values. That is why loans, such as preferential tariffs and incentive state subsidies, can be a decisive factor in implementing projects that do not pose a risk for investors and increase profitability.

3.2.1. Impact of Public Policy and Financial Factors

LCOE analyses show that public policy has a decisive impact on these indicators. For example, a 50 USD/ton carbon tax on carbon dioxide, when added to the LCOE of coal plants, can increase its cost by 50 USD/MW to 200 USD/MW (Grammatico, 2023). In contrast, a 30% subsidy or feed-in tariff for solar PV projects can reduce their LCOE from 60 USD/MW to 42 USD/MW. This further increases the economic advantage and environmental benefit of RES over traditional energy. In the Azerbaijani context, the 10-15% annual interest rates applied by financial institutions directly affect the discount rate of projects, i.e., the LCOE. For example, while the LCOE of a solar PV project with a 10% interest rate is 50 USD/MW, at a 15% interest rate, this figure can increase to 65 USD/MW. For example, in European countries, the price of 1 kWh of electricity varies between 0.05 and 0.26 EUR, depending on the sources and place of production (IRENA, 2021). It is possible to eliminate the difference by providing subsidies to state entrepreneurs for the development of RES. In this direction, we can note initiatives such as "green energy zones" implemented in Karabakh. In 2024, 49.9% of the total 50.1 million TOE of energy exports fell on crude oil, 48.6% on natural gas, and only 0.2% on electricity (Energy of Azerbaijan, 2025). This fact, in addition to showing the export-oriented hydrocarbon dependence of the country's economy, once again confirms the need for state support for the development of RES.

3.2.2. Impact of Risk Factors

Economic assessment risk factors also play an important role in the construction of RES-based plants. Risks such as technological obsolescence and model renewal should also be taken into account. In addition, the energy production efficiency of solar panels decreases by about one percent every year. This is a predictable value over their 25-30-year operational life (20-30% decrease). Another risk is the volatility of energy market prices, mainly the risk of price declines (Dallas Fed, 2025). However, CAPEX costs for solar energy are paid at the beginning of the project, which is less exposed to long-term price risk than gas resources, which are tied to fuel prices. In addition to the comparative analysis, the GDP dynamics of the Azerbaijani economy are also sensitive to the impact of the energy sector. In recent years, the GDP volume has fluctuated: 93.2 billion manat in 2021, 134.0 billion manat in 2022, and 123.0 billion manat in 2023 (Statistical Yearbook of Azerbaijan, 2024). The main reason for these changes is related to price volatility in hydrocarbon exports and external factors in the energy market. The fact that the share of energy exports in total trade has reached approximately 90% clearly shows the country's economy's continued dependence on hydrocarbons.

3.2.3. Limitations of the Study

The analysis conducted in the article and the conclusions drawn from it are formed within certain limitations and have some shortcomings. Since the study was mainly conducted on solar (PV) and wind (onshore) energy, the potential of other renewable sources (bioenergy, geothermal) was not taken into account. In addition, the presented LCOE values were calculated based on medium-sized utility-scale power plants and were not included in the analysis conducted on the economics of small-scale and distributed energy systems. The calculations based on financial assumptions of a 10-15% interest rate and incentive tariff expectations may change in real market conditions. Also, the study did not take into account technical and economic factors such as the level

of readiness of the republic's energy network for the full integration of renewable energy sources. As a result, this analysis should be evaluated within the scope of the above-mentioned limitations, and both energy sources should be taken as a basis.

3.3. Comparison with Literature Data

The results obtained in this study are consistent with the global trends reported in the 2023 report of the Renewable Energy Agency. The IRENA report states that the price of PV batteries has decreased by 85% since 2010 (IRENA, 2023). This has reduced the LCOE of solar modules to a level comparable to hydrocarbon-based energy sources in several countries. The price reported for our country in that report is between 40 and 70 USD/MW, which is consistent with the average figure of 48 USD/MW for the Middle East region. The price difference is mainly due to differences in land use and solar energy potential. There is a lot of scientific literature on the assessment of production capacity. For example, Smith et al. (2022) calculated LCOE values with lower figures, such as 30-50 USD/MW, as noted in their study for European countries. This difference is mainly due to the lower cost of capital (low interest rates) and more developed and integrated market conditions in this region. Given the unique financial and natural conditions for Azerbaijan, which emerged in our analysis, the fact that prices are around 20% higher confirms global trends in a local context.

3.4. Historical Dynamics and Structural Changes of Energy Production in Azerbaijan

In Azerbaijan, there has been no significant change in the share of alternative energy in the country's energy balance in the near term in the direction of reducing the share of air-polluting hydrocarbon fuels in the energy balance. According to official statistics, in 2024, total energy production amounted to 74.7 million TOE (tons of oil equivalent), of which 45.0% was crude oil, 54.4% was natural gas, and only 0.6% was renewable energy sources (Energy of Azerbaijan, 2024). That is, even if energy production through renewable energy sources has increased, this is not reflected in the statistics. From the point of view of sustainable development, this is a negative trend, and the share of fuel in energy production has increased instead of decreasing; in 2020, this indicator was even 95.1%. The share of hydropower in total energy production decreased from 8.2% to 6.0% in 2000-2023 (Ministry of Energy, 2023). During the same 24-year period, energy production at HPPs increased by only 15%, from 1534.2 million kWh to 1763.4 million kWh, which is not a high result (Energy of Azerbaijan, 2024, p. 133). Over the past 5 years, the percentage of electricity produced through solar energy has decreased from 0.2% to 0.3%, while the share of wind energy has decreased from 0.4% to 0.2% (from 105.4 million kWh to 55.4 million kWh), or 1.9 times (Ministry of Energy, 2023). Finally, in 2023, 92.8% of energy production was accounted for by gas-fired thermal power plants, and only 7.2% by renewable energy sources.

3.5. RES usage situation

In 2024, Azerbaijan's total electricity production was 28.4 billion kWh, of which 24.5 billion kWh (86%) was obtained from thermal power plants and 3.8 billion kWh (14%) from RES. Energy production by sources is 3,011 million kWh, or 10.6%, from HPPs; 556.3 million kWh, or 2%, from solar PV; 232.5 million kWh, or 0.8%, from biomass energy; and 50.9 million kWh, or 0.2%, from wind energy (Ministry of Energy, 2024).

According to the installed capacity indicators for 2024, the country's electricity generation capacity was 8.4 GW, of which 6623 MW was thermal power plants, 1406.6 MW hydropower, 278 MW solar power, 63.62 MW wind, 37 MW bioenergy, and 7.4 MW hybrid power plants. In total, the installed capacity of RES is 1.8 GW (21%) (Energy of Azerbaijan, 2024, p. 133). According to these indicators, it can be seen that thermal power plants still dominate the energy production structure of Azerbaijan.

Looking at the structure of final energy consumption, in 2024, 39.0% was accounted for by households, 30.8% by the transport sector, 15.3% by industry and construction, and 14.9% by other sectors (Ministry of Energy, 2025) (figure). This indicates that there are wide opportunities for the application of alternative energy technologies, especially in the transport sector.

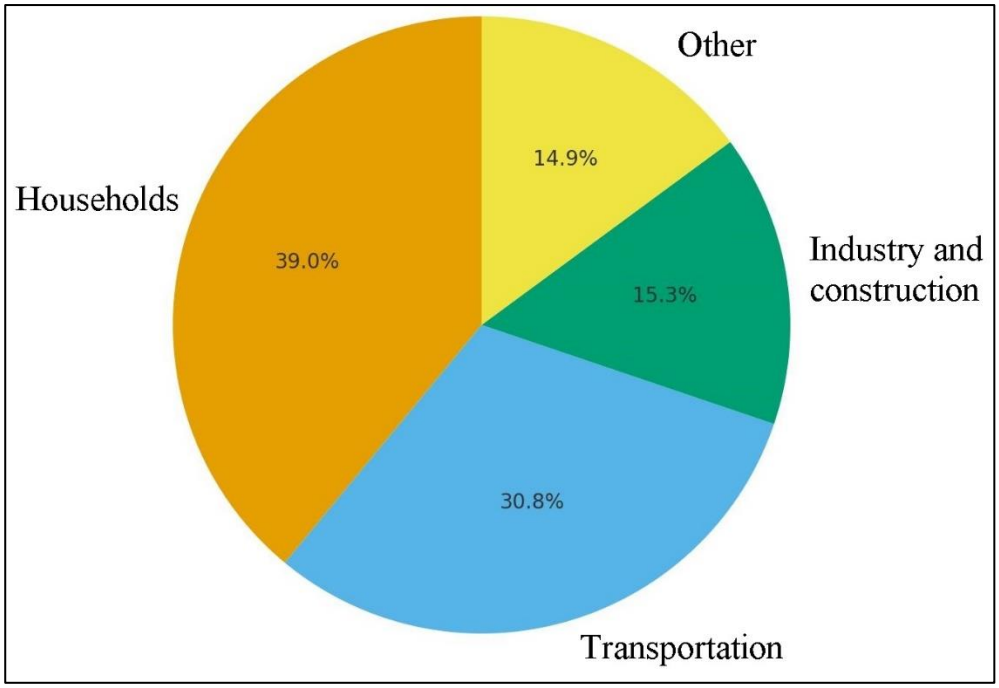

Figure 1. Structure of final energy consumption (2024)

3.6. Prospects of renewable energy in the energy balance of Azerbaijan

While the share of renewable energy is increasing, the main power in its structure is hydropower, but a decrease in water resources has been observed over the years. The role of solar and wind energy is gradually increasing, and bioenergy has remained stable at 232.5 million kWh since 2012 (AREA, 2024). However, the growth trend in wind energy in the forecasts for 2025, as well as the fact that the sun has more favorable economic indicators, indicates that the position of renewable energy in the energy balance of Azerbaijan will strengthen. In general, the discussion shows that the main strategic goal in the energy sector of Azerbaijan is to increase the share of renewable energy and reduce dependence on thermal power plants. In particular, solar and wind energy can be the main driving force of the renewable energy portfolio in the coming decade. The state concept of "green energy zones" (in Karabakh and East Zangezur) will give an additional impetus to accelerating this process. Within the framework of Azerbaijan's green economy, achieving both ecological and macroeconomic stability and reaching a share of 25% with state support could lead to a reduction of approximately 4 million tons of CO_2 emissions per year (Environment in Azerbaijan, 2024).

3.7. Impact of Tariff Policy

The fact that wholesale prices for renewable sources (small hydropower plants - 7.1cents/kWh, wind - 7.3cents/kWh, solar and other sources - 8.5cents/kWh) are set higher in the tariff structure for electricity in the republic than for traditional fuel-based plants (6.2 cents/kWh) reflects the state's priorities for energy transition (Tariff Council, 2024). This difference indicates that market mechanisms do not create additional incentives for investments in renewable energy from an economic perspective. Because the analytical approach shows that if the goal is to increase the share of green energy in the country, the price of these sources should be lower than that of hydrocarbon fuels in market conditions. Thus, producers and consumers always prefer a cheaper energy resource as a choice. Otherwise, the fact that RES is more expensive than traditional sources means additional investment and a long payback period for the entrepreneur. In this regard, various studies also note that prices should be regulated to develop RES. For example, low interest rates in the European market allow green energy projects to become profitable faster, while in countries with high interest rates, LCOE indicators remain higher (Smith & Johnson, 2022; IRENA, 2023).

In the long term, a rapid increase in the share of RES is possible only if the price of these sources drops below that of traditional energy and gains a real competitive advantage in the market (Mustafayev, Kulawczuk, & Orobello, 2022). International reports also confirm that the levelized cost of energy (LCOE) of solar PV and wind energy has decreased by 70–85% in the last decade (Mustafayev, Kulawczuk, & Orobello, 2022). This has already approached the indicators of traditional coal and gas plants in many regions (IRENA, 2023; S&P Global, 2025). Although LCOE indicators are 15–20% higher than in developed countries due to high interest rates in the specific conditions of Azerbaijan, this difference is expected to decrease as a result of technological development and market integration.

CONCLUSION

In 2024, the share of renewable energy sources (RES) in Azerbaijan's total energy supply was only 2.2%, of which 258.7 thousand TOE was hydropower, 101.2 thousand TOE was biomass and waste, 47.9 thousand TOE was solar PV, and 4.4 thousand TOE was wind energy. Of the total electricity generation of 28.4 billion kWh, only 3.8 billion kWh (14%) was provided by RES. This indicator, while in the European Union it is 44%, confirms Azerbaijan's still high dependence on traditional hydrocarbon fuels.

A comparative economic assessment shows that the LCOE of solar PV plants is in the range of 40–70 USD/MWh, and for wind (onshore) projects, it is in the range of 35–55 USD/MWh. These figures are already competitive with those of traditional natural gas plants (45–100 USD/MWh) (Dallas Fed, 2025). In addition, as a result of the introduction of a 30% subsidy or feed-in tariff, the LCOE of solar PV could decrease from 60 USD/MWh to 42 USD/MWh, which increases the economic advantage of RES in the market.

The total installed electricity generation capacity in 2024 was 8.4 GW. Of this, 6.6 GW was thermal, 1.4 GW hydro, 278 MW solar, 63.6 MW wind, and 37 MW bioenergy. That is, RES's share in total generation capacity was 21%, while in actual production it was only 14%.

The dynamics of GDP also reflect the macroeconomic impact of the energy sector: in 2021, it was 93.2 billion manat; in 2022, it was 134.0 billion manat; and in 2023, it was 123.0 billion manat. These changes are mainly due to the volatility of hydrocarbon export prices. The share of energy exports in total trade remains close to 90%, which indicates the high dependence of the country's economy.

Calculations show that increasing the share of RES to 25% could result in a reduction of approximately 4 million tons of CO_2 emissions per year. Since the life cycle CO_2 emissions of coal-fired thermal power plants are 10–15 times higher than those of solar and wind power plants, the development of RES is of strategic importance from both an ecological and economic perspective.

Based on the results of the research, it can be concluded that certain measures should be taken to increase the share of RES in the energy sector of Azerbaijan. The volume of subsidies and concessions provided to renewable sources in energy policy should be increased, tariffs should be regulated in such a way that RES becomes more attractive in real market conditions, the legal and regulatory environment for foreign and local investors should be simplified and investment risks should be reduced, the "Green Energy Zones" project should be extended to other regions of the country, and the share of RES should be increased in the long term, ensuring economic diversification and environmental stability.

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Azərbaycanda bərpa olan enerji mənbələri istehsalının iqtisadi səmərəliyinin qiymətləndirilməsi

Xülasə

Yaşıl enerji resurslarının istehsal imkanlarının iqtisadi səmərəliliyinin qiymətləndirilməsində əsas məqsəd ölkədə tikintisi planlaşdırılan bərpa olunan enerji stansiyaları ilə ənənəvi zavodların qiymət fərqini və perspektivlərini aşkara çıxarmaqdır. Tədqiqat enerji vahidi üçün səviyyəli maya dəyəri (LCOE), ilkin kapital məsrəfləri (CAPEX), əməliyyat xərcləri (OPEX), xalis cari dəyər (NPV), tutum əmsalı və tədarük tarifi şərtlərinin təhlili yolu ilə həyata keçirilmişdir. Zavodun quraşdırılmasının rentabelliyi statistik metodların və vahid yanaşmanın köməyi ilə ayrı-ayrılıqda əldə edilmiş nəticələrin müqayisəsi yolu ilə qiymətləndirilmişdir. Müəyyən edilmişdir ki, bərpa olunan enerjiyə əsaslanan stansiyaların (günəş və külək) quraşdırılması və istismarı zamanı enerji vahidinin dəyəri ənənəvi enerji resurslarından daha yüksəkdir. Bunun həlledici yolu iqlim dəyişikliyi ilə mübarizədə dövlətin beynəlxalq öhdəliklərini yerinə yetirmək üçün dövlət subsidiyalarına uyğun olaraq onları inkişaf etdirməkdir. Bu araşdırmada bərpa olunan enerji stansiyalarının tikintisində xərc-fayda faktoru təhlil edilmiş və investorlar üçün investisiyanın məqsədəuyğunluğu müəyyən edilmişdir. Bu, həm də ölkənin enerji siyasətinin prioritetləri sırasında olan karbonsizləşdirmə, qlobal istiləşmənin qarşısının alınması və enerji mənbələrinin şaxələndirilməsində fundamental rol oynayır.

Açar sözlər: *bərpa olunan enerji resursları, enerji siyasəti, iqtisadi səmərəlilik, LCOE, yem tarifi, investisiya.*