The study's focus is the country's energy sector, including renewable energy production. The problem to be solved is modeling the impact of energy efficiency and renewable energy production on greenhouse gas emissions in the country. This study investigates the impact of energy efficiency and the transition to renewable energy sources on greenhouse gas emissions in Azerbaijan, where the energy mix remains dominated by fossil fuels. Using a regression–based analytical framework, the research quantifies the contribution of these factors to changes in emission levels over time. The empirical results demonstrate that improvements in energy efficiency, measured as gross domestic product (GDP) generated per unit of total energy consumption, exert the greatest influence on emission reductions. This finding suggests that economic growth driven by efficient energy use can serve as a key mechanism for decarbonization. In contrast, the expected mitigating effect of the share of renewable energy sources in the national energy balance was not statistically significant. This outcome is likely explained by the relatively small share of renewables in Azerbaijan's total energy supply and the early stage of the country's renewable sector. The study concludes that effective climate policy should combine measures to accelerate improvements in energy efficiency with initiatives to expand the use of renewable energy. The proposed model highlights the dual importance of optimizing existing energy consumption while investing in cleaner technologies. Based on the results, 80% of the annual change in a country's greenhouse gas emissions can be explained by changes in factors such as renewable electricity generation, the share of renewable electricity in total electricity generation, and GDP per unit of energy consumption. The findings can be applied to the design of sustainable energy strategies and long-term decarbonization policies

Keywords: decarbonization, sustainable energy, emission reduction strategies, environmental policy, regression analysis

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DEVELOPMENT OF AN INTEGRATED MODEL FOR EMISSION REDUCTION THROUGH ENERGY EFFICIENCY AND RENEWABLE ENERGY

Emin Nemat Ahmadzade
PhD in Economics,
PhD Student in the Doctor of Science Program
Agrarian Research Center of the Ministry of Agriculture of the Republic of Azerbaijan
S. Vazirov str., 91, Baku, Azerbaijan, AZ1072
Rasul Balayev
Doctor of Science in Economics, Professor*
Ulviyya Rzayeva
Corresponding author
PhD, Associate Professor*
E-mail: ulviyya_rzayeva@unec.edu.az
Konul Mirzammadova
Senior Lecturer*
*Department of Digital Technologies and Applied Informatics
Azerbaijan State University of Economics (UNEC)
İstiglaliyyat str., 6, Baku, Azerbaijan, AZ1001

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1. Introduction

The deepening of the global ecological crisis and the depletion of natural resources, including residual energy resources, have made it necessary to change man's attitude toward nature. Understanding this necessity encourages continuous steps towards sustainable development in various directions. Currently, there is disagreement over the role of the energy factor in the consequences of climate change [1]. However, the number of studies showing a fairly close relationship between energy use and greenhouse gas emissions is increasing. It has been demonstrated that energy efficiency levels significantly impact greenhouse gas emissions and climate change [2].

It can be said that greenhouse gases play an important role in global climate change, which worries most people. The increase in emissions of these gases is directly related to increased consumption of residual (traditional) energy sources [3].

In terms of sustainable development requirements, the characteristics of the transition to renewable energy are an important factor in determining energy efficiency [4]. It is considered essential to regard the overall efficiency of the energy system, including renewable energy sources, as a crucial factor influencing greenhouse gas emissions. Another aspect that attracts attention in the source referred to is the presentation of the results of observations on the direct relationship between the use of renewable energy and greenhouse gas emissions. The point is that, as already noted, the idea that consuming renewable energy resources reduces greenhouse gas emissions, especially carbon emissions, has become a self-evident long-term stereotype. According to some studies [5, 6], the period up to 2030 will be particularly important for the development of renewable energy and its impact on greenhouse gas emissions.

Increasingly, sources highlight the importance of discussing energy efficiency, including the impact of transitioning to renewable energy sources on greenhouse gas emissions, such as carbon emissions. Many researchers and experts recommend accepting that the transition to renewable energy sources unequivocally reduces greenhouse gas emissions [7, 8]. The reason is that greenhouse gas emissions may decrease sharply when using renewable sources compared to traditional energy sources.

Thus, although the issue of energy efficiency is becoming a priority due to the worsening climate crisis, and the global community is sparing no effort to address it quickly, reliable assessments of greenhouse gas emissions, expressed in figures, are rare. In this regard, several objective factors are encountered, including the lack of reliable historical databases, the varying economic, environmental, and technological characteristics of countries, and specific legal differences across countries.

Given the diverse realities of current energy policies, it isn't easy to formulate a unified climate and energy policy that satisfies all stakeholders.

Therefore, studies devoted to energy efficiency using alternative energy sources, along with their impact on greenhouse gas levels, are scientifically relevant.

2. Literature review and problem statement

In fact, as indicated in the following source [9], each type of renewable energy source should be studied in more detail in terms of its impact on the environment, and the transition to a specific type of renewable energy should be characterized in technological, environmental, and economic terms for each country and region. One reason for this approach is the inadequacy of the data and methodologies. Studies [10, 11] indicate that indicators for assessing the energy efficiency of sustainable product value chains have not yet formed a comprehensive system. The database for assessing the impact of energy efficiency and the transition to renewable energy on greenhouse gas emissions is not at the desired level in terms of reducing asymmetry and ensuring representativeness.

The efficiency of the transition to renewable energy is related to its economic feasibility. Although there are different positions on the economic criteria for the efficient use of energy resources, the relevant sources [11] primarily mention the amount of energy savings, the payback period of investments, and the current value of payments within the existing incentive system.

In general, energy efficiency depends on many criteria, including tariff policy [12]. The paper describes in detail the mechanisms that activate energy conservation processes. However, the relationship between greenhouse gas emissions and energy pricing is not addressed in this paper. The relationship between greenhouse gas emissions and alternative energy pricing also deserves special attention.

Despite the problem's relevance in [13], which affects many countries, this scientific work, however, does not provide a definitive solution to the energy problem. The paper lacks a unified methodology that serves as a basis for decision-making and applies to at least some countries with relatively similar economies.

The paper [14] emphasizes the importance of implementing effective energy policies, fostering innovation, and promoting international cooperation to harness the full potential of the renewable energy system in combating climate change. However, the paper does not provide a theoretical justification for why an increase in the share of renewable energy should lead to a reduction in CO_2 emissions, meaning the cause-and-effect mechanism is described somewhat weakly.

The carbon footprint, measured in units of carbon dioxide equivalent, has become a key concept in scientific discourse, used to analyze and assess the environmental impact of anthropogenic activities. The carbon footprint has a significant impact on economic activity and financial results, driving environmental degradation and climate change. Extensive research [15] indicates that reducing carbon footprints enables businesses to lower costs, mitigate risks, and enhance returns on invested capital. Limitations of the study include differences in emissions and environmental, social, and governance (ESG) reporting systems across countries. Further study of the impact of carbon pricing, innovation activity, and investment attractiveness on financial performance in the context of decarbonization appears worthwhile.

The results of the econometric analysis in [16], which examined the impact of carbon footprint on economic growth in Azerbaijan from 1990 to 2023, show that economic growth is accompanied by an increase in per capita carbon emissions. The article offers a comprehensive understanding of the interplay between factors influencing CO_2 emissions and provides a thorough political-economic interpretation for Azerbaijan. However, it lacks a more clearly defined theoretical framework (e.g., an explanation of the mechanism by which total factor productivity (TFP), renewable energy consumption (REC), and emissions trading operate), as well as a discussion of the study's limitations and avenues for future work.

Innovations in the production, transmission, and use of renewable energy primarily serve to reduce costs and increase economic and energy efficiency. Reducing greenhouse gas emissions is accepted as one of the goals of innovative management of energy resource utilization technologies, supported by the development of human capital.

In relevant studies, the impact of renewable energy sources on greenhouse gas emissions is examined, revealing that these sources do not always meet the requirements for clean energy. It is believed that additional measures, including regulatory measures, are needed to ensure the environmental friendliness of renewable energy sources [17]. As noted in the referenced source, public–private partnerships offer real advantages in ensuring the environmental friendliness of renewable energy sources. However, the article does not provide detailed proposals for policy implementation (financing mechanisms, incentive measures, models of state participation), which limits its practical significance.

The transition to renewable energy sources requires investment support from the public and private sectors [18]. Globally, investor interest in green technologies is accompanied by varied reactions at the national level. The differences are primarily due to the nature of national legislation, the result-oriented nature of incentive measures (including tax, customs, and credit benefits, as well as subsidies and grants), the state of the relevant infrastructure, and the dynamics of the employment market. Among the shortcomings, in our view, is the lack of a theoretical framework to explain the mechanisms by which public-private investment, globalization, and urbanization influence demand for renewable energy. Without this, the results appear merely as statistical dependencies, not causal relationships.

It is challenging to consider the database used to analyze and regulate the impact of transitioning to large-scale use of renewable energy sources on greenhouse gas emissions as satisfactory. In particular, the adequate development of the existing system of tax breaks and other subsidies in the economic regulation of the development of the energy sector at both the production and consumption levels, to the requirements of the widespread use of renewable energy, as shown by studies, necessitates the acceleration of the processes of forming the necessary database. Each country has its own vision for shifting its energy balance toward alternative sources

and is developing its own approaches to addressing this issue, including various tools. This paper [19] examines an interesting question: the extent to which administrative mechanisms can influence the adoption of alternative energy sources. However, the study's methodological basis was not thoroughly developed; a comparative analysis across countries (even those at the same economic and institutional levels) was not conducted. Theoretically, the scientific work comprehensively describes various administrative methods, but the authors did not devote due attention to their practical implementation. The paper [20] considers another interesting and relevant problem: identifying the factors hindering a smooth transition to alternative energy across all sectors of the economy. To this end, the authors first identify the characteristics of this transition, which require a meticulous analysis of the topic under study, and then correlate these characteristics with the proposed factors. The paper provides an in-depth study of the factors hindering the use of alternative energy, but its methodological conclusions remain limited.

The paper [21] examines the transition to alternative energy from the perspective of institutional constraints in countries. These constraints determine regulatory capabilities and structural features of the public sector. However, the paper provides insufficient consideration of the step governments have taken in this direction.

The paper [22] presents a bibliometric analysis of energy policy. However, despite the in-depth analysis, measuring energy efficiency in the transition to alternative energy sources poses particular challenges. These include causal inconsistency, data shortages, inconsistent data across countries due to statistical errors, and differences in pricing policies across countries. Therefore, given current trends in addressing climate issues, constructing econometric models that account for a greater number of variables in the alternative energy-efficiency-emissions relationship is particularly relevant.

In summary, although the relationship between energy efficiency, the transition to alternative energy sources, and greenhouse gas reduction has been widely studied, this research has been conducted primarily in developed countries with abundant material and financial resources. However, such studies remain extremely limited for countries rich in natural resources (oil and gas) but in transition to economic development.

3. The aim and objectives of the study

The aim of this study is to assess the impact of energy efficiency and the transition to renewable energy sources on reducing greenhouse gas emissions.

To achieve this aim, the following objectives were accomplished:

– to assess the current level of energy efficiency and priorities for the transition to alternative energy sources, as well as their contribution to economic indicators;

– to create an econometric model to assess the impact of electricity generation from alternative sources on greenhouse gas emissions.

4. Materials and methods

The study's object is the country's energy sector.

The main hypothesis of the study is that improving energy efficiency and switching to renewable energy can reduce greenhouse gas emissions. The assumptions of the study are energy efficiency has a stronger impact on greenhouse gas emissions, and indicators of overall energy efficiency, the amount of renewable electricity, and the share of renewable electricity in total energy supply are significant in assessing this impact.

For this study, a methodology was developed that involves constructing and subsequently evaluating an econometric model measuring the impact of energy efficiency and the use of renewable energy sources on greenhouse gas emissions in Azerbaijan. Key indicators of the energy consumption structure and the national economy for the period from 2007 to 2023 were selected as variables: data on greenhouse gas emissions (in millions of tons of CO_2 equivalent), electricity generated using renewable energy sources (in quantity and percentage), and energy efficiency (expressed in GDP/energy consumption). This time period was chosen given the availability of reliable, comparable data on key indicators from official international websites, such as the State Statistical Committee of the Republic of Azerbaijan, Macrotrends, and Climate Watch (World Resources Institute). A regression equation was constructed to test short- and long-term trends and to confirm or reject hypotheses about the impact of energy policy on the environment. To ensure the reliability of subsequent estimates, the data were statistically normalized beforehand, and potential outliers and missing values were not identified. The regression model was constructed, and the results were evaluated using EViews. Quantitative tests were used for validation: the coefficient of determination and Fisher's exact test were calculated, and the statistical significance of the coefficients and residuals was assessed, demonstrating the absence of autocorrelation.

5. Results of studying the interaction between energy efficiency measures, the share of renewable energy sources, and greenhouse gas emission levels

5. 1. Analysis of the current state of energy efficiency and the transition to renewable energy

It is demonstrated that energy efficiency in oil- and gas-producing countries is influenced by their energy structures and prices. It should also be noted that most of these countries are not at the forefront of the ranking in terms of energy efficiency level [23].

Given the existing database, GDP per unit of energy consumption in the country (purchasing power parity, USD per kg of oil equivalent) was used as an energy-efficiency indicator. In order to clarify the impact of the energy factor on the total annual emission of greenhouse gases in the country, the specific weight of electricity supply from renewable sources in the country's total electricity production, energy supply from renewable sources, and electricity production from these sources, indicators were included in the analysis along with the energy efficiency level (Table 1).

It should be noted that the attempt to compare with 1990 was not possible due to incomplete data.

In Azerbaijan, carbon dioxide (CO_2) accounts for a higher percentage (56.5%) of the greenhouse gas structure. Methane gas (CH_4) accounts for 36.6 percent, nitrous oxide (N_2O) for 4.7 percent, and F gases for 2.2 percent.

It can be said that the relationship between total energy supply from renewable sources and greenhouse gas emissions is, at first glance, non-existent (Fig. 1).

Table 1

Dynamics of energy supply from renewable sources in Azerbaijan, electricity production from renewable sources, share of electricity supply from these sources in the total energy supply in the country, GDP value per 1 kg of gross domestic energy consumption, and total annual greenhouse gas emissions

Years	Total energy supply from renewable sources, thousand NET [24]	Electricity production, million kWh [25]	Electricity generation from renewable sources X_1, million kWh [26]	Share of electricity from renewable sources in the total electricity production in the country X_2, in percent [26]	Value of GDP per 1 kg of gross domestic energy consumption X_3 (1 USD/kg of oil equivalent) [27]	Total annual greenhouse gas emissions Y_{fact}, million tons (in CO_2 equivalent) [28]
1990	N/A	23152	1597	6.90	...	78.11
2007	291.3	21847	2364	10.82	50.0	44.43
2008	277.5	21642	2231	10.31	53.5	48.99
2009	272.0	18868	2311	12.25	41.7	45.01
2010	386.6	18709	3446	18.42	40.8	43.88
2011	327.0	20294	2677	13.19	44.5	45.13
2012	255.0	22988	1821	7.92	44.7	48.09
2013	285.4	23354	1626	6.96	44.5	48.32
2014	271.1	24728	1479	5.98	45.5	50.42
2015	303.4	24688	1829	7.41	45.6	50.23
2016	274.3	24953	2182	8.78	48.9	51.56
2017	257.7	24321	1977	8.13	48.3	50.83
2018	273.2	25229	2051	8.13	50.3	52.19
2019	263.4	26073	1911	7.33	56.3	54.05
2020	212.7	25839	1414	5.47	58.4	52.00
2021	225.1	27888	1617	5.80	59.1	54.46
2022	245.9	29040	1713	5.90	62.3	56.91
2023	261.2	29306	1700	5.80	64.2	56.50

The dynamics of electricity generation from renewable sources in Azerbaijan exhibit significant fluctuations over the period 2007–2023 (Fig. 2). As indicated in relevant sources, although electricity generation is currently a significant source of carbon dioxide emissions, it is this sector that is leading the transition to renewable energy, aiming to achieve zero carbon emissions [21].

It is appropriate to assess the impact of electricity production from renewable sources on the dynamics of total annual greenhouse gas emissions in Azerbaijan by conducting a regression analysis (Fig. 3).

The relationship between energy efficiency and total annual greenhouse gas emissions in the country appears quite close at first glance (Fig. 4).

The graphs reflect the country's energy efficiency, the share of electricity production from renewable sources, the share of electricity supply from these sources in the country's total energy supply, and the dynamics of total annual greenhouse gas emissions, indicating that it is appropriate to investigate the relevant dependencies.

Thus, the analysis in this subsection confirms the first research task by demonstrating that the current state of energy efficiency and the limited pace of renewable energy deployment constitute the initial structural conditions that determine Azerbaijan's potential for emission reduction.

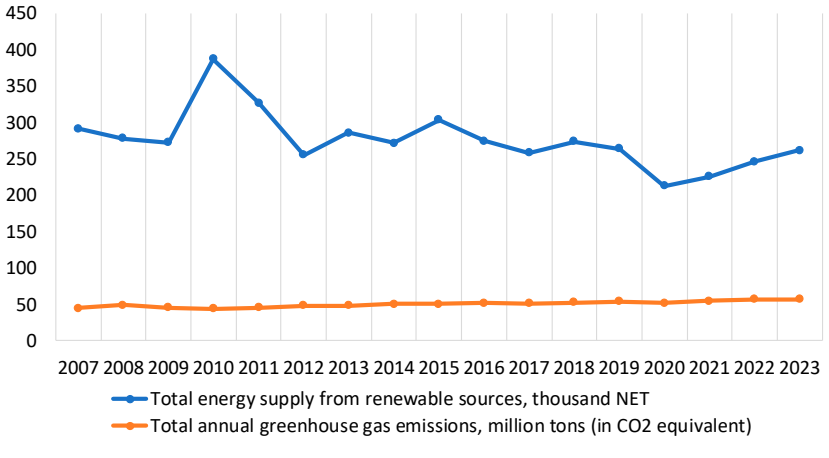


Fig. 1. Dynamics of total energy supply from renewable sources (thousand NET) and total annual emissions of greenhouse gases (million tons (in CO_2 equivalent)) in Azerbaijan

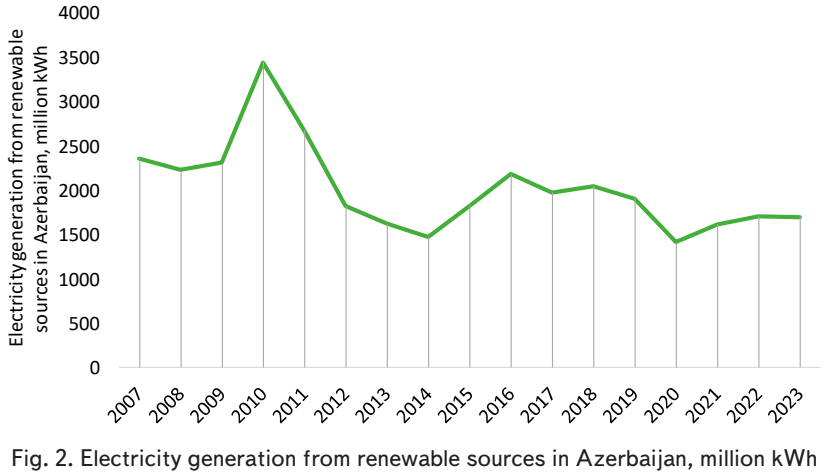


Fig. 2. Electricity generation from renewable sources in Azerbaijan, million kWh

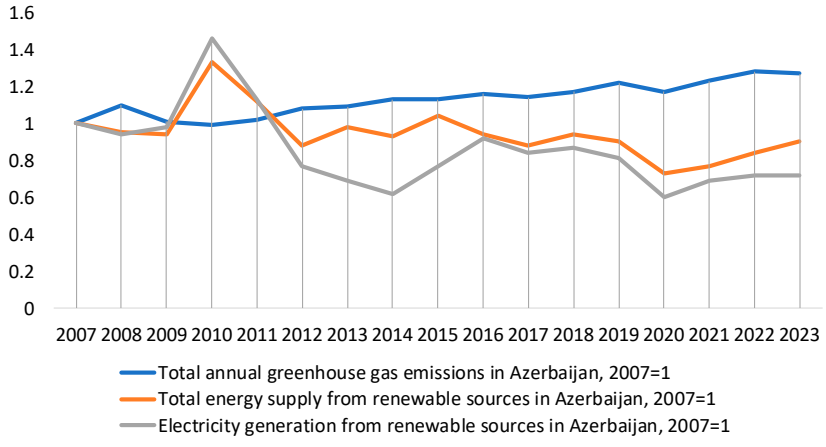


Fig. 3. Dynamics of total annual greenhouse gas emissions, energy supply from renewable sources, and electricity production from renewable sources in Azerbaijan

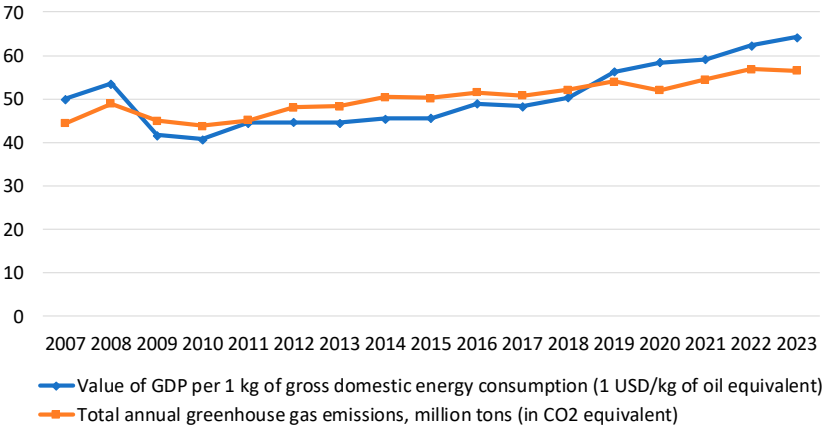


Fig. 4. Dynamics of GDP per unit of energy consumption in Azerbaijan (purchasing power parity: USD per kg of oil equivalent) and total annual emissions of greenhouse gases in the country during 2007–2023

5. 2. An econometric analysis of the impact of electricity generation from renewable sources on greenhouse gas emissions

To assess the impact of electricity production from renewable sources in the country (X_1), the specific weight of electricity from renewable sources in the country's total electricity production (X_2), and GDP per unit of energy consumption (X_3) on total annual greenhouse gas emissions (Y), the expression is recommended

$$Y = aX_1 + bX_2 + \\ + cX_3 + d. \quad (1)$$

As mentioned, GDP per unit of energy consumption in the country (purchasing power parity, USD per kg of oil equivalent) was used as an energy-efficiency indicator in the calculations. The Eviews economic package was used in the research process. The initial data in Table 1 were used to perform the calculations. Upon applying the package, a correlation relationship was revealed between two or more variables (Table 2).

As shown in the correlation matrix, the X_3 variable has a strong impact on greenhouse gas emissions. There is a moderate negative relationship between the X_1 variable and greenhouse gases.

Based on the available data, the relevant indicators were calculated to build a regression equation (relationship model) (Table 3).

Table 2

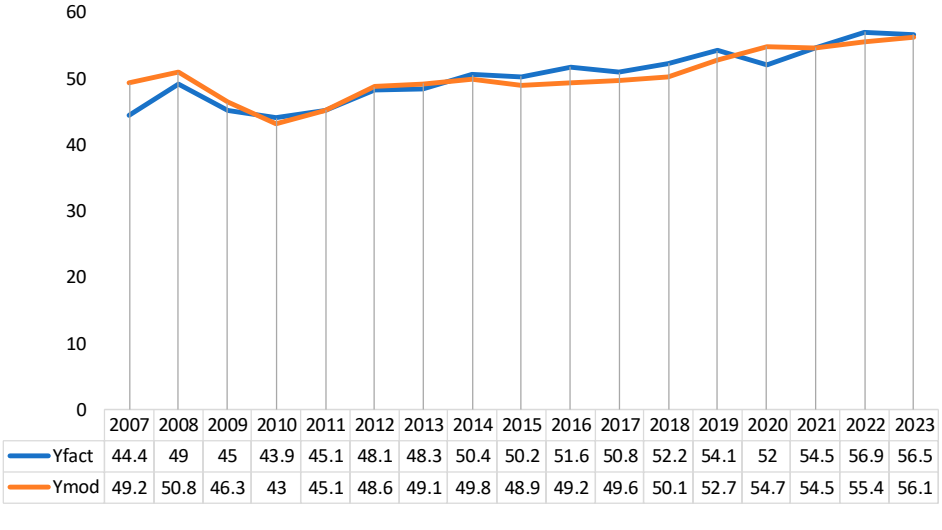
Correlation matrix

Variables	X_1	X_2	X_3	Y
X_1	1.0000	0.3474	–0.5135	–0.6819
X_2	0.3474	1.0000	–0.2195	–0.3284
X_3	–0.5135	–0.2195	1.0000	0.8384
Y	–0.6819	–0.3284	0.8384	1.0000

The coefficient of determination (R-squared = 0.80) indicates that the model's included factors can explain 80% of the annual variation in the greenhouse gases under study. After the linear regression equation is determined and its parameters are estimated, the significance of both the equation as a whole and its individual parameters should be characterized. Fisher's exact test (F-statistic) was used to assess the significance of the regression equation as a whole. As shown in Fig. 5, the p-value for Fisher's F-statistic is significantly greater than the 0.0001 significance level, indicating that the calculation from our model is statistically reliable. The theoretical (calculated) graph is constructed using equation (2) (Fig. 5).

The resulting model can be said to be adequate

$$Y_{mod} = -0.00258x_1 - 0.00093x_2 + 0.36843x_3 + 36.85115. \quad (2)$$



	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Yfact	44.4	49	45	43.9	45.1	48.1	48.3	50.4	50.2	51.6	50.8	52.2	54.1	52	54.5	56.9	56.5
Ymod	49.2	50.8	46.3	43	45.1	48.6	49.1	49.8	48.9	49.2	49.6	50.1	52.7	54.7	54.5	55.4	56.1

Fig. 5. Actual and modeled dynamics of greenhouse gas emissions taking into account the impact of the energy factor

Table 3

Final result

Dependent Variable: *Y* Method: Least Squares Date: 09/09/25 Time: 23:33 Sample: 2007 2023 Included observations: 17				
Variable	Coefficient	Std Error	t-Statistic	Prob
C	36.85115	5.795701	6.358360	0.0000
X1	–0.002575	0.001239	–2.077837	0.0481
X2	–0.000934	0.001715	–0.544232	0.0495
X3	0.368432	0.082244	4.479725	0.0006
R-squared	0.793401	Mean dependent var		50.17647
Adjusted R-squared	0.745724	S.D. dependent var		4.050444
S.E. of regression	2.042469	Akaike info criterion		4.468520
Sum squared resid	54.23182	Schwarz criterion		4.664570
Log likelihood	–33.98242	Hannan-Quinn criter.		4.488008
F-statistic	16.64125	Durbin-Watson stat		0.885381
Prob (F-statistic)	0.000097			

When interpreting the calculations, it is important to note that certain factors were excluded from the analysis due to incomplete data. This is especially true for the role of modeled dependencies in the carbon neutrality of economic activity and in the characteristics of sustainable development.

Accordingly, the econometric modelling performed in this subsection fulfils the second research task by empirically quantifying the influence of renewable electricity generation and energy efficiency on greenhouse gas emissions and confirming that the model's explanatory power is sufficient to derive reliable conclusions.

6. Discussion of findings on energy efficiency, renewable energy, and emission reduction

As a resource-rich country, Azerbaijan's economy relies on carbon-intensive energy sources such as oil and natural gas. The national context also requires consideration of the time required to implement changes in the energy transition. The results demonstrate a lack of maturity in approaches to the energy transition: energy efficiency is already included in the national economic strategy and has yielded tangible benefits; however, the scale of renewable energy use remains insufficient to significantly reduce overall emissions. Thus, the low correlation between the share of renewable energy and emission reductions is not only a problem of the low efficiency of renewable energy sources themselves, but also a limitation of their current development and infrastructure. It is necessary to acknowledge the existence of objective barriers to the development of alternative energy infrastructure. These include structural and institutional barriers to renewable energy development in Azerbaijan, a lack of private investment, the absence of flexible market pricing mechanisms, and a shortage of technological solutions for energy storage and integration into power grids. These conditions currently complicate achieving significant emission reductions in the renewable energy sector. However, given the right environmental conditions – an improved legal framework, financial incentives, and the attraction of foreign direct investment – they are likely to make a significant contribution. Naturally, addressing the problem of reducing greenhouse gas emissions requires a comprehensive approach that takes into account a multitude of tactical issues, including institutional, legal, technical, technological, and infrastructural factors. However, an effective climate policy must include two key strategies: increasing energy efficiency and introducing renewable energy sources. The successful implementation of the first strategy, given Azerbaijan's 150-year history of hydrocarbon development, is beyond doubt. The second strategy requires implementing indirect measures, including improving the tax and investment incentive system, promoting public-private partnerships, and creating a favorable environment for the introduction of innovative technologies in the energy sector. Undoubtedly, in the long term, the second strategy will contribute not only to reducing carbon emissions but also to enhancing energy security and diversifying energy sources. However, for all the above reasons, Azerbaijan's current transition to low-carbon sustainable development cannot include improving energy efficiency. Accordingly, the findings of this subsection are consistent with the study's third objective: improving energy efficiency makes the greatest contribution to reducing carbon emissions. However, the integration of renewable energy sources into these solutions is limited by their insufficient contribution to the overall national energy balance.

Observations confirmed that the impact of energy efficiency on greenhouse gas emissions in Azerbaijan is significantly higher than the share of renewable electricity. This is confirmed by the regression analysis results (Table 3) and the dynamics shown in Fig. 5. Variable X_3 (GDP per unit of energy consumed) shows a strong positive correlation with reductions in emissions. In contrast, X_1, which denotes total energy from renewable sources, and X_2, which represents the share of electricity from renewable sources, correlate weakly, with a negative sign. Renewable electricity production slightly increased between 2007 and 2023 (Fig. 1–4). Accordingly, the correlation analysis indicates that this increase did not lead to a corresponding decrease in total greenhouse gas emissions. It should be noted that energy efficiency – the economic value of energy production per unit of energy consumed – makes a significant contribution to emission reductions in Azerbaijan. One explanation for these results is that the underdeveloped infrastructure of the alternative energy sector does not create a balanced basis for achieving truly significant environmental effects. This finding is consistent with earlier studies [29], which report that substantial emission reductions are not achieved immediately; they occur gradually as renewable energy sources are deployed and developed. Moreover, it happens only when their share exceeds 15–20% of total energy consumption. On the other hand, improved energy efficiency has a stronger and more rapid impact on emissions reduction, as confirmed by previous data [30] and the empirical results of our study.

While many cross-country studies [31, 32] focus on comparing different economies, this paper uses a regression model that accommodates Azerbaijan's specific situation: a country where the oil and gas sector is dominant in determining the energy mix and economic policy. Including energy efficiency and renewable electricity indicators in the model enabled to separate the contributions of each factor and choose the most active factor at which emission reductions would occur under the current set of conditions.

Overall, this study has confirmed that short-term energy efficiency is the most effective tool for reducing emissions in Azerbaijan. Renewable energy has an impact only as long as it is increasing as a share of total energy consumption. As such, the combined approach of the two (efficient energy use and in-

creased utilization of renewables) should underpin Azerbaijan's national sustainable energy and climate development strategy. Within this framework, the research lays out a transparent solution to a scientific and an applied challenge. On the scientific side, it proposes an empirically verified model that details the balance between efficiency (and renewable electricity) in shaping the dynamics of greenhouse gas emissions in an economy that relies on fossil fuels. From an applied perspective, the research is evidence-based. Given current structural conditions (i.e., the existing climate and energy situation), enhancing energy efficiency is the most effective means to achieve immediate emission reductions in Azerbaijan. On the other hand, renewable power will be a key mitigation instrument in only a much smaller share of the energy equation. In this way, it is possible to bridge the gap between theory and practical energy policy requirements, laying a solid analytic foundation for the design of targeted decarbonization processes.

Although the results are sound, several limitations should be noted. The cross-country comparisons are constrained by structural differences in energy systems, which hinder the direct transferability of quantitative results, and by the limited number of indicators, which impairs the generalizability of the results to other countries. Further study of the impact of carbon pricing, innovation activity, and investment attractiveness on financial performance in the context of decarbonization appears worthwhile.

7. Conclusion

1. An analysis of the current state of energy efficiency and progress in renewable energy production was conducted. This analysis assesses the current state of the Azerbaijani energy sector in terms of energy efficiency and renewable energy adoption. It was established that energy efficiency reduces the carbon intensity of economic activity. Energy policy development should focus on energy transformation to enable a smooth energy transition that supports sustainable economic growth, energy security, and reduced demand for fossil fuels. Improving energy efficiency in the country, namely a 1% increase in GDP per kilogram of gross domestic energy consumption, could lead to a 0.83% reduction in total annual greenhouse gas emissions. The decrease in the share of renewable sources in the country's total electricity production (X_2) over the past 15 years has weakened their impact on greenhouse gas dynamics. However, in 2010, when the highest share of electricity from renewable sources in total electricity production in the country was observed during the analysis period ($X_2 = 18.42\%$), total annual greenhouse gas emissions received the lowest value for the analysis period ($Y = 43.88$ million tons CO_2 equivalent). This demonstrates that short-term emission reduction in Azerbaijan is best achieved through efficiency measures, whereas long-term reductions require expanding the share of renewable energy sources.

2. An econometric analysis of the impact of renewable energy use on greenhouse gas emissions in Azerbaijan was conducted. Regression analysis was used to identify statistically significant relationships between the selected variables for 2007–2023. Statistics show that 80% of the country's total greenhouse gas emissions come from both hydrocarbon and renewable energy sources.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this study, whether financial, personal, authorship, or otherwise, that could affect the study and its results presented in this paper.

Financing

The study was performed without financial support.

Data availability

Data will be made available on reasonable request.

Use of artificial intelligence tools

The authors used artificial intelligence technologies solely as an auxiliary tool to process text information, organize data, and edit the scientific material during the preparation of this study. AI did not influence scientific conclusions, modeled outputs, or data interpretation.

Authors' contributions

Emin Ahmadzade: Conceptualization, Methodology, Supervision, Validation; **Rasul Balayev**: Data curation, Formal analysis, Visualization, Software; **Ulviyya Rzayeva**: Writing – original draft, Writing – review & editing, Investigation, Project administration; **Konul Mirzammadova**: Resources, Literature review, Editing support.

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