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The Impact of Dirty and Clean Energy Consumption on Carbon Emissions in Azerbaijan

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ABSTRACT

Abstract. This study investigates the impact of dirty (gas, oil) and clean (renewable) energy consumption on CO_2 emissions in Azerbaijan. Utilizing annual data from 1985 to 2022, the analysis examines the stationarity of the variables using ADF, Flexible Fourier ADF, and Fractional Flexible Fourier ADF unit root tests, finding that all variables are stationary at the first difference. To explore the cointegration relationships among the variables, the Bayer-Hanck combined cointegration test is employed. Three econometric models are established, revealing a long-run equilibrium relationship solely between renewable energy consumption and carbon emissions (CO_2). According to the long-run estimation results from FMOLS, DOLS, and CCR methods, renewable energy consumption negatively impacts carbon emissions in Azerbaijan, with a 1% increase in renewable energy consumption leading to a 0.60% decrease in carbon emissions. Additionally, the Fourier Toda-Yamamoto causality test uncovers a unidirectional causality from gas consumption to carbon emissions in Azerbaijan. The study concludes with policy recommendations for Azerbaijan to effectively manage and reduce carbon emissions.

Keywords: Renewable Energy Consumption, CO_2 Emissions, Bayer-Hanck Cointegration, Fourier Unit Root Tests, Oil Consumption, Gas Consumption

JEL Classification: C1, Q4, Q5, Q2, Q3

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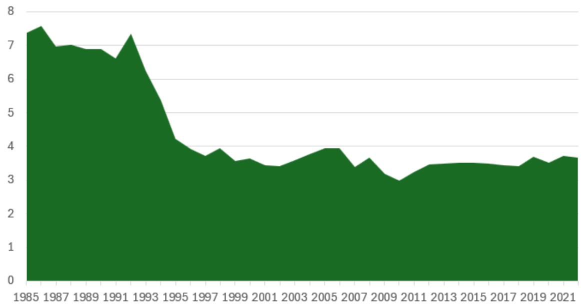
1. INTRODUCTION

Environmental degradation and rising energy consumption are two major challenges facing the international community today (Li and Ullah, 2022; Zhang et al., 2024). The current energy system is largely defined by its heavy reliance on fossil fuels. While coal, oil and natural gas account for 85% of global energy consumption, about one-third of the world's population, 2.4 billion people, still rely on biomass energy to meet their basic needs for cooking, heating and lighting. Since the beginning of the industrial age in the mid-19th century, global energy consumption has been steadily increasing due to the increasing complexity of industries, transportation, heating and electricity. However, this progress has been made possible largely by the intensive use of fossil fuels such as coal and oil (Ferhi and Helali, 2024).

The study investigates the impact of dirty and clean energy consumption on carbon emissions (CO2) in Azerbaijan. Azerbaijan ranks 18th in the world with $19.5 billion in energy exports (Investing Channel, 2024). Approximately 90% of Azerbaijan's export revenues come from underground resources, particularly oil and natural gas. These resources also finance about 60% of the government's budget. This indicates that Azerbaijan's economy is heavily dependent on natural resources, and energy exports play a critical role in the country's economy (IEA, 2021).

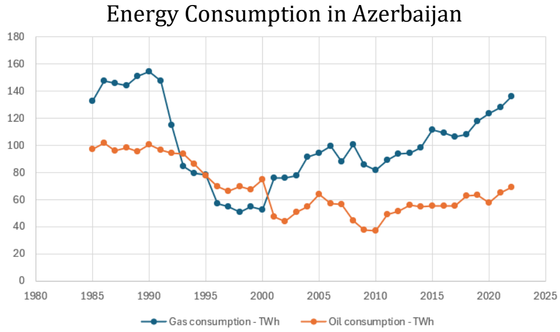
Figure 1 shows the per capita carbon emissions in Azerbaijan from 1985 to 2022. The Republic of Azerbaijan gained independence on October 18, 1991. As seen in the graph, there was a decline in carbon emissions from 1992 to 1995, which is attributed to crisis situations related to the war. From 1995 to 2022, per capita carbon emissions have remained relatively stable at similar levels. In Figure 2, the graph of gas and oil energy consumption from non-renewable energy sources in Azerbaijan between 1985 and 2022 is shown. Looking at the time series graph, it can be observed that both types of energy consumption have moved almost in the same way. After the year 2000, gas consumption in Azerbaijan increased significantly, surpassing oil consumption.

Figure 1: Carbon Emission in Azerbaijan



Source: Our World in Data (2024a)

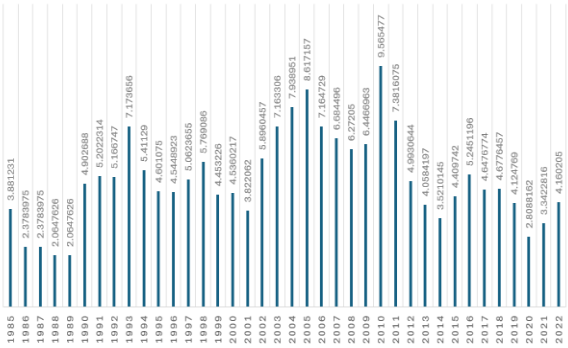
Figure 2: Gas and Oil Non-Renewable Energy Consumption in Azerbaijan



Source: Our World in Data (2024b)

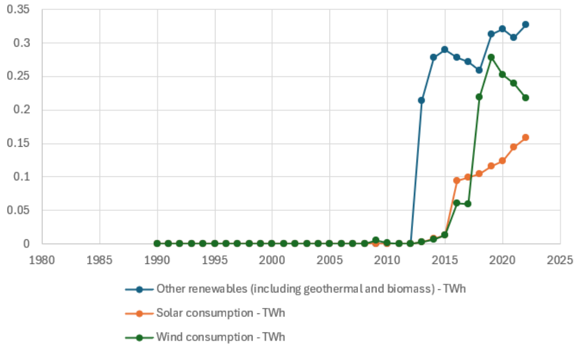
Figure 3 shows the time series graph of hydro energy consumption, which is one of the most consumed renewable energy sources in Azerbaijan, between 1985 and 2022. From this graph, it is evident that hydro renewable energy consumption has fluctuated over the years due to various reasons. Figure 4 illustrates other renewable energy sources such as wind, solar, and others, which have been used less in Azerbaijan. However, solar and wind renewable energy sources have continued to grow rapidly after 2015.

Figure 3: Hydro Renewable Energy Consumption in Azerbaijan



Source: Our World in Data (2024b)

Figure 4: Wind, Solar and Other Renewable Energy Consumption in Azerbaijan



Source: Our World in Data (2024b)

There is a growing body of literature examining the relationship between energy consumption and carbon emissions, with a particular focus on both renewable and non-renewable energy consumption's effects on carbon emissions. Non-renewable energy consumption positively affects carbon emissions, as found in studies by Lebe (2016), Shaari et al. (2022), and Khan et al. (2019). Conversely, renewable energy consumption negatively impacts carbon emissions, as evidenced by Yuping et al. (2021), Leitão et al. (2021), and Bekun (2022). Although there are limited studies specifically on Azerbaijan, Mukhtarov et al. (2022) and Hasanov et al. (2023) have found that renewable energy consumption in Azerbaijan negatively affects carbon emissions. Unlike these studies, this research aims to contribute to the literature by establishing three different econometric models for Azerbaijan to investigate the effects of both renewable and non-renewable energy consumption on carbon emissions. The Bayer-Hanck (2013) combined cointegration test and the Fourier Toda-Yamamoto causality test by Nazlioglu et al. (2016) will be used to explore these relationships.

Following the introduction, the second section of the study presents a literature review that examines previous studies on the impact of using dirty (non-renewable) and clean (renewable) energy on carbon emissions (CO2). The third section, Model and data, is an introduction to the econometric models and provides information on the variables used in the study. The fourth section, Methodology, provides a brief overview of the econometric methods used in the study. The fifth section, Empirical Results, presents the results of the econometric methods. Finally, the sixth section offers policy recommendations for Azerbaijan.

2. LITERATURE REVIEW

This section of the study reviews research that investigates the impact of both clean (renewable) and dirty (non-renewable) energy consumption on carbon emissions (CO_2). Apergis et al. (2023) investigated the impact of renewable and non-renewable energy consumption on carbon emissions in Uzbekistan for the period 1985-2020. The ARDL cointegration method, a time series approach, was employed, and a cointegration relationship was found among the variables. According to the ARDL long-run estimation results, the renewable energy consumption variable, hydro, negatively affects carbon emissions, while the non-renewable energy consumption variable, oil, positively affects carbon emissions. Eylasov et al. (2023a) investigated the impact of non-renewable energy consumption on carbon emissions in Türkiye within the framework of the Environmental Kuznets Curve hypothesis. Using annual data from 1971 to 2019, the study applied the ARDL method to explore the cointegration relationship among the variables. The ARDL long- and short-run results indicate that non-renewable energy consumption positively influences carbon emissions. Khan et al. (2023) examined the impact of renewable and non-renewable energy consumption on carbon emissions in 41 Sub-Saharan countries using annual data from 2004 to 2021. The study employed panel data estimation methods, including Fixed-effects (Driscoll-Kraay standard errors) and Two-Step System GMM. The results indicate that renewable energy consumption negatively affects carbon emissions, while non-renewable energy consumption has a positive impact in the 41 Sub-Saharan countries. Mukhtarov et al. (2022) investigated the impact of renewable energy consumption on carbon emissions in Azerbaijan for the period 1990-2019. According to the DOLS estimation results, renewable energy consumption negatively affects carbon emissions in Azerbaijan. In another study on Azerbaijan, Hasanov et al. (2023) examined the impact of renewable energy consumption on carbon emissions using ADL and ARDL methods, and the results indicated that renewable energy consumption negatively affects carbon emissions. Eylasov et al. (2023b) studied the impact of renewable energy consumption on carbon emissions in Türkiye using the ARDL and Bayer-Hanck cointegration approaches. According to the ARDL long-run estimation results, renewable energy consumption negatively affects carbon emissions in Türkiye. Ali et al. (2023) investigated the impact of renewable and non-renewable energy consumption on carbon emissions for Asian countries between 1975 and 2020. The study employed panel data methods, including Pedroni, Kao, and Westerlund cointegration tests. According to the MG, AMG, and CCEMG estimation results, renewable energy consumption negatively affects carbon emissions, while non-renewable energy consumption positively affects carbon emissions in Asian countries. Ali and Kirikkaleli (2022) examined the impact of renewable energy consumption on carbon emissions in Italy using quarterly data for the period 1970-2018. The study employed Gregory–Hansen and non-linear ARDL cointegration tests and concluded that renewable energy consumption negatively affects carbon emissions. Kirikkaleli and Adebayo (2021) investigated the impact of renewable energy consumption on carbon emissions in India for the period 1990-2015, using quarterly data and taking structural breaks into account with Maki cointegration test. According to the long-run estimation results from FMOLS and DOLS, renewable energy consumption negatively affects carbon emissions. Idroes et al. (2024) investigated the impact of renewable and non-renewable energy consumption on carbon emissions in Indonesia using the Johansen and Engle-Granger cointegration tests for the period 1965-2022. According to the FMOLS and DOLS estimation results, coal and gas consumption positively affect carbon emissions, while renewable energy consumption negatively affects carbon emissions. Finally, studies conducted for different countries (Liu, 2021; Jebli and Youssef, 2015; Mulali et al., 2016) have also found that the impact of renewable energy consumption on carbon emissions is negative, while the impact of non-renewable energy consumption is positive. In addition, Aliyev et al. (2024) used the Fourier Bootstrap ARDL method to investigate the impact of nuclear energy consumption on carbon emissions in South Korea, concluding that nuclear energy consumption has a negative impact on carbon emissions. In their study, Pata and Kartal (2024) highlight the importance of a robust financial system for increasing the use of renewable energy in Azerbaijan. Using the Bayer-Hanck cointegration method, they find that access to finance has no impact on renewable energy consumption; however, financial depth and efficiency have a positive impact on renewable energy consumption. They also find that urbanisation has a negative effect on renewable energy consumption. In general, when the literature is reviewed, it is found that using econometric methods such as time series and panel data methods for different countries and country groups, renewable energy consumption has a negative impact on carbon emissions, while non-renewable energy consumption has a positive impact on carbon emissions. In this study, however, due to the limited number of studies conducted on Azerbaijan within this context and for the first time using the Bayer-Hanck cointegration methods, the impact of clean (renewable) and dirty (non-renewable) energy consumption on carbon emissions is investigated, and it is expected to contribute to the literature.

3. MODEL AND DATA

This study analyses the long-run effects of clean (renewable) and dirty (non-renewable) energy consumption on carbon dioxide (CO_2) emissions in Azerbaijan for the period 1985 to 2022, using three different functions as shown in equations 1, 2 and 3.

$$LnCO_2 = f(LnREC) \tag{1}$$

$$LnCO_2 = f(LnGAS) \quad (2)$$

$$\mathrm{LnCO_2} = \mathrm{f(LnOIL)} \quad (3)$$

If we express the above functions as econometric models, they transform into the following equations.

$$LnCO_{2t} = \beta_0 + \beta_1 LnREC_t + u_t \quad (4)$$

$$\mathrm{LnCO_{2t}} = \beta_0 + \beta_1 \mathrm{LnGAS_t} + \mathrm{u_t} \quad (5)$$

$$\mathrm{LnCO_{2t}} = \beta_0 + \beta_1 \mathrm{LnOIL_t} + \mathrm{u_t} \quad (6)$$

In the equations above, β_0 represents the constant term, and u_t represents the error term. The β_1 values correspond to the elasticities of renewable energy consumption, gas energy consumption, and oil energy consumption, respectively. As observed in the literature and from an economic perspective, the coefficient for renewable energy consumption is expected to be negative (Mukhtarov et al., 2022; Eylasov et al., 2023b; Apergis et al., 2023; Idroes et al., 2024), while the coefficients for gas and oil variables are expected to be positive (Eylasov et al., 2023a; Apergis et al., 2023; Idroes et al., 2024). Therefore, β_1 in Equation 4 is expected to be negative, while the β_1 values in Equations 5 and 6 are expected to be positive. All variables used in the study were obtained from the Our World in Data (2024a, 2024b) database and are detailed in Table 1. In the study, the Renewable Energy Consumption variable consists of the sums of the following variables: Other renewables (including geothermal and biomass) – TWh, Solar consumption – TWh, Wind consumption – TWh, Hydro consumption – TWh. The analysis was carried out using the logarithms of all variables.

Table 1: Variable Detail

Variables	*Symbol*	*Unit*	*References*
Annual CO_2, emissions	CO_2	Tonnes per person	Our World in Data (2024a)
Gas consumption	GAS	TWh	Our World in Data (2024b)
Oil consumption	OIL	TWh	Our World in Data (2024b)
Renewable Energy Consumption	REC	TWh	Our World in Data (2024b)

Table 2 presents both the unit and logarithmic descriptive statistics of the variables used in the study. In Azerbaijan, between 1985 and 2022, the average gas consumption was observed to be 101 TWh, oil consumption was 67 TWh, and renewable energy consumption was 5.20 TWh. The average annual per capita carbon emissions in Azerbaijan were 4.44 tonnes. Both the unit data and the logarithmic data show that all variables except for the carbon emissions variable are normally distributed. Since the probability value of the calculated Jarque-Bera test statistic for the GAS, OIL, and REC variables is greater than 0.05, the null hypothesis of 'normally distributed' is not rejected. However, for the CO2 variable, since the value is less than 0.05, the null hypothesis is rejected.

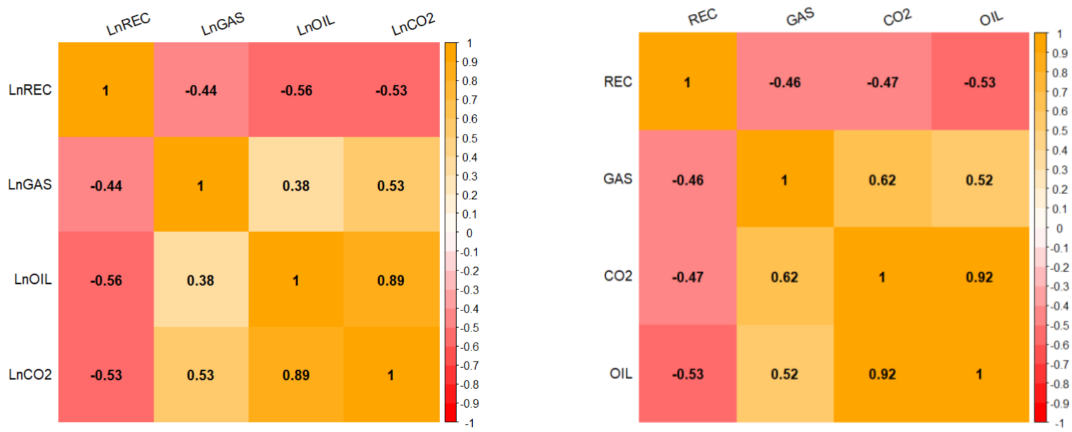
Table 2: Descriptive Statistics

Unit Data	*CO_2*	*GAS*	*OIL*	*REC*
Mean	4.441594	101.0124	67.76945	5.200218
Median	3.681316	96.46437	63.47863	5.027715
Maximum	7.578455	154.2186	101.8174	9.566865
Minimum	2.982402	51.00259	37.24386	2.064763
Std. Dev.	1.497238	29.86080	19.40619	1.718600
Skewness	1.127447	0.162789	0.444339	0.330002
Kurtosis	2.518495	2.131621	1.968160	3.102089
Jarque-Bera	8.417627	1.361799	2.936203	0.706208
Probability	0.014864	0.506161	0.230362	0.702504
Logarithmic Data	*$LNCO_2$*	*LNGAS*	*LNOIL*	*LNREC*
Mean	1.444109	4.569781	4.176543	1.589888
Median	1.303269	4.568941	4.150691	1.614942
Maximum	2.025309	5.038371	4.623181	2.258306
Minimum	1.092729	3.931876	3.617487	0.725015

Std. Dev.	0.297210	0.312568	0.285364	0.362171
Skewness	1.005891	-0.394319	0.045581	-0.716064
Kurtosis	2.323697	2.441818	2.102995	3.482264
Jarque-Bera	7.132361	1.478070	1.287136	3.615655
Probability	0.028264	0.477575	0.525414	0.164010
Observations	38	38	38	38

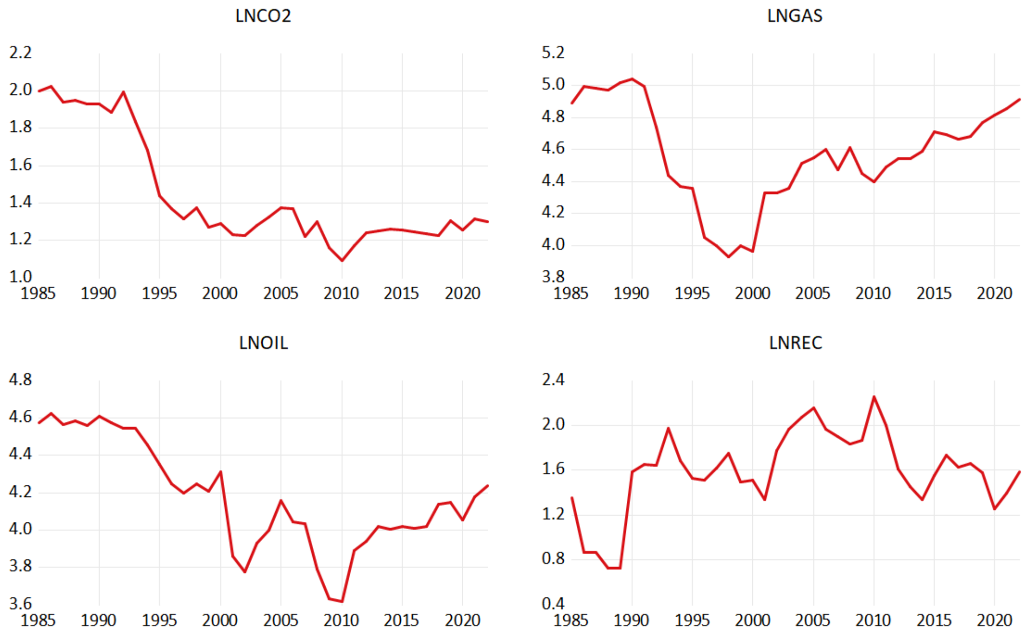
Figure 5 presents the correlations between the variables both in unit and logarithmic form. As expected, there is a moderately negative correlation between carbon emissions and clean (renewable) energy consumption in Azerbaijan. Among the dirty variables, there is a moderate positive correlation between gas energy consumption and carbon emissions, and a high positive correlation between oil energy consumption and carbon emissions.

Figure 5: Correlation Matrix



Finally, in this section, time series graphs of gas, oil, renewable energy consumption, and carbon emissions variables used in the study have been plotted and are shown in Figure 6. Upon examining the graphs, sharp and smooth breaks can be observed in all variables at different times due to various crises, pandemics, and wars. Considering these observations, it was decided to examine the stationarity of the variables using Fourier unit root tests, which take into account both smooth and sharp structural breaks. This approach is believed to yield more reliable results.

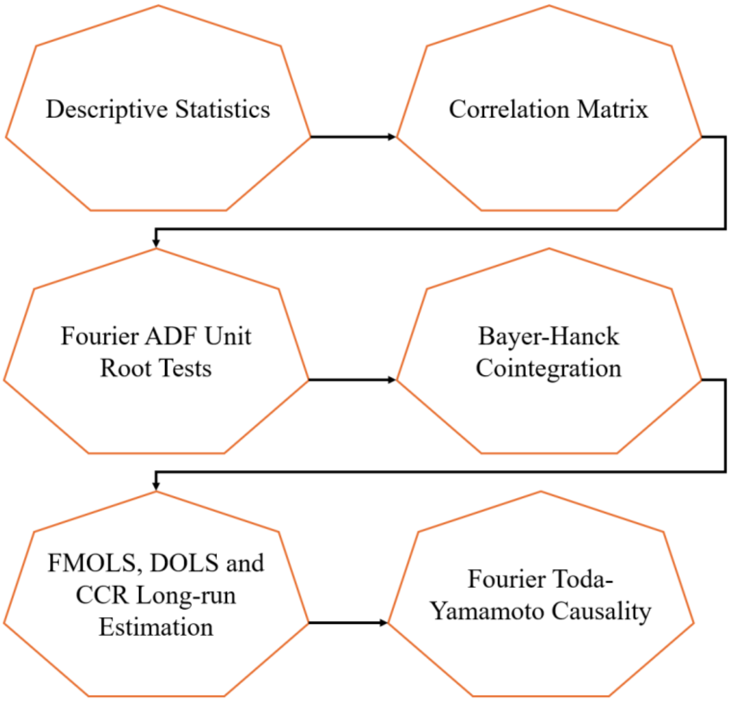
Figure 6: Time Series Graph of Variables



4. METHODOLOGY

In the methodology section of the study, a brief description of the econometric methods used will be provided. As seen in Figure 7, the study first presents the descriptive statistics of the variables, followed by the correlation matrix. The stationarity of the variables, as observed in Figure 6, was examined using unit root tests such as the Dickey-Fuller (1979, 1981) ADF test, the Enders and Lee (2012a, 2012b) Flexible Fourier ADF test, and the Omay (2015) Fractional Flexible Fourier ADF test due to sharp and smooth structural breaks. Subsequently, for the first time in this context, the Bayer-Hanck combined cointegration test by Bayer and Hanck (2013) was used to investigate the cointegration relationship between gas, oil, CO_2 emissions, and renewable energy consumption in Azerbaijan, contributing to the literature. Long-term estimation results were reported using FMOLS, DOLS, and CCR methods. Finally, the causal relationships between the variables were examined using the Fourier Toda-Yamamoto causality test by Nazlioglu et al. (2016), concluding the study.

Figure 7: Methodology Way



4.1. Unit Root Tests

In this study, the stationarity of the variables was tested using the Dickey and Fuller (1981) ADF, Enders and Lee (2012a, 2012b) Flexible Fourier ADF and Omay (2015) Fractional Flexible Fourier ADF unit root tests. The Dickey and Fuller (1981) ADF unit root test is an extension of the Dickey and Fuller (1979) DF unit root test, which was developed to address the autocorrelation problem present in the DF test. The ADF unit root test consists of three regression models: none (no constant or trend), constant (with no trend) and constant with trend. In the study, the GAS variable is modelled using the constant with trend model of the ADF regression equation with one lag, as shown below.

$$\Delta GAS_t = \beta_0 + \beta t + \beta_1 GAS_{t-1} + \beta_2 \Delta GAS_{t-1} + u_t \quad (7)$$

In the above equation, Δ represents the difference operator, β_0 represents the constant term, βt represents the trend, and u_t denotes the error term. If the tau statistic value of the β_1 coefficient, which corresponds to the one-lagged GAS variable in the equation, is found to be greater than the critical values of MacKinnon (1996), the null hypothesis of 'non-stationary, unit root exists' will be rejected. This means that the GAS variable will be found stationary at the level. Structural breaks can be observed in an economy due to various crises, pandemics and similar events. If the stationarity of a variable is tested with tests that do not take these structural breaks into account, a series that is actually stationary may appear to be non-stationary. Similarly, the ADF unit root test does not provide reliable results in the presence of structural breaks. Enders and Lee (2012a, 2012b) introduced the Flexible Fourier ADF unit root test to the literature to provide reliable results of the ADF unit root test under sharp breaks. This test examines the presence of sharp breaks by adding Fourier terms, such as sine and cosine, to the ADF regression equations. When sine and cosine terms are added to the ADF model with a constant and trend, as shown in Equation 7, it transforms into the following form.

$$\Delta GAS_t = \beta_0 + \beta t + \alpha_1 \sin\left(\frac{2\pi kt}{T}\right) + \alpha_2 \cos\left(\frac{2\pi kt}{T}\right) + \beta_1 GAS_{t-1} + \beta_2 \Delta GAS_{t-1} + u_t \quad (8)$$

Here, π is 3.1415, k represents the number of frequencies, t denotes the trend, and T indicates the number of observations. The frequency value k is investigated from 1 to 5. The most crucial point here is that the sine and cosine terms must be statistically significant. If they are not significant, it indicates that no sudden breaks are observed in the series, and the classic ADF results will be valid (Aliyev et. al., 2022; Eylasov and Çiçek, 2024; Gasim and Şenyay, 2023). If sine and cosine are significant and the t-statistic value of the β_1 coefficient of the first lag of the GAS variable is found to be greater than the critical value provided in the study by Enders and Lee (2012b), the null hypothesis will be rejected. In other words, the series will be found to be stationary at level. In the study by Omay (2015), the fractional values of the frequency k were investigated, introducing the Fractional Flexible Fourier ADF unit root test to the literature. The aim here is to explore k from 0.1 to 5, ensuring that the ADF unit root test provides good results even in the presence of both sharp and smooth breaks. Since both sharp and smooth breaks are observed in the time series graph of the variables shown in Figure 6, it is considered more reliable to check the stationarity of the variables using both tests in the study.

4.2. Cointegration and Causality Test

In the study, the cointegration relationship between the variables was examined using the Bayer-Hanck (2013) combined cointegration test. This test is used when all variables are stationary at their first differences, I(1). This cointegration test jointly evaluates the cointegration tests of Engle and Granger (1987), Johansen (1995), Boswijk (1994) and Banerjee et al. (1998). In the Bayer and Hanck (2013) study, Fisher's formula is used to combine the p-values of these cointegration tests. The p-values and the formula for the single cointegration test are given below.

$$EG - JOH = -2[\ln(P_{EG}) + \ln(P_{JOH})] \quad (9)$$

$$EG - JOH - BO - BDM = -2[\ln(P_{EG}) + \ln(P_{JOH}) + \ln(P_{BO}) + \ln(P_{BDM})] \quad (10)$$

If the Fisher test statistic calculated for each of the above equations is found to be greater than the critical values reported in Bayer-Hanck (2013), the null hypothesis that 'there is no cointegration relationship between the variables' will be rejected. Therefore, a cointegration relationship between the variables will be established. Finally, the causal relationship between the variables was determined using the Fourier Toda-Yamamoto causality test by Nazlioglu et al. (2016). The Toda Yamamoto (TY) test, introduced to the literature by Toda and Yamamoto (1995), allows for the investigation of causal relationships between variables even if they are stationary at different levels, I(1) and I(0). However, this test does not perform well under structural breaks. In their study, Nazlioglu et al. (2016) contributed to the literature by adding Fourier terms, specifically sine and cosine terms, to the TY causality test equation, creating a new causality test that performs well even in the presence of structural breaks.

5. EMPIRICAL RESULTS

In this section, the stationarity levels of the variables were first determined. As seen in Figure 6, sharp and smooth breaks are present in all variables. Since the ADF unit root test does not provide robust results under structural breaks, the study additionally employed the Flexible Fourier ADF unit root test, which considers sharp breaks, and the Fractional Flexible Fourier ADF unit root test, which accounts for smooth breaks. The results of all unit root tests are presented in Table 3. According to the results of the ADF unit root test, all variables are stationary at the first difference, not at the level. The key point in the Flexible Fourier ADF and Fractional Flexible Fourier ADF unit root tests is the statistical significance of the Fourier terms. It is observed that the F-statistic values, which indicate the significance of the Fourier terms in both unit root tests, are not statistically significant. Therefore, no sharp or smooth breaks are found in the variables. Since the F-statistic values of the Flexible Fourier ADF and Fractional Flexible Fourier ADF tests are not significant, the results of the conventional ADF unit root test are valid. Consequently, all variables are determined to be stationary at the first difference I(1).

Table 3: Unit Root Test Results

Tests	*ADF*		*Flexible Fourier ADF*			*Fractional Flexible Fourier ADF*		
Variables	*Test stat.*	*Prob*	*Test stat.*	*Frequency*	*F stat.*	*Test stat.*	*Frequency*	*F stat.*
$LnCO_2$	-1.032	0.926	-2.585	1	2.985	-2.635	0.20	3.133
$\Delta LnCO_2$	-5.901***	0.000	---	---	---	---	---	---
LnGAS	-1.065	0.921	-1.453	2	2.847	-2.617	0.10	2.509
ΔLnGAS	-5.318***	0.000	---	---	---	---	---	---
LnOIL	-1.250	0.884	-3.588	1	6.436	-3.261	0.20	5.320
ΔLnOIL	-5.551***	0.000	---	---	---	---	---	---
LnREC	-2.763	0.219	-3.638	1	2.626	-3.738	0.10	3.035
ΔLnREC	-5.910***	0.000	---	---	---	---	---	---

Note: *** indicates significance at the 1% level. All unit root tests were investigated in the model with constant and trend. The critical value of the Flexible Fourier ADF F-statistic is 7.78 at the 10% level. The critical value of the Fractional Flexible Fourier ADF F-statistic is 9.38 at the 10% level.

Since all variables are found to be stationary at the first difference, the long-run cointegration relationship among the variables can be investigated using the Bayer-Hanck (2013) cointegration test. In the study, three econometric models were established to examine the impact of gas consumption, oil consumption, and renewable energy consumption on carbon emissions. Table 4 presents the results of the Bayer-Hanck combined cointegration test. According to these results, a cointegration relationship is found only between renewable energy consumption and carbon emissions. The Fisher test statistics of EG-JOH and EG-JOH-BO-BDM for Equation 1 are greater than the 10% and 5% critical values, respectively, thus rejecting the null hypothesis of "no cointegration".

Table 4: Bayer-Hanck Cointegration Test Results

Equation 1	*Constant Model (Lag =2)*	*Critical Values*			
$LnCO_2 = f(LnREC)$	Fisher Type Test statistics	%1	%5	%10	*Results*
EG-JOH	9.52965*	17.304	11.229	8.678	*Cointegration*
EG-JOH-BO-BDM	28.954723**	33.969	21.931	16.964	*Cointegration*
Equation 2	*Constant Model (Lag =2)*	*Critical Values*			
$LnCO_2 = f(LnGAS)$	Fisher Type Test statistics	%1	%5	%10	*Results*
EG-JOH	1.0435157	17.304	11.229	8.678	*Cointegration*
EG-JOH-BO-BDM	2.5083029	33.969	21.931	16.964	*Cointegration*
Equation 3	*Constant Model (Lag =2)*	*Critical Values*			
$LnCO_2 = f(LnOIL)$	Fisher Type Test statistics	%1	%5	%10	*Results*
EG-JOH	2.8550782	17.304	11.229	8.678	*Cointegration*
EG-JOH-BO-BDM	4.5870398	33.969	21.931	16.964	*Cointegration*

Notes: * and ** indicate significance at the 10% and 5% levels, respectively.

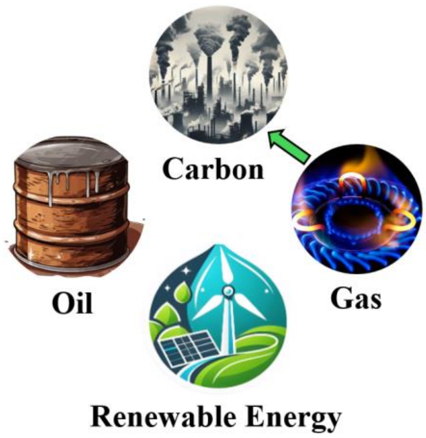
According to the results of the Bayer-Hanck cointegration test, a long-run cointegration relationship is found only between the variables of renewable energy consumption and carbon emissions in Equation 1. Therefore, the long-run estimation results for Equation 1 are reported. Table 5 presents the long-run estimation results of FMOLS, DOLS, and CCR. According to all three long-run estimation results, renewable energy consumption negatively affects carbon emissions in Azerbaijan. A 1% increase in renewable energy consumption will lead to a 0.60% reduction in carbon emissions in Azerbaijan. This finding is consistent with the findings of Mukhtarov et al. (2022), Eylasov et al. (2023b), Apergis et al. (2023), Idroes et al. (2024), and Hasanov et al. (2023).

Table 5: Long-run Estimation Results

Panel A: FMOLS long-run estimation results				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
LnREC	-0.605049	0.183518	-3.296942	0.0022
Constant	2.390677	0.300293	7.961139	0.0000
Panel B: DOLS long-run estimation results				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
LnREC	-0.600682	0.223747	-2.684655	0.0117
Constant	2.384802	0.368776	6.466809	0.0000
Panel C: CCR long-run estimation results				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
LnREC	-0.581589	0.170577	-3.409531	0.0017
Constant	2.353494	0.280477	8.391051	0.0000

Finally, the causal relationship among the variables was investigated using the Fourier Toda-Yamamoto causality test, with the results presented in Table 6 and visually in Figure 8. According to the FTY results, a unidirectional causality relationship is found only from gas consumption to carbon emissions. This indicates that gas consumption causes carbon emissions in Azerbaijan.

Figure 8: Fourier Toda-Yamamoto Causality Direction



Note: The sign indicates unidirectional causality.

Table 6: Fourier Toda-Yamamoto Causality Results

Direction	*Max Lag*	*Max difference*	*Frequency*	*Chi-sq*	*Prob*
GAS ⟹ CO_2	1	1	1	2.962*	0.085
CO_2 ⟹ GAS	1	1	1	1.137	0.286
OIL ⟹ CO_2	1	1	1	0.337	0.561
CO_2 ⟹ OIL	1	1	1	1.063	0.302
REC ⟹ CO_2	1	1	1	0.087	0.767
CO_2 ⟹ REC	1	1	1	0.054	0.816

Note: * indicate significance at the 10% level.

6. CONCLUSION

In this study, the impact of dirty and clean energy consumption on carbon emissions (CO2) in Azerbaijan was investigated. Using annual data for the period 1985-2022, three econometric models were established. The first econometric model examines the impact of clean (renewable) energy consumption on carbon emissions (CO2), while the last two econometric models investigate the impact of dirty (non-renewable) energy consumption, specifically gas and oil, on carbon emissions (CO2). The study aims to contribute to the literature by using the Bayer-Hanck (2013) combined cointegration test for the first time to assess the cointegration relationship between variables for Azerbaijan. First, the stationarity of the variables was examined, and it was concluded that all variables are stationary at their first differences. According to the results of the Bayer-Hanck cointegration test, a cointegration relationship was found only in the third econometric model between clean (renewable) energy consumption and carbon emissions. According to the long-run estimation results of FMOLS, DOLS, and CCR, clean (renewable) energy consumption negatively affects carbon emissions (CO2) in Azerbaijan. Considering that renewable energy consumption is effective in reducing carbon emissions in Azerbaijan, it is necessary to implement various policies to support this situation. Firstly, incentives such as tax reductions, subsidies, and low-interest loans should be provided to companies investing in renewable energy projects, particularly supporting wind, solar, and biomass energy production. Additionally, to increase the domestic production of renewable energy equipment, technology transfers, R&D support, and incentives provided to local manufacturers should be strengthened. Mandatory standards should be applied in energy efficiency in buildings, industrial facilities, and the transportation sector, and energy savings should be achieved by promoting the integration of energy management systems in public institutions and the private sector. Furthermore, fossil fuel subsidies should be gradually reduced, and regulations should be implemented to pave the way for renewable energy investments, including carbon taxes to encourage sectors emitting carbon to shift towards renewable energy. Green certificates can be issued to renewable energy producers, and the trading of these certificates can be facilitated, along with long-term purchase guarantees for renewable energy. Investments should also be made in smart grid and energy storage systems to facilitate the integration of renewable energy sources into the grid. International collaborations should be enhanced with green funds and climate finance sources to secure international financing for renewable energy projects. In this context, international cooperation should be developed to facilitate the transfer of renewable energy technologies to Azerbaijan, thereby increasing renewable energy consumption and creating a sustainable energy system that significantly reduces carbon emissions. The study also investigated the causal relationships between variables using the Fourier Toda-Yamamoto causality test and found a unidirectional causality relationship from gas consumption to carbon emissions. This indicates that gas consumption is determined by energy demand and economic activities, while emissions do not have a direct impact on these factors. The results emphasize that controlling gas consumption can be effective in reducing carbon emissions, but other regulatory measures, such as transitioning to renewable energy and enhancing energy efficiency, are also necessary for emission control.

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