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Empirical Findings on the Relationship of Energy Consumption, Gross Domestic Product Per Capita and Carbon Dioxide (CO_2) Emissions

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ABSTRACT

The energy industry drives all economic sectors and improves people's well-being. Energy supply reliability underpins national security, economic growth, and global stability. Energy use, especially electricity, affects GDP per capita. Power-to-weight ratio is energy consumption per person. The main purpose of the study, as used in the literature, is to investigate the relationship between carbon dioxide (CO_2) emission and energy consumption, per capita gross domestic product for Azerbaijan using the Toda-Yamamoto causality test using annual data for the period 1991-2021. According to the results of the research, while there is no relationship between energy consumption and GDP, an increase in per capita income reduces CO_2 emissions; it was also found that there is a unidirectional causality running from CO_2 emissions to an increase in per capita income. An increase in energy consumption per capita leads to a decrease in CO_2. However, there is bidirectional causality running both from energy consumption per capita to CO_2 and from CO_2 to per capita income. As a result, a 1% increase in energy consumption per capita causes a 0.946% increase in CO_2. It has been determined that a 1% increase in gross domestic product per capita does not cause a 0.086% decrease in CO_2.

Keywords: CO_2 Emission, Energy Consumption, Per Capita Gross Domestic Product
JEL Classifications: F21, O13, Q4

1. INTRODUCTION

Energy consumption is inherent in almost all types of human economic activity, namely, heating houses, cooking, moving vehicles, industry, agricultural production, etc. The development of various types of energy on a global scale has led to an unprecedented increase in living standards. Today's people are very dependent on energy. Energy and environmental issues are closely linked, as it is almost impossible to produce, transport, or consume energy without significant environmental impact. Environmental issues directly related to energy production and consumption include air pollution, climate change, water pollution, thermal pollution, and solid waste disposal. Emissions of air pollutants from the burning of fossil fuels are the main cause of air pollution in cities. The burning of fossil fuels is also a major source of greenhouse gas emissions, and they create a blanket on the earth's surface that prevents the short rays of the sun from escaping at night. Thus, the energy crisis contributes to an increase in the temperature on Earth, contributing to global warming. The environmentally conditioned threat to the existence of human civilization is officially recognised at the highest interstate level; scientific and technological progress has created the danger of an ecological catastrophe, and the very concept of "development" is called into question. There was an urgent need to revise the scale of human values. The consumer attitude toward nature has pushed it to the brink of extinction. Dominant patterns of production and consumption lead to ecological devastation and increased risk to human life and health due to a decrease in the quality of the environment. The foundations of global security are under threat.

For centuries, people have ignored the damage caused by the unlimited use of resources offered by nature and the unconscious consumption of resources. Since the industrial revolution, production has accelerated with the mechanisation process, and the damage to the environment and natural resources has started to increase at the same rate. The danger in the resources was discovered much later. With the increase in environmental damage, some difficulties in meeting basic needs have emerged. With all these experiences, awareness of the concept of sustainable development has begun to increase. The phenomenon, which was previously considered only as development, has been expanded with this situation, and the environment, natural resources, and human aspects have been added to it (Najam and Cleveland, 2003). Pollution, which causes the deterioration of the functioning of the ecosystem, mainly occurs with the increase of industrialization, population, and urbanization. The pollution evaluated in the first group can disappear spontaneously in the process, so it can be said that it is temporary. However, the pollution evaluated in the second group cannot be said to be temporary. This contamination is transmitted from soil and animals to humans. In such a case, it becomes impossible to remove the substances that cause pollution (Taofeek et al., 2014). The ability of goods and services to meet needs is called utility, and the act of creating utility is called production. Abundant production means meeting more needs, which in turn provides a high standard of living. In order to meet the needs, the scarcity of production factors and resources within the country necessitates outsourcing. The unconscious consumption of fossil energy sources resulted in the emission of greenhouse gases and thus the accumulation of CO_2 emissions, the most important greenhouse gas, in the atmosphere as a result of the combination of carbon and oxygen. This has led to environmental disasters such as climate changes, global warming, the melting of glaciers, rising ocean levels, and tropical storms (Demir, 2022).

The primary goal of this study is to investigate the relationship between carbon dioxide emissions, energy consumption, and GDP per capita in Azerbaijan from 1991 to 2021, as used in the literature on pollution and the protection of basic natural resources. In the study, firstly, the empirical literature will be searched, and then the relationship between the variables will be examined with the model to be established.

2. LITERATURE REVIEW

There are many studies on the determinants of carbon dioxide emissions in the world. However, although there are studies on this subject in Azerbaijan, studies with the help of econometric models are very few. Some of these studies have been summarised as follows:

Atici and Kurt (2007) analysed the time series of CO_2, income, and foreign trade for Turkey for the 1968-2000 period, and according to their findings, it was concluded that economic development increased income and income inequality.

Pao and Tsai (2010) also explore the relationship between pollution levels, economic development, and energy consumption. The authors show that there is a strong two-way causality between emissions and FDI and a one-way causality from output to FDI. The authors proved that there is a strong two-way causal relationship between carbon dioxide emissions and emissions and between energy emissions and energy consumption, while a strong one-way causality goes from energy consumption to carbon dioxide emissions.

Özturk and Acaravcı (2013) investigated the relationships between financial development, trade, growth, energy consumption, and CO_2 for Turkey over the period 1960-2007. There is a long-term relationship between ARDL variables, according to the findings.

In his study, Koçak (2014) examined the relations between CO_2, income, and energy consumption for the period 1960-2010 in Turkey. According to research findings, ARDL energy consumption increases carbon dioxide emissions.

According to Artan et al. (2015), they analysed the relationships between growth, openness, and environmental pollution in Turkey in the 1981-2012 period. According to the findings of the analysis, VAR analysisThere is a relationship between growth, openness, and environmental pollution.

In his study from 2008, Hatemi-J looked at the relationship between CO_2 and energy use. The cointegration test result showed that as energy use went up, CO_2 went up as well.

Doğan and Topallı (2016) investigated the relationship between CO_2, GDP, and energy consumption in Turkey in the period 1965-2013. According to the research findings, there is causality from energy consumption and CO_2 to growth.

In his study, Kizilkaya (2017) analysed the relationship between economic growth, energy consumption, foreign direct investments, and CO_2 for the period 1970-2014 in Turkey. According to the results the presenter obtained with the ARDL test in the research, it has been determined that growth and energy consumption have a positive effect on CO_2.

Solarin et al. (2017) examine the relationship between CO_2 emissions, hydropower consumption, urbanization, and real GDP in China and India over the period 1965-2013. The authors conclude that real GDP and urbanisation have a long-term positive impact on carbon dioxide emissions, while hydropower consumption has a long-term negative impact on CO_2 emissions in both countries.

Yenisu (2018) analysed the relationship between CO_2, GDP, and energy consumption in Turkey in the period 1960-2013. According to the results of the causality test obtained in the study, it was determined that there is unidirectional causality from energy consumption to growth and CO_2.

Kurt et al. (2019) examined the relationship between CO_2, foreign direct investments, energy consumption, and per capita income for the 1974-2014 period in Turkey. According to the findings obtained with the help of the ARDL test, while income reduces CO_2, it was concluded that energy consumption and foreign direct investments increased.

Haug and Ucal (2019) analysed the relationship between foreign trade, foreign direct investments, and CO_2 for Turkey in the 1974-2014 period. According to the findings obtained with the help of the ARDL test, it was concluded that decreases in exports and increases in imports increase CO_2 per capita.

In his study, Benli (2020) examined the relationship between foreign direct investments, CO_2, energy, and growth in Turkey in the 1974-2014 period. Directed acyclic graphs (DAGs): Foreign direct investment increases carbon emissions.

In their study, Dinç and Dinç (2021) examined the relationship between energy, financial development, income, and foreign direct investments for Turkey over the period 1970-2015. In the study, according to the findings obtained with the help of the Toda Yamamoto causality test, it was concluded that financial development affects energy consumption, income, and foreign direct investments.

In his study, Demir (2022) investigated the relationship between carbon dioxide (CO_2) emissions and net foreign direct investments, energy consumption, and per capita gross domestic product for Turkey using annual data for the 1974-2015 period using the Toda-Yamamoto causality test. According to the research findings, while there is no relationship between net foreign direct investments and CO_2 emissions, the increase in energy consumption increases CO_2 emissions. It was also found that there is a unidirectional causality running from CO_2 emissions to energy consumption. An increase in per capita income causes a decrease in CO_2. However, there is bidirectional causality running from both per capita income and CO_2 to per capita income.

When the findings of the studies in the literature summary are examined in general, it is seen that energy consumption increases carbon dioxide emissions. It is seen that it has a positive effect on economic growth and CO_2 emissions.

3. METHODS

The studies taken as references while creating the empirical model used in the study; (Uysal and Yapraklı (2016); Kurt et al., 2019; and Demir, 2022). In the econometric analysis, CO_2 emissions (metric tonnes per capita), energy consumption (kg oil equivalent per capita), and gross domestic product per capita (US$) are included in the model logarithmically. The econometric analysis period covers the period 1991-2021. Annual data were used in the analysis. The model established by obtaining the data of the econometric analysis period from BP (a British company) and the World Bank database is as follows:

$$InCOPC_t = \beta_0 + \beta_1 In\text{PECPC}_t + \beta_2 InGDPPC_t + \mu_t \quad (1)$$

The abbreviations of the variables used in the model and the names of the variables they represent are: COPC: CO_2 Emission; PECPC: Per Capita Energy Consumption; GDPPC: GDP per capita; and t is the error term. Toda and Yamamoto's (1995) causality analysis was performed as a method. The Wald test is applied in this causality analysis. The distribution of the Wald test has the c2 distribution obtained by adding the number of lags in the VAR model and the integration degrees of the series. The Toda-Yamamoto causality test creates a standard VAR model at the level values of the variables and thus eliminates the problems that occur while determining the cointegration degrees of the series (Zapata and Rambaldi, 1997; Duase, 2007). The VAR process was created accordingly;

$$InX_t = \sum_{i=1}^{k+d_{max}} a_{1i} InX_{ti} + \sum_{i=1}^{k+d_{max}} \beta_{1i} InY_{ti} + \varepsilon_{1t} \quad (2)$$

$$InY_t = \sum_{i=1}^{k+d_{max}} a_{2i} InY_{ti} + \sum_{i=1}^{k+d_{max}} \beta_{2i} InX_{ti} + \varepsilon_{2t} \quad (3)$$

Can be expressed as. The max d expression in equations (2) and (3) denotes the maximum integration degrees of the variables in the model, and the expression k denotes the optimal lag length obtained from the VAR model. The error correction term is t. Descriptive statistics of the variables are given in Table 1. Looking at the standard errors, which are indicators of volatility, it is seen that the highest volatility is in GDP per capita and CO_2, respectively. When we look at the Jargue-Bera statistics, which show whether the series are normally distributed or not, it can be said that the series is normally distributed only because the probability value of the energy consumption series is >5%. However, since the probability values of the series in GDP and CO_2 are <5%, it is seen that the series are not normally distributed. Also, COPC, PECPC, and GDP averaged −0.023031, −0.022432, and 0.047532; the median was −0.009491, −0.021047, and 0.105787; the maximum was 0.18528, 0.115265, and 1.242669; the minimum was −0.373585, −0.208634, and −2.995752; the standard error was 0.113601, 0.077727, and 0.641903; the availability of the data was decisive in choosing the period.

The time path of the variables is shown in Figure 1. According to this, the appearance of the CO_2 series is very similar to the energy series' appearance in the examined period, and their appearances are constantly increasing with short pauses. The biggest decrease in 1992 was the increase after 1993.

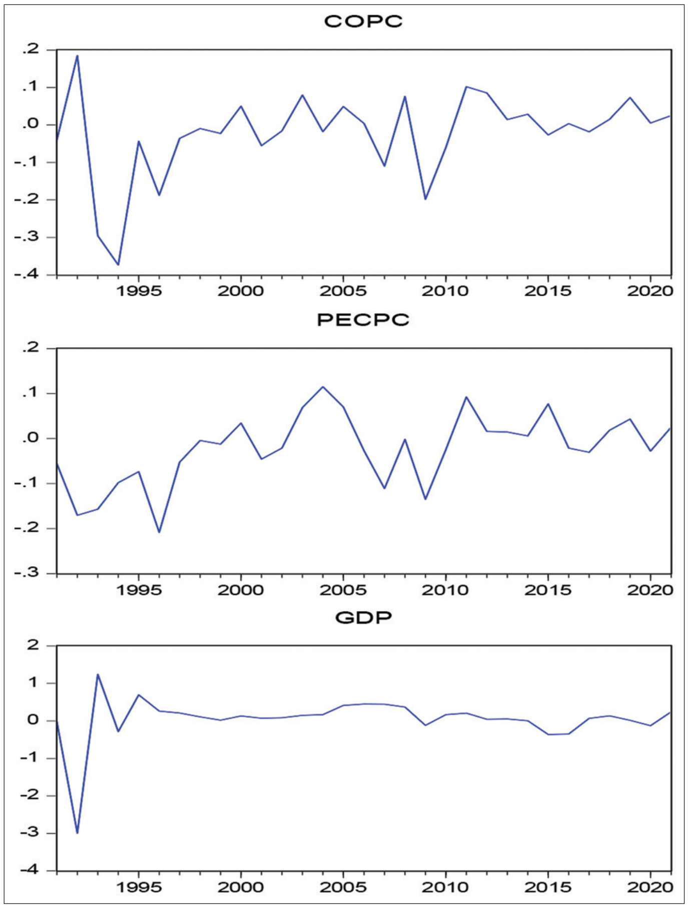
4. RESULTS

The results of the stationarity tests of the series performed with the ADF Dickey Fuller (1981) and Phillips and Perron (1988) tests are shown in Table 2. Accordingly, according to the ADF unit root

Table 1: Descriptive statistics of variables

Identifiers	COPC	PECPC	GDPPC
Mean	−0.023031	−0.022432	0.047532
Median	−0.009491	−0.021047	0.105787
Maximum	0.185258	0.115265	1.242669
Minimum	−0.373585	−0.208634	−2.995752
Std. Dev.	0.113601	0.077727	0.641903
Skewness	−1.329330	−0.535271	−3.349640
Kurtosis	5.169810	2.916413	17.88264
Jarque-Bera	15.21138	1.489350	344.0657
Probability	0.000498	0.474889	0.000000
Sum	−0.713950	−0.695381	1.473483
Sum Sq. Dev.	0.387155	0.181246	12.36118
Observations	31	31	31

Figure 1: Time path of the variables



test results, all of the variables were stationary at level values. That is, it is significant at the level value at the 1% and 5% levels of significance. According to the PP unit root test results, all of the variables were stationary at level values.

Table 2 shows the regression results of the model first and then the coefficients, which are looked at to see whether they are significant or not. It is seen that the explained variable CO_2 is significant when the probability values of the explanatory variables PECPC and GDPPC are examined. Since the sign of the coefficient of the Energy Consumption Per Capita variable is positive, the effect is in the same direction. A 1% increase in energy results in a 0.946% increase in CO_2. Since the sign of the coefficient of the GDP per capita variable is negative, the effect is inverse, and a 1 unit increase in per capita income causes a 0.086% decrease in CO_2. Since there is more than one variable, the corrected R-square value (0.506340) for the explanatory power of the model shows that the explanatory variables are very significant in explaining CO_2, and the probability (0.000019) value of the F statistic is significant, which also supports this view.

When the results in Tables 2 and 3 were evaluated together, it was seen that the established model was significant and the variables became stationary after taking the first difference. After this stage, a Johansen cointegration analysis was performed. Before performing the Johansen cointegration analysis, the appropriate lag number

Table 2: Regression results

Variable	Coefficient	Std. error	t-statistic	Prob.
PECPC	0.946469	0.190836	4.959585	0.0000
GDP	−0.086292	0.023108	−3.734267	0.0009
C	0.002302	0.015060	0.152846	0.8796
R-squared	0.539250	Mean dependent var		−0.023031
Adjusted R-squared	0.506340	S.D. dependent var		0.113601
S.E. of regression	0.079817	Akaike info criterion		−2.126392
Sum squared resid	0.178382	Schwarz criterion		−1.987619
Log likelihood	35.95908	Hannan-Quinn criter.		−2.081156
F-statistic	16.38526	Durbin-Watson stat		2.183349
Prob (F-statistic)	0.000019			

Table 3: Results of unit root test

Unıt root test table (PP)			
At level			
Levels	**GDPPC**	**COPC**	**PECPC**
With constant			
t-statistic	−6.9355	−4.6298	−3.1023
Prob.	0.0000***	0.0009***	0.0371**
With constant and trend			
t-statistic	−6.8745	−5.1739	−3.8307
Prob.	0.0000***	0.0012***	0.0286**
Without constant and trend			
t-statistic	−7.0125	−4.6089	−3.0327
Prob.	0.0000***	0.0000***	0.0037***
At first difference			
Levels	**d (GDPPC)**	**d (COPC)**	**d (PECPC)**
With constant			
t-statistic	−15.2633	−9.1770	−10.5103
Prob.	0.0000***	0.0000***	0.0000***
With constant and trend			
t-statistic	−16.0682	−8.8775	−12.5595
Prob.	0.0000***	0.0000***	0.0000***
Without constant and trend			
t-statistic	−15.2487	−9.3871	−9.3555
Prob.	0.0000***	0.0000***	0.0000***
Unıt root test table (ADF)			
At level			
Levels	**GDPPC**	**COPC**	**PECPC**
With constant			
t-statistic	−6.9425	−4.6379	−3.1296
Prob.	0.0000***	0.0009***	0.0350**
With constant and trend			
t-statistic	−6.8745	−5.1739	−3.7941
Prob.	0.0000***	0.0012***	0.0310**
Without constant and trend			
t-statistic	−7.0125	−4.5707	−3.0757
Prob.	0.0000***	0.0000***	0.0033***
At first difference			
Levels	**d (GDPPC)**	**d (COPC)**	**d (PECPC)**
With constant			
t-statistic	−9.0379	−7.7390	−7.1882
Prob.	0.0000***	0.0000***	0.0000***
With constant and trend			
t-statistic	−8.0287	−7.4963	−7.0956
Prob.	0.0000***	0.0000***	0.0000***
Without constant and trend			
t-statistic	−9.4034	−7.8588	−7.2819
Prob.	0.0000***	0.0000***	0.0000***

(*) Significant at the 10%; (**) Significant at the 5%; (***) Significant at the 1%. and (no) Not Significant

Table 4: Determination of appropriate lag length

Lag	LogL	LR	FPE	AIC	SC	HQ
0	84.13582	NA	4.93e-07	−6.010061	−5.866079*	−5.967248
1	97.26474	22.36779*	3.65e-07	−6.315907	−5.739979	−6.144653*
2	106.9245	14.31068	3.58e-07*	−6.364774*	−5.356901	−6.065081
3	110.1457	4.056347	5.92e-07	−5.936716	−4.496898	−5.508583
4	117.5891	7.719147	7.72e-07	−5.821417	−3.949653	−5.264844

*indicates lag order selected by the criterion

Table 5: Johansen cointegration test

Unrestricted cointegration rank test (trace)				
Hypothesized No. of CE (s)	Eigenvalue	Trace statistic	0.05 critical value	Prob.**
None*	0.890185	101.3325	29.79707	0.0000
At most 1*	0.643380	37.27262	15.49471	0.0000
At most 2*	0.224446	7.371162	3.841466	0.0066
Unrestricted cointegration rank test (maximum eigenvalue)				
Hypothesized No. of CE (s)	Eigenvalue	Max-Eigen statistic	0.05 critical value	Prob.**
None*	0.890185	64.05990	21.13162	0.0000
At most 1*	0.643380	29.90145	14.26460	0.0001
At most 2*	0.224446	7.371162	3.841466	0.0066

Table 6: Error correction model (VECM) results

Variable	Coefficient	Std. error	t-statistic	Prob.
PECPC	0.946469	5.83E-17	1.62E+16	0.0000
GDP	−0.086292	7.06E-18	−1.22E+16	0.0000
ERROR	1.000000	5.77E-17	1.73E+16	0.0000
C	0.002302	4.60E-18	5.00E+14	0.0000
R-squared	1.000000	Mean dependent var		−0.023031
Adjusted R-squared	1.000000	S.D. dependent var		0.113601
S.E. of regression	2.44E-17	Sum squared resid		1.60E-32
F-statistic	2.17E+32	Durbin-Watson stat		1.620203
Prob (F-statistic)	0.000000			

Table 7: LM test for serial correlation

Lags	LM-stat	Prob
1	3.746961	0.9273
2	5.893057	0.7506
3	16.27021	0.0614
4	2.774297	0.9726
5	4.284317	0.8917

Table 8: Tests of variance and normality of variance

Component	Skewness	Chi-sq	df	Prob.
1	0.572142	1.473057	1	0.2249
2	−0.244085	0.268098	1	0.6046
3	1.718241	13.28559	1	0.0003
Joint		15.02674	3	0.0018
Component	**Kurtosis**	**Chi-sq**	**df**	**Prob.**
1	3.127727	0.018354	1	0.8922
2	4.300648	1.903145	1	0.1677
3	6.106675	10.85786	1	0.0010
Joint		12.77935	3	0.0051
Component	**Jarque-Bera**	**df**	**Prob.**	
1	1.491411	2	0.4744	
2	2.171243	2	0.3377	
3	24.14344	2	0.0000	
Joint	27.80610	6	0.0001	

needs to be determined. The test results for the determination of the most appropriate lag length are shown in Table 4.

As can be seen from Table 4, optimal delay lengths are indicated with an asterisk (*). Accordingly, Schwarz information criterion (SC) and Hannan-Quinn information criterion (HQ) statistics set the appropriate lag length as 1 and 2, and the sequentially modified LR test statistic, final estimation error (FPE), and Akaike information criterion (AIC) information criterion fit 2 determined the lag length. Since the information delay with the most (*) is the most appropriate delay length, the lag length is set to 2.

Table 5 shows the cointegration test results between the variables. When the findings measuring and showing cointegration were examined, it was understood that the variables were cointegrated because both the trace statistics and the maximum eigenvalue statistics were larger than the critical values of 5%, and the null hypothesis, which said that there was no cointegration vector, was rejected. Probability values also support this view.

The results of the cointegration test between the variables in Table 5 show that there is a long-term relationship (cointegration) between CO_2 and the variables that explain it, energy consumption per capita and national income per capita. For the reliability of Johansen test results and/or short-term coefficient estimates, vector error correction estimation is required. Table 6 shows the results of the error correction model.

When we look at the results of the error correction model in Table 6, it means that the error terms work in the model, and when a shock occurs on the variables in the long run, they will again converge towards equilibrium when they are separated from each other. The cointegration test results showing that there is a long-term relationship (cointegration) between these specific variables are reliable. In addition, it is understood that the model is significant, there is no autocorrelation in the model (Table 7), the process is stationary (Table 8), and the model is stable (Figure 2).

Table 9 shows the relationship between carbon dioxide emissions and foreign direct investments, energy consumption, per capita

Figure 2: Inverse roots of the AR characteristic polynomials

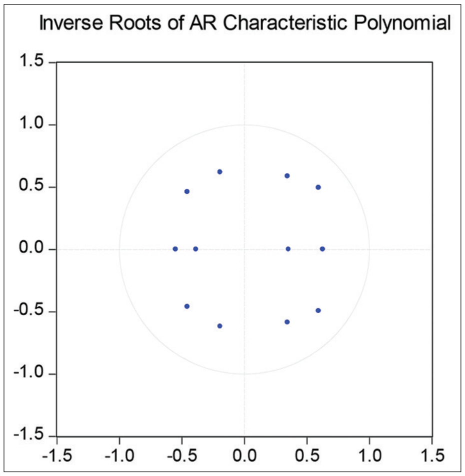


Table 9: Toda-yamamoto causality test results

Excluded	Chi-sq	df	Prob.
Dependent variable: COPC			
PECPC	5.193781	2	0.0745
GDP	8.094883	2	0.0175
All	23.37708	4	0.0001
Dependent variable: PECPC			
Excluded	**Chi-sq**	**Df**	**Prob.**
COPC	5.429729	2	0.0662
GDP	2.153924	2	0.3406
All	5.661969	4	0.2259
Dependent variable: GDP			
Excluded	**Chi-sq**	**Df**	**Prob.**
COPC	3.296858	2	0.1924
PECPC	3.619102	2	0.1637
All	7.236813	4	0.1239

gross domestic product, and Toda-Yamamoto causality test findings. During this test, the Granger causality relationship was investigated by including per capita carbon dioxide emission, energy consumption, and per capita gross national product variables in the model as explained variables.

5. DISCUSSION AND CONCLUSION

The relationship between economy and environment can be traced back to the agricultural revolution centuries ago. With the industrial revolution in the 18th century, the increasing needs after the increase in population density led to an increase in production. With the increase in production, economic growth has become the main goal of every country. The use of energy sources, which are mostly fossil fuels, to make up for the increase in production after industrialization and the increase in the supply of raw materials has led to more pollution and has made the environment an important issue (Işik et al., 2015). The environment is an input to the production process, but it is also influenced by the output. However, increases in production cause environmental degradation due to the use of more production factors. CO_2 emissions are used as key indicators of environmental degradation. Factors such as population growth, economic growth, energy consumption, and per capita income affect CO_2 emissions. The most common pollutant causing environmental pollution is CO_2 emissions. CO_2 emissions are not only related to the burning of fossil fuels for power generation and transportation. It is also about industrial production, deforestation, and the conversion of grassland to farmland (Vogel, 1999). However, if examples such as industrialization activities carried out in the name of development result in the pouring of industrial wastes into the sea without treatment, forest destruction, and the destruction of clean water resources, irreversible results may occur (Demir, 2022). Energy production significantly affects the state of the environment. The combustion of fossil solid and liquid fuels is accompanied by the release of sulphur dioxide, carbon dioxide, and carbon monoxide, as well as nitrogen oxides, dust, soot, and other pollutants (Bogolyubov, 2018). Energy production and consumption affect the health of the world's population and threaten environmental problems. Among the most dangerous consequences are air and water pollution, climate change, and the accumulation of nuclear waste. The need for energy supply is growing, and with it, the burden on the environment is also increasing.

The main goal of this study was to investigate the relationship between carbon dioxide emissions, energy consumption per capita with CO_2, and gross domestic product per capita for Azerbaijan with annual data from 1991 to 2021. It was discovered that they were stable at the preliminary test level. Then, based on the regression analysis and the explained variable CO_2, the probability values of the explanatory variables PECPC and GDPPC are seen to be significant as to whether the coefficients are significant or not. Since the sign of the coefficient of the energy variable is positive, the effect is in the same direction: the increase in energy consumption causes an increase in CO_2. Since the sign of the coefficient of the per capita income variable is negative, the effect is reversed, and it is understood that an increase in per capita income causes a decrease in CO_2. The fact that the probability value of the F statistic is significant also supports this view. It was observed that the variables for which the established model was significant became stationary after taking the first difference.

After this stage, the appropriate number of delays was determined and Johansen cointegration analysis was performed; it was observed that there was a long-term relationship between CO_2 and the variables that explain it, namely energy consumption and per capita national income. When the results of the error correction model are examined, it is understood that the error terms work in the model, and when there is a shock on the variables in the long run, they will converge towards equilibrium again when they are separated from each other. According to Toda-Yamamoto causality test results, there is bidirectional causality between energy consumption and CO_2 emissions. There is a Granger causality running from gross domestic product per capita to CO_2.

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