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The Mediating Role of Energy Consumption in the Impact of Trade Openness and Economic Growth on Carbon Emissions: The Case of Turkey

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ABSTRACT

Research on carbon emissions (CO2 emissions) and their determinants as part of environmental pollution has been ongoing for a long time and continues. The aim of this study is to examine the mediating role of energy consumption in the relationship between economic growth, trade openness, and carbon emissions (CO_2) in the context of Turkey. Data analysis, statistical evaluations, and visualization processes were conducted using the R programming language for the period 1965–2022. The analysis results indicate that Gross Domestic Product (GDP) variable, representing economic growth, has a negative and statistically significant effect on both energy consumption and CO_2 emissions in Turkey. Furthermore, it was determined that approximately 73.8% of the total effect of GDP on CO_2 emissions occurs indirectly through energy consumption. The effect of trade openness on both energy consumption and CO_2 emissions was found to be positive and statistically significant. However, when examined in terms of mediation, the mediating role of energy consumption in the relationship between trade openness and CO_2 emissions was not found to be statistically significant. On the other hand, the direct effect of the mediator variable (energy consumption) on CO_2 emissions was negative and statistically significant.

Keywords: Economic Growth, Trade Openness, Carbon Emissions, Energy Consumption, Mediation Effect

Ticaret Açıklığı ve Ekonomik Büyümenin Karbon Emisyonları Üzerindeki Etkisinde Enerji Tüketiminin Aracı Rolü: Türkiye Örneği

ÖZ

Çevresel kirliliğin bir parçası olarak karbon emisyonları (CO_2 emisyonu) ve belirleyicileri üzerine uzun süredir araştırmalar yapılmakta ve devam etmektedir. Bu çalışmanın amacı, ekonomik büyüme ve ticaret açıklığının CO_2 emisyonu üzerindeki etkisinde enerji tüketiminin aracı rolünün Türkiye açısından incelenmesidir. Çalışmada veri analizi, istatistiksel değerlendirmeler ve görselleştirme süreçleri R programı aracılığıyla ve 1965-2022 dönemi için gerçekleştirilmiştir. Analizler sonucunda, Türkiye'de ekonomik büyümeyi temsil eden Gayri Safi Yurt İçi Hasıla (GSYİH) değişkeninin hem enerji tüketimi hem de CO_2 emisyonu üzerindeki etkisinin negatif ve istatistiksel olarak anlamlı olduğu bulunmuştur. Ayrıca, GSYİH'nın CO_2 emisyonları üzerindeki toplam etkisinin yaklaşık %73.8'lik kısmının enerji tüketimi aracılığıyla dolaylı olarak gerçekleştiği belirlenmiştir. Ticaret açıklığının, enerji tüketimi ile CO_2 emisyonu üzerindeki etkisi ise pozitif ve anlamlı olarak bulunmuştur. Aracılık etkisi açısından incelendiğinde ise ticaret açıklığının CO_2 emisyonları üzerindeki etkisinde enerji tüketiminin aracı rolü istatistiksel olarak anlamlı bulunmamıştır. Aracı değişkenin tek başına CO_2 üzerindeki doğrudan etkisi ise negatif yönde ve istatistiksel olarak anlamlıdır.

Anahtar Kelimeler: Ekonomik Büyüme, Ticaret Açıklığı, Karbon Emisyonları, Enerji Tüketimi, Aracılık Etkisi

1. Introduction

Today, the global mindset is shaped by the concept of 'EEE' (Energy, Environment, Economy), which centers on the interrelationships between energy, the environment, and the economy (Rauf et al., 2018, p. 32066). Within the dynamics of the modern economy, the diversification of economic activities has

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positioned itself as a strategy to accelerate economic growth (Mata et al., 2024, p. 580). Rapid development and growth on a global scale lead to greater environmental degradation, causing global warming (Türköz, 2025, p. 133). In order to successfully limit global climate change to "safe" levels in the long term, climate change policies in both developing and industrialized countries must be linked to sustainable development strategies (Beg et al., 2002, p. 130). Sustainable development defines the balance of society in economic, social, and environmental terms. The economic dimension refers to the use of scarce resources, while the social dimension is concerned with being human-centered. The environmental dimension, on the other hand, envisages the balance of biological and physical systems (ecosystems) (Gürlük, 2010, pp. 86-87). In this context, the rapid increase in CO_2 emissions, especially after the Industrial Revolution, necessitates that countries' activities be addressed and improved with a holistic approach in the context of sustainable development.

The rapid increase in CO_2 emissions as a result of human activities (development and industrialization) (Munir & Khan, 2014, p. 327) has led to an increase in academic studies on the factors causing this. These studies generally focus on economic growth, trade openness, and energy consumption variables; many studies have found that these factors are among the determinants of CO_2 emissions (Adebayo & Beton Kalmaz, 2021; Ansari, Haider, & Khan 2020; Ertugrul et al., 2015; Itoo & Ali, 2023; Samreth, Iwata, & Okada, 2010; Sharma, 2011; Zmami & Ben-Salha, 2020). Energy consumption, a fundamental element supporting economic growth and sustainable development, requires increased economic activity; commercial openness is also considered an integral component of this development process (Hongxing, Abban, & Boadi, 2021, p. 2). Countries turning to foreign trade to meet the growing needs of their people are increasing their foreign trade activities in this direction; this leads to expansion in production, while the increased use of energy sources such as fossil fuels in the production process results in a significant increase in CO_2 emissions (Akbulut Yıldız 2021; Kesgingöz & Karamelikli 2015). In this context, examining the environmental impact of trade openness and economic growth in Turkey, a developing country, is important for the formulation of sustainable development policies. The role of energy consumption in the context of environmental sustainability as a result of increasing commercial activities remains important for researchers today. In this context, the increase in energy demand alongside the expansion of trade volume creates a potential conflict with environmental sustainability goals, necessitating comprehensive analysis by policymakers and academics.

This study aims to fill the scientific gap arising from the limited number of research that examines the impact of economic growth and trade openness on carbon emissions while addressing the mediating role of energy consumption specifically for Turkey, and to reveal the dynamics of this relationship given Turkey's rapidly increasing energy demand and high level of openness. Although studies investigating the mediating effect in the literature are limited, it is observed that existing analyses are mostly conducted using econometric methods. In this study, data analysis, statistical evaluations, and visualization processes will be performed using the R program. Therefore, both the differentiation of the analysis method and the examination of the mediating role of an important variable such as energy consumption reveal the original value of this study. The analyses aim to yield meaningful findings specific to Turkey for the period 1965-2022. To this end, a conceptual framework for the subject was first outlined, followed by a literature review summarizing the findings from studies on the subject. Finally, comparisons were made with other studies that obtained similar or differEC findings in the literature, based on the results obtained from the analyses performed using the R program.

2. Literature

2.1. The Impact of Trade Openness on CO_2 Emissions

Globalization has been an important supporter of trade openness for developing economies (Karedla, Mishra, & Patel, 2021). Increased trade activity between countries has led to its examination in the context of environmental degradation. Studies in the literature examining the effect of trade openness on CO_2 emissions are as follows:

An empirical study conducted by Chebbi, Olarreaga, & Zitouna (2010) on the Tunisian economy examined the environmental effects of trade openness using data from 1960 to 2004. The findings reveal

that the direct effect of trade openness on CO_2 emissions is positive in both the short and long term. However, it was found that the indirect effect of trade openness, especially in the long term, reduces emissions. This shows that the effect of trade openness on environmental sustainability varies depending on the time dimension and the channel of impact. A study by Ohlan (2015) using Indian data from 1970 to 2013 found that population density, energy consumption, and economic growth have a statistically significant and positive effect on CO_2 emissions in both the short and long term.

A study conducted by Mahmood, Maalel, & Zarrad (2019) found that commercial openness in Tunisia had positive effects on CO_2 emissions in the linear ARDL model and asymmetric effects in the nonlinear ARDL model over the period 1971-2014. The increase in Tunisia's trade openness was found to be responsible for the increase in CO_2 emissions in Tunisia, while the effect of the decrease in trade openness was estimated to be insignificant. Topallı (2022) examined the long-term relationship between trade openness and CO_2 emissions for China, Indonesia, Malaysia, and Thailand for the period 1960-2016. No long-term relationship was found between trade openness and CO_2 emissions for China, Malaysia, and Thailand, while a positive relationship between the variables was found for Indonesia.

A study conducted by Mata et al. (2024) examined the effects of urban population density and trade openness on CO_2 emissions in 30 high-income countries during the period 2000–2020. The findings show that trade openness increases CO_2 emissions. Abdulle & Mohamed (2024) examined the effect of trade openness on CO_2 emissions in Somalia during the period 1980–2021. The study found a statistically significant and inverse relationship between trade openness and CO_2 emissions in the short term. Güler & Petek (2025), in their study on Turkey for the period 1980-2023, used the ARDL bounds test and the Toda-Yamamoto causality test to determine the causality relationship and concluded that trade openness increases CO_2 emissions in the long term.

Overall, when the findings are evaluated, it is seen that the effect of trade openness on CO_2 emissions varies across studies. In short, studies by Chebbi, Olarreaga, and Zitouna (2010), Ohlan (2015), Mahmood, Maalel, and Zarrad (2019), Mata et al. (2024), and Güler and Petek (2025) found that the trade gap increases CO_2 emissions, Abdulle & Mohamed (2024) identified an inverse relationship in the short term, and Topallı (2022) found no long-term relationship for China, Malaysia, and Thailand, with only Indonesia showing a positive relationship.

2.2. The Impact of Economic Growth on CO_2 Emissions

All economic activities require energy, and to the extent that this energy comes from fossil fuels, energy use leads to CO_2 emissions (Schröder & Storm, 2020, p. 156). Wu (2023) states that approximately 72.5% of the increase in total global CO_2 emissions is due to economic growth. Green growth establishes an important link between economic growth and environmental sustainability. The fundamental objective of green growth is to ensure improvements in environmental quality and social inclusion as an integral part of the process of increased investment and economic growth (Özçağ & Hotunluoğlu, 2015, p.314). Studies in the relevant literature can be listed as follows:

Çinar (2011) investigated per capita CO_2 emissions and real per capita GDP panel data for OECD countries for the period 1971-2007. The results of the study found a cointegration relationship between income and CO_2 emissions and statistically significant linear long-term coefficients. Accordingly, income growth increases pollution levels and, contrary to the EKC (Environmental Kuznets Curve) hypothesis, income growth continues to increase pollution levels after certain income levels. (Çetintaş & Sarıkaya 2015) analyzed the relationship between CO_2 emissions, energy consumption, and economic growth in the US and the UK using data from 1960 to 2004. Findings indicate that economic growth has a positive effect on CO_2 emissions in the UK in both the short and long term. In the US, however, economic growth has no effect on CO_2 emissions. A positive relationship between energy consumption and CO_2 emissions was found in both countries.

In their study examining the effect of economic growth on CO_2 emissions in developing countries, Aye & Edoja (2017) concluded that economic growth has a negative effect on CO_2 emissions in low-growth regimes and a positive effect in high-growth regimes. Furthermore, energy consumption was

found to have a positive and significant effect on CO_2 emissions. Jamel & Maktouf (2017) examined annual panel data from 40 European economies for the period 1985-2014 using the least squares technique. The researchers found that GDP and environmental degradation are positively and highly correlated. A positive relationship was also found between per capita GDP and CO_2 emissions.

In his study, Özçağ (2019) aimed to identify the relationships between CO_2 emissions and GDP variables in the Fragile Five countries (Brazil, Indonesia, South Africa, India, Turkey) using data covering the years 1970-2016. Unidirectional causality relationships were found from per capita GDP to per capita CO_2 emissions in Brazil and Indonesia, and from per capita CO_2 emissions to per capita GDP in South Africa and Turkey. A bidirectional causality relationship was also found between CO_2 emissions and GDP in India. In the study conducted by Artekin (2024), data obtained for Brazil for the period 1990-2020 was analyzed using PP and ADF unit root tests, Johansen cointegration analysis, and FMOLS estimation methods to examine the effect of GDP, income distribution, and renewable energy on CO_2 emissions. The multiple regression analysis revealed that the relevant independent variables affect CO_2 emissions. Akın Özdemir (2024), in his study on G-20 countries, found a positive relationship between per capita Gross Domestic Product (GDP) and CO_2 emissions.

2.3. Impact of Energy Consumption on CO_2 Emissions

The increase in global goods trade has also led to an increase in economic efficiency and industrial activity. The exponential growth in global production has resulted in higher energy consumption, which in turn has led to an increase in carbon dioxide emissions (Abdulle & Mohamed, 2024, p. 353). Studies examining the effect of energy consumption on CO_2 emissions are as follows:

The study by Samreth et al. (2010) shows that energy consumption has a positive effect on CO_2 emissions in most of the 11 OECD countries examined in the study. Oh & Bhuyan (2018) investigated the relationship between economic growth, energy consumption, trade openness, population density, and CO_2 emissions in Bangladesh for the period 1975-2013. The results show that energy consumption has a statistically significant and positive effect on CO_2 emissions in both the short and long term.

Al-Mulali & Binti Che Sab (2012) examined the impact of energy consumption on economic and financial development in 19 countries during the period 1980-2008. The research results revealed that energy consumption enabled these countries to achieve high economic and financial development. However, it was found that the high development achieved by these countries over the last thirty years increased CO_2 emissions. Uysal & Yapraklı (2016) examined the relationship between per capita income, energy consumption, and CO_2 emissions in Turkey using structural break analysis. Analysis of data from 1968 to 2011 showed that CO_2 emissions increased due to the rise in energy consumption necessary for countries' long-term growth. It was concluded that increases in income levels reduce CO_2 emissions. As in other developing countries, it was observed that energy consumption, which is the most important factor for investment and growth in Turkey, causes more environmental pollution, but this negative trend will be followed by a positive one with the increase in income levels.

A study by Ansari et al. (2020) covering the United States, Canada, Iran, Saudi Arabia, the United Kingdom, Australia, Italy, France, and Spain found a long-term relationship between CO_2 emissions and the variables of economic growth, energy consumption, and trade openness; it also concluded that energy consumption is the main determinant of CO_2 emissions in the long term. Another study revealed that energy consumption leads to greater environmental degradation in the long term (Zmami & Ben-Salha 2020).

As seen, studies have only examined the direct effect of such an important variable as energy consumption. However, energy consumption is an important channel that drives the environmental impacts of economic growth and trade openness; therefore, this study analyzes the mediating role of this variable to examine the mechanism of these relationships more comprehensively.

3. Data set and method

This study, which aims to examine the effects of trade openness and economic growth on carbon emissions and to assess the mediating role of energy consumption in this effect, uses annual data covering the period from 1965 to 2022. When preparing the data set to be used in the analysis, the earliest date for which the series were available was set as 1965, and the most recent observations were obtained up to 2022. Accordingly, the scope of the study covers the period 1965-2022. In the analyses performed using the R program, the dependent variable was carbon emissions, the independent variables were economic growth and trade openness, and the mediator variable was energy consumption. Information on all variables is summarized in Table 1.

Table 1. Information Regarding Variables

Variables	Variable Name and Abbreviation	Formula	References
Dependent Variable	Carbon Emission (CO_2)	Annual change in CO_2 per capita	https://ourworldindata.org/
Independent Variable	Economic growth (GDP)	Annual change rate in Gross Domestic Product	https://data.worldbank.org/
Independent Variable	Trade Openness (TO)	Annual "(exports + imports)/GDP" change rate	https://data.worldbank.org/
Mediator Variable	Energy Consumption (EC)	Annual change rate in per capita energy consumption	https://ourworldindata.org/

As shown in Table 1, in order to eliminate unit differences in the data set and make meaningful comparisons in time series analyses, all variables were evaluated based on annual rates of change. The research model developed in line with this study, which aims to evaluate the effects of trade openness and economic growth on carbon emissions and the mediating role of energy consumption in this effect, is as shown in Figure 1.

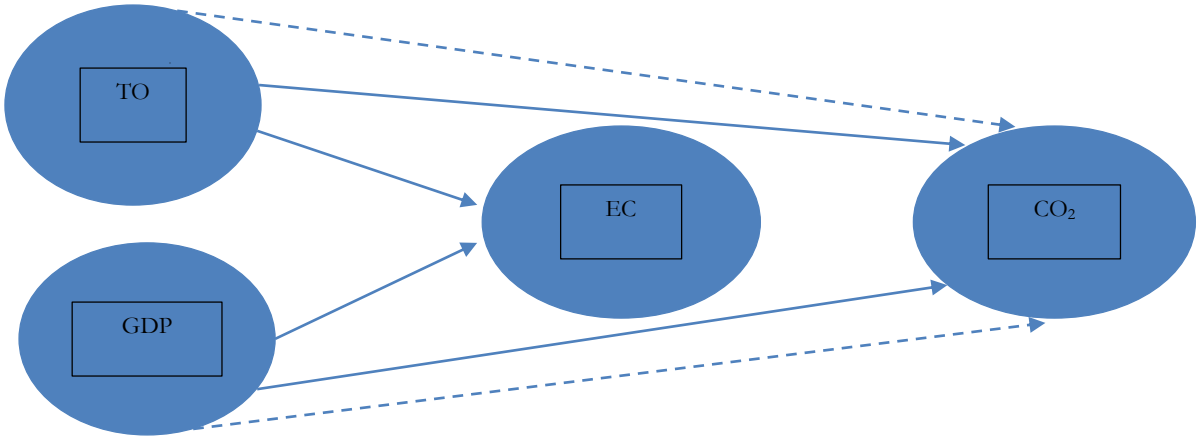

Figure 1. Research Model

The model explains the key factors determining CO_2 emissions through a two-stage causality chain. In the first stage, it is assumed that TO and GDP have a direct effect on EC, and this relationship is expressed by Equation 1.

$$EC_t = \beta_0 + \beta_1 TO_t + \beta_2 GDP_t + \mu_{1t} \quad (1)$$

Here, the β_1 and β_2 coefficients measure the effects of commercial openness and economic growth on energy demand. The role of energy consumption as a key instrumental variable theoretically supports the notion that the environmental consequences of economic and commercial policies emerge not only through indirect channels but also through energy consumption.

In the second stage, the analysis examines how EC affects CO_2 levels both directly and indirectly through TO and GDP. This allows for the analysis of the total impact on CO_2 emissions (direct and indirect) and is shown in Equation 2.

$$CO_{2t} = \gamma_0 + \gamma_1 EC_t + \gamma_2 TO_t + \gamma_3 GDP_t + \mu_{2t} \quad (2)$$

This framework aims to empirically test emissions arising from energy intensity using the γ_1 coefficient, and the direct environmental impacts of trade openness and economic growth using the γ_2 and γ_3 coefficients, respectively. The simultaneous estimation of these two equations aims to reveal the quantitative effects of economic activities, international trade, and energy policies on CO_2 emissions, thereby providing important policy inputs for sustainable development strategies.

In line with the objective of the study and within the scope of the research model visualized in Figure 1, the following hypotheses were formulated to test the relationships between the variables.

H_1: Economic growth in Turkey has a significant effect on energy consumption.

H_2: Trade openness in Turkey has a significant effect on energy consumption.

H_3: Economic growth in Turkey has a significant effect on carbon emissions.

H_4: Trade openness in Turkey has a significant effect on carbon emissions.

H_5: Energy consumption in Turkey has a significant effect on carbon emissions.

H_6: Energy consumption plays a mediating role in the effect of economic growth on carbon emissions in Turkey.

H_7: Energy consumption plays a mediating role in the effect of trade openness on carbon emissions in Turkey.

All statistical analyses in the scope of the research were performed using the R program. R is a computer language and works slightly differently from most programs users are familiar with. Commands evaluated and executed by the program must be written (Gardener, 2012). Causal mediation analysis, which is important for quantitative social science research, can estimate causal mediation effects for linear and nonlinear relationships, parametric and nonparametric models, and continuous and discrete mediators using newly developed algorithms (Imai et al., 2025). To apply causal mediation analysis in R, the mediation package is typically used. For the application, two separate regression models must first be estimated: a mediator model for Energy Consumption and then an outcome model. When working with macroeconomic time series, these models should be estimated using methods that account for the time series structure, such as VAR or ARIMA, or by adding lagged variables to address autocorrelation and stationarity issues. Finally, the outputs of these two models are fed into the mediate function to obtain all predictions, and the significance of these predictions is tested using bootstrap simulation. Therefore, conducting causal mediation analysis with the R program offers researchers the flexibility to work on extensive and diverse datasets (Imai et al. 2025). Therefore, performing causal mediation analysis with the R program offers researchers the flexibility to work on large and diverse datasets.

In the first stage of the analysis, regression analyses were performed to determine the effects between the dependent and independent variables. Subsequently, mediation analysis was applied using the "mediation" package to examine the possible mediating effects between the variables. The statistical significance of the indirect and direct effects was tested using the bootstrap method with 500 repetitions.

4. Findings

Before interpreting the estimated coefficients and values of an econometric model, several underlying assumptions must be examined. These include stationarity, normality, multicollinearity, and autocorrelation. Within the scope of this study, the analyses conducted and the findings obtained in order to test all the proposed hypotheses are presented as follows.

4.1. Results of Assumption Tests

During the analysis process, the inclusion of non-stationary time series in regression models may lead to spurious relationships, causing statistically significant results even when no genuine relationship exists. Therefore, before proceeding with regression analysis, it is necessary to examine the stationarity of the series by applying unit root tests.

Although various tests can be used to determine the stationarity properties of time series, the Augmented Dickey–Fuller (ADF) test is employed in this study. The test results are evaluated at the 5% significance level. Accordingly, the hypotheses formulated for the ADF test and the findings obtained based on the test results are presented as follows:

H_0: The series contains a unit root / is non-stationary.

H_1: The series does not contain a unit root / is stationary.

Table 2. Unit Root Test Results

Variables	ADF Statistic	p value
CO_2	-1.87	0.000
TO	-1.42	0.000
GDP	-1.11	0.000
EC	-1.66	0.000

According to the ADF test results presented in Table 2, the null hypotheses (H_0) are rejected since the probability values are smaller than the 0.05 significance level. In other words, it is concluded that all variables are stationary at level. As the series are stationary, there is no need to conduct a cointegration test.

In time series analysis, it is of great importance that observation values occur randomly. When observation values change in a dependent manner over time, this situation is referred to as lagged autocorrelation. In other words, when analyzing the observation values of a given year, it is assumed that they are influenced by the values of the previous year. Autocorrelation constitutes a problem in time series models, and it is desirable that there is no autocorrelation or that it remains at a very low level among observation values (Nakip, 2006: 351–352). In this study, the autocorrelation problem is examined using the Durbin–Watson test, and the obtained results are reported in Table 3.

Table 3. Autocorrelation Analysis Results

Dependent Variable	Independent Variables	Durbin-Watson Statistic	p value
CO_2	TO, GDP, EC	0.512	0.009

According to the results reported in Table 3, the Durbin–Watson statistic is calculated as 0.512. This statistic is expected to take values between zero and four. A value close to two indicates the absence of autocorrelation, a value close to zero implies positive autocorrelation, and a value close to four suggests negative autocorrelation. Based on this result (DW statistic: 0.512), it is determined that the estimated model exhibits positive autocorrelation among the series. This situation is a common issue in time series analyses and is particularly expected in long-term macroeconomic series. Nevertheless, the estimation of mediation effects using the bootstrap method in this study indicates that potential standard error biases arising from autocorrelation can be substantially mitigated.

Due to the limitations of the classical Baron and Kenny (1986) approach in the presence of autocorrelation and violations of distributional assumptions commonly encountered in time series data, bootstrap-based mediation analyses have been increasingly employed in recent years. The bootstrap method offers significant advantages for time series applications, as it does not require strict assumptions regarding the sampling distribution and provides reliable standard error estimates even in relatively small samples (Preacher & Hayes, 2008).

4.2. Results of Regression Analysis

In the first stage of mediation analysis, it is necessary to test the extent to which the relationship between the variables is "mediated." In other words, it is the process of testing whether the mediator variable is meaningfully predicted by the independent variables. The aim here is to determine the effects of the independent variables (GDP and TO) on the mediator variable (EC) and to see whether EC is truly a variable that can mediate. The model established for this purpose and the results obtained can be summarized as follows:

Model 1: EC ~ GDP + TO

Table 4. Regression analysis results on the impact of GDP and TO on EC

Variable	Estimate	Std Error	T	p-value	Significance
Intercept	0.552276	0.14061	3.928	0.000241	***
GDP	-1.082806	0.379588	-2.853	0.006099	**
TO	0.069163	0.003338	20.718	2E-16	***

- GDP → EC: β = -1.08, p = 0.006
- TO → EC: β = 0.069, p < 0.001

According to these results, the model explains 88.9% of the total variation in EC. Since the F-statistic = 220.3 and p < 0.001, the model is statistically significant. In terms of GDP, since the coefficient is -1.083 (p = 0.006), a one-unit increase in GDP leads to an approximate 1.08-unit decrease in energy consumption.

This may indicate that economic growth is occurring with more efficient structures that consume less energy. In terms of trade openness; since the coefficient is +0.069 (p < 0.001), it is stated that a one-unit increase in trade openness causes an average increase of 0.069 units in energy consumption.

This finding can be interpreted as increased foreign trade increasing energy needs or openness encouraging the growth of energy-intensive sectors. In summary, this model shows that both economic growth and foreign trade significantly affect energy consumption. In particular, while the trade deficit has a very strong effect in increasing energy demand, economic growth is associated with more efficient energy use. Therefore, it is evident that energy policies should take into account not only economic growth but also transformations in the structure of foreign trade.

Model 2: CO_2 ~ GDP + TO

The regression analysis results of the effects of independent variables (GDP and TO) on the dependent variable (CO_2), without mediation effects, are shown in Table 5.

Table 5. Regression analysis results on the effect of GDP and TO on CO_2

Variable	Estimate	Std Error	p-value	Significance
Intercept	0.552	0.0002	***	***
GDP	-1.083	0.379588	0.006	***
TO	0.069	0.003338	0.000	***

- GDP → CO_2 : β = -1.083, p = 0.006
- TO → CO_2 : β = 0.069, p < 0.001

The GDP and TO variables together explain approximately 88.9% of the variation in carbon emissions (R^2=0.889). Since the F-statistic = 220.3 (p < 0.001), the model is generally significant and the variables have a high explanatory power. Since the coefficient for GDP is -1.983 (p=0.006), a one-unit increase in GDP leads to an average decrease of 1.08 units in carbon emissions. This finding may reflect that economic growth is being pursued with more environmentally friendly policies or increased energy efficiency. A one-unit increase in trade openness, on the other hand, causes an average increase of 0.069 units in carbon emissions. This positive and significant effect shows that openness to the outside world may carry environmental costs. It is seen that increasing export and import volumes have an effect that increases energy consumption and, consequently, carbon emissions. Therefore, while GDP has a positive impact on the environment, TO has a negative impact. This indicates that the environmental impacts of trade must be carefully managed in terms of sustainable development goals.

Regression analyses were performed separately to understand the effects of the independent variables on the dependent variable individually.

Model 3: EC ~ CO_2

Table 6. EC'nin CO_2 üzerindeki etkisine ilişkin regresyon analizi sonuçları

Variable	Estimate	Std. Error	T	p-value	Significance
Intercept	3.5249	0.2405	14.658	2E-16	***
EC	-10.2342	3.1844	-3.214	0.00217	**
R^2: 0.1557 Adj. R^2: 0.1406 F p-value: 0.002174					

- EC ~ CO_2 → β = -10.2342, p = 0.00217

To explain the change in carbon emissions, this model, which considers energy consumption as the sole independent variable, has a low model fit (R^2 = 0.1557). This result means that energy consumption explains approximately 15.6% of the change in carbon emissions. However, the model is statistically significant (F-statistic = 10.33, p = 0.00217). In terms of coefficients, a one-unit increase in energy consumption leads to an average decrease of 10.23 units in carbon emissions. Generally, since carbon emissions are expected to increase as energy consumption increases, this result may seem surprising at first, but there may be some reasons for this. Indeed, based on information shared by the Ministry of Environment, Urbanization, and Climate Change, changes in the fuel distribution within total energy consumption may have led to this result (Ministry of Environment, Urbanization, and Climate Change of the Republic of Turkey, 2023).

> "Turkey's primary energy consumption rose from 52,465 Mtae in 1990 to 159,432 Mtae in 2021. As of 1990, solid fuels accounted for 30.2% of Turkey's primary energy consumption. Petroleum and petroleum products accounted for 46.1%, natural gas accounted for 5.4%, and renewable energy sources accounted for 18.4%. As of 2021, 26% of Turkey's primary energy consumption was met by solid fuels. The share of petroleum and petroleum products fell to 27.6%, while the share of natural gas rose to 30.9%. The share covered by renewable energy sources is at 15.6%."

Another reason for this can be attributed to the increase in energy efficiency and the use of new technologies. According to the Ministry of Energy and Natural Resources (2024), between 2017 and 2023, a total of $8.47 billion was invested in energy efficiency in Turkey through the National Energy Efficiency Action Plan between 2017 and 2023, a total investment of $8.47 billion was made in energy efficiency in Turkey, resulting in energy savings of 24 million 625 thousand TEP and a reduction of 68.62 million tons of CO_2 equivalent emissions.

4.3. Mediation Analysis Results

In the mediation analysis, the mediating effects of all independent variables were examined. In this context, first (Model A), it was examined whether the effect of the GDP variable on carbon emissions occurred indirectly through the energy consumption variable. In other words, it was investigated whether the effect of economic growth on carbon emissions involved an indirect mechanism through energy consumption or whether energy consumption played a mediating role in this effect. The model established in this regard is as follows:

Model A: GDP → EC → CO_2

Table 7. Results of the mediation analysis of energy consumption for GDP and carbon emissions

Type of impact	Estimate	Lower Confidence (90% CI)	Upper Confidence (90% CI)	p-value	Significance
ACME	-0.94279	-2.879191	0.056989	0.068	***
Mediation Rate	0.737964	-3.902265	7.087771	0.022	***

- ACME: -0.9472, p = 0.068
- Mediation Rate: %73, p = 0.022

Mediation analyses were conducted using the "mediation" package in the R program and are based on the causal mediation analysis framework developed by Imai, Keele, & Tingley (2010). Although causal mediation analysis does not completely differ from traditional mediation analysis in terms of modeling perspective, it is based on a potential outcomes framework and offers methods that allow for the evaluation of assumptions necessary to reveal the causal effect of a mediator (Chi et al. 2022, p. 2).

Mediation analyses were performed using two models:

- **Mediator Model:** EC ~ GDP
- **Outcome Model:** CO_2 ~ GDP + EC

In the mediation analyses conducted using a combination of these two models, the results were obtained using the nonparametric bootstrap method (500 repetitions). This method provides reliable results, especially when the sample size is small or the distributions are not normal (Preacher & Hayes 2004, pp. 721-722).

According to the findings in Table 7, in terms of indirect effect, the indirect effect of GDP on CO_2 through EC is negative and significant at the 10% significance level (p = 0.068). This finding shows that an increase in GDP indirectly reduces CO_2 emissions through energy consumption. Therefore, the indirect effect of GDP presents a positive sign in terms of environmental sustainability. Approximately 73.8% of the mediation occurs through EC (p = 0.022). Thus, it is seen that a large part of GDP's effect on CO_2 emissions occurs through EC; in other words, the mediation effect is strong.

Secondly, it was tested whether the effect of the other independent variable, trade openness, on carbon emissions occurs indirectly through energy consumption. The analysis was conducted using the causal mediation framework developed by Imai et al. (2010), and the results were obtained using the nonparametric bootstrap method.

Model B: TO → EC → CO_2

Table 8. Results of the intermediary analysis of energy consumption for trade openness and carbon emissions

Type of impact	Estimate	Lower Confidence (90% CI)	Upper Confidence (90% CI)	p-value	Significance
ACME	0.00187435	-0.00059488	0.00467101	0.096	***
Mediation Rate	0.02700836	-0.00849825	0.06568786	0.112	***

- ACME: 0.0018, p = 0.096
- Mediation Rate: %2.7, p= 0.112

All processes in Model A have been repeated for Model B. The regressions used in the model are as follows:

- **Mediator Model:** EC ~ TO
- **Outcome Model:** CO_2 ~ TO + EC

As shown in Table 8, in terms of indirect effect, although the indirect effect of TO on CO_2 via EC is quite small (0.00187), it is statistically significant (p = 0.096). In terms of the mediation ratio, it was found that only 2.7% of the total effect occurred via EC. Although this indicates that the mediation mechanism is weak, the mediation effect is not statistically significant at the 10% significance level (p = 0.112). Therefore, in this model, it is understood that the effect of TO on CO_2 is largely direct. Many studies in the literature support this finding (Alper, 2018; Öztürk & Saygın, 2020; Özdemir & Koç, 2020; Akbulut Bekar & Terzi, 2018). These studies emphasize the positive effect of TO on CO_2.

5. Conclusions and Recommendations

Increased human activity following the Industrial Revolution has led to serious environmental concerns today. This situation has brought research aimed at reducing human impact or finding solutions to the forefront, and work in this area has steadily increased. Studies on the determinants of CO_2 emissions have long held an important place in the literature, and the persistence of environmental problems keeps this interest alive. In this context, the current study empirically tests the main determinants of CO_2 emissions, such as trade openness, economic growth, and energy consumption. The mediating role of energy consumption in this relationship is examined to offer a different perspective to the literature. To this end, data obtained from relevant databases for the period 1965-2022 were analyzed using the R program.

The findings obtained as a result of the study can be summarized as follows. It was determined that the effect of GDP on both energy consumption and CO_2 emissions is negative and significant. Therefore, research hypotheses H_1 and H_3 are supported. This is consistent with the findings of studies such as Dogan & Turkekul (2016), Destek & Sarkodie (2019), Pata (2021), and Kasperowicz (2015), which found a negative relationship between growth and CO_2 emissions in Turkey or indicated that growth provides environmental benefits after a certain stage within the framework of the Environmental Kuznets Curve (EKC). Pata (2021), and Kasperowicz (2015). On the other hand, the research findings contradict the findings of Korkmaz & Develi (2012), Mitić, Ivanović, & Zdravković (2017), and Akın Özdemir (2024). Furthermore, energy consumption was found to play a significant mediating role in the effect of GDP on CO_2 emissions, thus supporting hypothesis H_6. It was determined that approximately 73.8% of this mediating effect occurred through energy consumption.

The effect of trade openness on energy consumption and CO_2 emissions was found to be positive and significant. Therefore, research hypotheses H_2 and H_4 are supported. When examined in terms of the mediating effect, the mediating role of energy consumption in the effect of trade openness on CO_2 emissions was not found to be statistically significant. Therefore, the H_7 hypothesis is not supported. The direct effect of the mediating variable alone on CO_2 is negative and statistically significant. This result is similar to the findings of the study conducted by Agasalim (2024). On the other hand, this result does not coincide with the results of other studies in the literature (Arı & Zeren 2011; Çetintaş, Bicil, & Türköz 2016; Efeoğlu 2022; Kızılkaya, Sofuoğlu, & Çoban 2016; Yücesan, Yağış, & Torun 2019).

It has been stated that 73.8% of Turkey's CO2 emissions in 2023 will come from the energy sector (TÜİK, 2025). Turkey has adopted the transition to a sustainable and circular economy model based on resource efficiency as one of its top priorities in line with its net zero emissions target for 2053. In this context, the "Green Deal Action Plan" has been put into effect. The action plan envisages concrete actions in areas such as reducing carbon emissions, increasing the use of renewable energy, and promoting the circular economy (TB, 2021). In the energy sector specifically, sustainable resource management, increasing energy and resource efficiency, and applying circular economy principles will contribute to reducing emission intensity.

The findings of this study and the policies that can be recommended in line with Turkey's action plans are as follows: First, production processes in Turkiye must be restructured to increase energy efficiency. Considering that the indirect effect of GDP on carbon emissions occurs largely through energy consumption, ensuring that energy consumption is efficiency and sourced from environmentally friendly resources is critical for environmental sustainability. In particular, the direct effect of energy consumption on reducing CO_2 emissions highlights the importance of increasing the share of renewable energy sources.

The effect of trade openness on increasing CO_2 emissions necessitates aligning foreign trade policy with environmental concerns. In this context, it is recommended to encourage the import and export of products with a low carbon footprint and to consider practices such as border carbon adjustments. Furthermore, additional studies using microdata at the sectoral level to clarify the direct and indirect effects of energy consumption on the environment will contribute to the development of more specific strategies for policymakers. At the same time, faster transformation at the national level can be achieved through sectoral improvements. Future research could expand the investigation of the intermediary effect of energy consumption using different methods and make significant contributions to the literature by

revealing this effect for different periods and countries. For research to be conducted specifically on Turkey, different independent variables could be added to the study to produce more comprehensive studies, thereby enabling different recommendations to be made to policymakers.

Araştırmacıların Katkı Oran Beyanı / Contribution of Authors

Yazarların çalışmadaki katkı oranları Sinan BAĞDAŞ %50/ Gamze ŞEKEROĞLU %50 şeklindedir.
The authors' contribution rates in the study are Sinan BAĞDAŞ %50/ Gamze ŞEKEROĞLU %50 form.

Çıkar Çatışması Beyanı / Conflict of Interest

Çalışmada herhangi bir kurum veya kişi ile çıkar çatışması bulunmamaktadır.
There is no conflict of interest with any institution or person in the study.

İntihal Politikası Beyanı / Plagiarism Policy

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Bu çalışmada Yükseköğretim Kurumları Bilimsel Araştırma ve Yayın Etiği Yönergesi kapsamında belirtilen kurallara uyulmuştur.
In this study, the rules specified within the scope of the Higher Education Institutions Scientific Research and Publication Ethics Directive were followed.

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