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AN ASSESSMENT BETWEEN ECONOMIC DEVELOPMENT AND ENVIRONMENTAL SUSTAINABILITY IN TÜRKİYE: THE RELATIONSHIP BETWEEN HUMAN DEVELOPMENT INDEX AND ENERGY CONSUMPTION

TÜRKİYE'DE EKONOMİK KALKINMA İLE ÇEVRESEL SÜRDÜRÜLEBİLİRLİK ARASINDA BİR DEĞERLENDİRME: İNSANİ GELİŞME İNDEKSİ VE ENERJİ TÜKETİMİ İLİŞKİSİ

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ARTICLE INFO	ABSTRACT
Received 01.12.2025 **Revized** 18.01.2026 **Accepted** 17.03.2026 **Article Classification:** Research Article **JEL Codes** F63 Q10 Q43	*The competitive environment created by the integration of world economies and the idea of high growth at the expense of development have led to the emergence of various problems in the world. In this context, the production structures and development levels of countries have been called into question in terms of their results. The rapid growth processes in the world have caused negative effects such as climate change, air pollution, and global warming, especially on nature and the environment, which has led to increasing concern about future generations. The concept of sustainable development, which was developed due to increasing concerns regarding environmental degradation, supports the idea of a more liveable and sustainable environment by increasing the level of prosperity and living standards of current and future generations. In this context, the relationship between human development and energy consumption in Turkey is evaluated from the perspective of sustainable development and environmental sustainability, based on the worldview of sustainable development. The study utilised data on human development, carbon dioxide emissions, renewable energy production, and fossil fuel consumption—key indicators of sustainable development and environmental sustainability—to conduct a cointegration analysis. According to the cointegration test results, it was concluded that renewable energy consumption and fossil fuel consumption in Turkiye affect the human development index.* **Keywords:** *Economic Development, Environmental Sustainability, Energy Economics, Sustainable Development*

MAKALE BİLGİSİ	ÖZ
Gönderilme Tarihi 01.12.2025 **Revizyon Tarihi** 18.01.2026 **Kabul Tarihi** 17.03.2026 **Makale Kategorisi** Araştırma Makalesi **JEL Kodları** D21 K42 Q58	*Dünya ekonomilerinin birbirlerine entegre olma sürecinde yaşanan rekabet ortamı ile gelişmişlik pahasına hedeflenen yüksek büyüme düşüncesi, dünyada çeşitli sorunların ortaya çıkmasına neden olmuş ve bu çerçevede ülkelerin üretim yapılarının ve gelişme düzeylerinin sonuçları itibariyle sorgulanmasına neden olmuştur. Dünyada yaşanan yüksek hızlı büyüme süreçleri özellikle doğa ve çevre üzerinde iklim değişikliği, hava kirliliği, küresel ısınma vb. gibi olumsuzluklara neden olarak gelecek nesillere ilişkin kaygıların artmasına neden olmuştur. Artan kaygılar ve yaşanan çevresel bozulmalar neticesinde ortaya konulan sürdürülebilir kalkınma görüşü, bugünkü nesiller ile gelecek nesillerin refah düzeylerinin ve yaşam standartlarının artırılarak daha yaşanabilir ve sürdürülebilir bir çevre düşüncesini desteklemektedir. Bu çerçevede sürdürülebilir kalkınmaya ilişkin dünya görüşünden hareketle Türkiye'de insani gelişme ve enerji tüketimi ilişkisinin sürdürülebilir kalkınma ve çevresel sürdürülebilirlik bakış açısıyla değerlendirilmesi amaçlanmaktadır. Yapılan çalışmada sürdürülebilir kalkınma ve çevresel sürdürülebilirliğe ilişkin önemli göstergeler olan insani gelişme, karbondioksit emisyonu, yenilenebilir enerji üretimi ve fosil yakıt tüketimi verilerinden yararlanılarak eş bütünleşme analizi yapılmıştır. Yapılan eş bütünleşme test sonuçlarına göre Türkiye'de yenilenebilir enerji tüketimi ile fosil yakıt tüketiminin insani gelişme indeksini etkilediği sonucuna ulaşılmıştır.* **Anahtar Kelimeler:** *Ekonomik Gelişme, Çevresel Sürdürülebilirlik, Enerji Ekonomisi, Sürdürülebilir Kalkınma*

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Introduction

Due to technological developments worldwide, the trend of globalisation has increased and gained momentum over the years. This process has brought changes in many areas, including the economy, politics, art, culture, and the environment. Changes in these areas have increased the level of dependency between countries and led to greater integration. Developments in the globalisation process have also caused various environmental problems worldwide. In the early stages, these environmental problems were overlooked in favour of development and growth, with priority given to increasing production. However, in subsequent periods, the rise in production driven by industrialisation and competition changed the scale of environmental degradation, contributing to its emergence as a global problem. This process has led to the development of sustainable development discourses and has added a new dimension to globalisation, resulting in an increase in global trends focused on the environment (Kaypak, 2011). Indeed, the environmental problems arising from industrial production and population growth have changed people's perspectives on nature and the environment, leading to increased efforts to address environmental issues as environmental awareness has grown within society. Unlike in the past, environmental problems have acquired a global character, and as countries have become more interdependent, the mechanisms by which they influence each other have grown stronger. These developments have paved the way for the emergence and advancement of sustainable development thinking (Yılmaz, 2018). When assessed historically, it is evident that developments in the post-World War II period and the competitive environment created by development classifications among countries have contributed to the emergence of environmental issues. Since then, it has been discussed that economic growth which harms the environment negatively affects human welfare. Consequently, there is consensus that an economic growth strategy which takes environmental factors into account will positively affect human well-being. However, the economic development process – which includes factors such as individual welfare, social welfare, quality of life, health, environmental conditions, and increases in income and production – has limited economic growth in sustainability discussions. The concept of sustainable development, defined within this framework, highlights that the interests and benefits of future generations are as important as those of the current generation. Accordingly, as today's environmental conditions and natural resources are the common denominator between current and future generations, individuals living today cannot disregard the interests and benefits of future generations. Therefore, they do not have the right to unlimited use of environmental and natural resources. These statements, attributed to Anand and Sen (2000), are significant in demonstrating that sustainable development is based on the welfare of both individuals and society. It is stated that increase in individual and social welfare are possible through improvements in human development. Thus, it is argued that economic growth alone is insufficient to enhance the welfare of individuals and society, and that social welfare will increase and human development will be achieved by improving education, health, and nutrition, and by reducing crime rates in society alongside economic growth. For this reason, human development indicators are considered important parameters for determining the development levels of countries and for expressing welfare criteria (Bucak, 2021).

Another development in sustainable development was the inclusion of the concept in the report of the World Commission on Environment and Development, published in 1987. Sustainable development is defined as the use of natural resources in a way that considers the needs of future generations without depleting them (Kaypak, 2011). According to The United Nations, the concept of sustainable development is based on two assumptions. The first is the concept of needs, which refers to the priority needs of people living in poverty worldwide. The second is the concept of limitations, which refers to the restrictions that technology and development place on human needs and the environment. The concept of sustainable development was emphasised at the Millennium Summit held by the United Nations in 2000. At this summit, United Nations member states adopted a series of proposals focused on individuals and people rather than states, and published them in the Millennium Declaration. In the Millennium Declaration published in 2001, the following aims were set:

- Combating hunger and extreme poverty
- Providing universal primary education
- Ensuring gender equality
- Reducing child mortality
- Maternal health improvement measures
- Fight against infectious diseases
- It is aimed to ensure environmental sustainability (Gedik, 2020).

The inclusion of environmental sustainability among the goals set out to ensure sustainable development in the Millennium Declaration demonstrates that environmental pollution and degradation are priorities for the United Nations, alongside other factors. This also underscores the importance of environmental sustainability in achieving sustainable development. Environmental sustainability can be defined as maintaining and protecting environmental, economic, and social conditions that fulfil the expectations of future generations, resulting from harmony between humans and the natural environment. In other words, meeting human needs without compromising a healthy environment or ecosystem constitutes environmental sustainability (Gedik, 2020).

While sustainable development in developing countries is generally associated with social development issues such as combating poverty, creating a competitive market structure, and increasing investment in education and health services, in developed economies it is expressed as protecting the environment and ensuring social welfare through clean environmental policies. However, today, both developing and developed countries face the problem of global climate change. For this reason, environmental issues such as sea-level rise, soil erosion, and the spread of water and service-related disasters resulting from global climate change affect not only developed countries but also developing economies. These environmental problems cause more severe impacts and destruction in developing countries. Additionally, another issue faced by developing economies is the food supply problem caused by excessive population growth. Rapid industrialisation aimed at achieving swift economic development in both developed and developing economies, along with the use of primary (fossil) fuels in production, accelerates environmental degradation, increase natural destruction, and endangers the continuity of essential production resources (Kaypak, 2011).

In recent years, energy has been regarded as one of the main factors in ensuring social and economic development worldwide. However, the fact that energy resources are limited and continually decreasing globally has led countries to reconsider their energy policies. On a global scale, energy consumption increases by 2% each year. This rise is driven by the continuous growth of economies, population increases, and changes in living standards. The increase in energy consumption leads to the depletion of energy resources and a decline in energy efficiency. The reduction in energy efficiency, in turn, accelerates environmental degradation and results in increased environmental problems such as global warming, ozone layer depletion, and acid rain. The energy mix consumed worldwide generally consists of primary (fossil) fuels. This has contributed to increased environmental pollution and destruction, particularly with the rise in industrial production. Therefore, to ensure sustainability in the production process and achieve sustainable development, continuity in the reproduction process must be maintained. In this way, production capacity for both current and future generations can be secured by preserving the core of the resources used in production and considering the capacities of environmental factors (Selici et al., 2005). In fact, the energy factor, regarded as the main driving force of the production structure in all countries, is also identified as an element that accelerates environmental degradation. As a component of production and consumption activities in various forms, energy is important for its effects on ecological balance. Thus, the negative impact of energy consumption on the environment significantly affects sustainable development. For this reason, energy consumption is described as a strategic environmental factor (Yücel, 2003).

The success of countries' economies is generally evaluated by examining their economic growth and development performance. This situation increases the competitiveness and economic ambitions of countries to achieve high growth rates. However, the fact that human needs are unlimited while resources are scarce highlights the necessity for all countries to consider environmental factors in the growth and development process. Determining growth strategies that prioritise environmental policies will support the ecological growth process by contributing to sustainable development and growth with low carbon emissions (Bucak, 2021). For this reason, renewable energy production gains strategic importance in ensuring sustainable development and ecological sustainability (Aydın, 2018).

1. Literature

In this study, the relationship between economic development and environmental sustainability in Turkey is evaluated in the context of human development and energy consumption. Some recent national and international studies with similar aspects have been examined. Martinez and Ebenhack (2008) analysed the relationship between the United Nations Human Development Index (HDI) and per-capita energy consumption for 120 countries and concluded that there is a strong correlation between the Human Development Index (HDI) and per-capita energy consumption. Wu et al. (2010) analyzed the relationship between Human Development Index (HDI) and per capita energy consumption, and concluded that the effect of energy consumption on human development differs according to the socio-economic development levels of countries. In his study analysing the cointegration and causality relationship between energy consumption and Human Development Index (HDI) for 15 developing countries in the 1988-2008 period, Ouedraogo (2013) concluded that there is no causality relationship between energy consumption and HDI in the short run, but energy consumption has a one-way causal effect on HDI in the long run. Beşer et al. (2017) analyzed the relationship between environmental degradation and economic growth through the environmental Kuznets curve based on the data of 170 countries, and concluded that there is no relationship between carbon emissions and human development index. Aytun et al. (2017), in their study in which they analyzed the effect of environmental degradation on economic development in developing countries, concluded that environmental degradation decreases as the development levels of countries increase in the analyzes made between 1980-2010 based on the data of 10 developing countries. Akizu-Gardoki et al. (2018) concluded that the ecological footprint should be reduced to develop sustainable energy policies in their studies, in which they evaluated the divergence between human development and energy consumption within the scope of the ecological footprint and analysed the sustainability performance of countries and regions. Yıldırım and Nuri (2018) analysed the relationship between renewable energy sources and sustainable development and concluded that energy transformation should be achieved to ensure sustainable development. Van Tran et al. (2019) analyzed the interrelationship between energy consumption, carbon dioxide emissions and human development in terms of economic development levels, and concluded that the effects of energy consumption and carbon emissions on human development differ at different levels of economic development. Çınar et al. (2019) analyzed the impact of energy consumption on sustainable development in Turkey, and it was observed that there was a positive relationship between economic development and energy consumption in Turkey between 1970-2017. In the study by Wang et al. (2020), in which the relationships between biomass energy consumption and human development in BRICS (Brazil, Russia, India, China, and South Africa) countries were analysed, they concluded that there is a long-term cointegration relationship between biomass energy consumption and human development. Bucak (2021) analyzed the relationships between economic complexity, human development and carbon emissions in EU15 countries, and concluded that there is a long-term relationship between the variables and causality relationships are observed. Oluç (2023) analysed the relationships between the multidimensional human development index, economic growth, and energy consumption in Turkey and concluded that there is a long-term relationship between the carbon-free footprint and human development. In his study, in which he analysed the dynamics of environmental sustainability, Kara (2024) concluded that waste management activities and climate change indicators are effective for sustainable development. Özen et al. (2024) analyzed the relationship between human development, carbon emissions, agricultural development, urbanization and industrial development in Turkey, and concluded that there is a bidirectional causality relationship between human development index and carbon emissions. In his study analysing the relationship between the human development index as an indicator of economic sustainability and greenhouse gas emissions, which refers to environmental degradation, Durgun (2024) concluded that no relationship was found between human development and environmental degradation.However, Akyazı and Korkmaz (2024) concluded that there is a causality relationship between human development, energy consumption and carbon dioxide emissions and the green economy in their study analysing the relationship between the green economy and human development. Kutlu (2024), in his study in which he analyzed the sustainable development process based on human development and renewable energy consumption, concluded that the developments in the human development index in the long-term support environmental sustainability. Türköz (2025) analysed the relationships between human development, energy consumption, economic complexity, and environmental degradation based on the idea of seeking innovative solutions within the framework of the climate change problem and concluded that energy consumption, economic complexity, and human development significantly increase environmental degradation in Turkey. Bolayır and Eroğlu (2025) analysed the effects of recycling rates on sustainable development in Turkey between 2010-2020 and concluded that recycling rates positively affect sustainable development. Akın and Akçayır (2025) analysed the impact of sustainable development and renewable energy consumption on green production potential in MIST countries and concluded that sustainable development and renewable energy consumption affect production potential.

The studies exemplified above in the literature show the complex and multidimensional relationship between human development, energy consumption, environmental degradation, and sustainable development. This study aims to analyse regional and country-specific factors in more depth to better understand these dynamics and develop sustainable policies.

2. Dataset and Model

This study analyses the relationship between human development and energy consumption within the context of economic development and environmental sustainability in Turkiye. It aims to evaluate economic development and environmental policies based on energy consumption and carbon dioxide emission data. In this study, data on human development, carbon dioxide emissions, renewable energy, and primary (fossil) fuel consumption in Turkiye from 1990 to 2022 were used. The variables used in this study were obtained from the Our World in Data database. The definitions of the data included in the analysis are presented in the table below.

Table 1: Variable Definitions

Variable Name	Variable Definition
Human development index (HDI)	A criterion that expresses the basic dimensions of human development, such as a long and healthy life, a good education, and a decent standard of living
Carbon Dioxide Emission (CO_2)	Emission factor showing the average CO_2 output per unit of energy (% change)
Renewable Energy (RE)	Hydroelectric, solar, wind, geothermal, bioenergy, wave and tidal energy factors (% change)
Fossil Fuel Consumption (FFC)	Primary energy (fossil fuel) consumption (% change)

The linear model, which shows the relationship between the variables used in the analysis, is explained in the table;

$$\text{HDI}=\beta_0+\beta_1\text{RE}+\beta_2\text{FFC}+\beta_3 CO_2+\varepsilon_t \quad (1)$$

It is expressed as. In the analysis of the relationships between the variables in the model, the Johansen Cointegration and Vector Error Correction test was used, considering the stationarity levels of the variables. The next section explains the Johansen Cointegration and Vector Error Correction test.

3. Johansen Cointegration Test

In time series models, cointegration tests are used to test the long-term relationships between variables. Cointegration tests, on the other hand, have a different application structure according to the stationarity levels of the series. If the series are stationary in difference (I(1)), the cointegration relationship between the series can be analyzed with the Johansen cointegration test. The Johansen cointegration test has the ability to test long-term relationships between series using the maximum likelyhood method. Johansen in the co-integration method;

$$Xt=\mu+\Pi 1+Xt\text{-}1+...+\Pi_{kXt\text{-}k+\varepsilon t} \quad (2)$$

Based on the X_t unrestricted vector autoregression process defined as such, the VECM model derived with an nx1 dimensional vector consisting of n variables, an nxn dimensional Π parameter vector, and k lag order;

$$\Delta X_{t=}\ \mu+X\Gamma_1\Delta_{t-1+...+}\Gamma_{k-1}\Delta Xt\text{-}k_{+1+}\ \Pi Xt\text{-}k+\varepsilon t \quad (3)$$

It can be defined as. The constant term in the equation μ represents the series with the error vector ε_t and the difference Δ (Polat and Günay, 2014: 207).

4. Granger Causality Test

The Granger causality test was first proposed by C.W.J. Granger in 1969 and introduced into the literature. This study is called the Granger causality test because it tests the causal relationships between variables. In this context, the causality relationship between two stationary series with a fixed mean and constant variance can be tested using the Granger causality test. Therefore, to test the causality relationship between two time series, such as and, it is necessary that the series are stationary at the same level and aware [I(1)]. Therefore, in the process of testing the causality relationship between the series, it is necessary to use the stationary forms of the series used in the analysis. Therefore, the differences in the series are taken before the Granger causality test is applied (Çalış at al., 2022). Another condition in the Granger causality test is that the appropriate delay length must be determined before the analysis. Determining the appropriate delay length in the analysis is important for the test to yield reliable results (Kubar and Toprak, 2021). This is because the Granger causality test was developed as a hypersensitive model to the delay length criterion. Therefore, the Akaike (AIC) and Schwarz (SIC) information criteria are used to select the appropriate delay length while performing the Granger causality test (Erkekoğlu and Gül). After selecting the appropriate delay length, a causality analysis was performed. If the causality analysis yields meaningful results, the direction of causality is determined (Kubar and Toprak, 2021). Based on these explanations, the causality relationship between the series whose differences are taken in a model with two variables such as Y_t and X_t;

$$X_t=\sum_{j=1}^{m} a_j X_{t-j}+\sum_{j=1}^{m} b_j Y_{t-j}+\varepsilon_t \quad (4)$$

$$Y_t=\sum_{j=1}^{m} c_j X_{t-j}+\sum_{j=1}^{m} d_j Y_{t-j}+u_t \quad (5)$$

It is defined as. The terms ε_t and u_t in the model are called random error terms and refer to the parts that the model cannot explain. The terms, $a_j,\ b_j,\ c_j$ and d_j are considered as coefficients expressing the effect of the past values of the time series in the analysis on the current value. In this context, if $b_j \neq 0$, then Y_t is expressed as a Granger cause of X_t. Similarly, if $c_j \neq 0$, then X_t is evaluated as a Granger cause of Y_t (Granger, 1969).

5. Vector Error Correction Model (VECM)

The Vector Error Correction Model (VECM) was developed by Engle and Granger in 1987 to distinguish between long- and short-term relationships between series. Based on the VECM model, it can be determined whether the series encounter any shocks in the long term (Gökçe and Babacanoğlu, 2020: 169). At the same time, the common trends and dynamics of two or more interrelated time series can be analyzed with the VECM model. According to this model, by determining the long-run relationships of the series, the balancing process of short-run deviations can also be predicted. In this case, long- and short-term causality relationships between the series can be analyzed and the imbalance between the variables can be corrected. In addition, the VECM model derives more stable results in the presence of a cointegration relationship between the series. Errors obtained from the VECM model refer to temporary long-term deviations in the series. These temporary deviations indicate that the deviations of the previous period may affect the relations of the next period. Therefore, the VECM model ensures the balancing of series through the error correction mechanism (Ceyhan et al., 2023: 449).

6. Results of Empirical Application

In this study, which analyzes were made using human development index, carbon dioxide emission, renewable energy production, and fossil fuel consumption data between 1990-2022 in Turkey, descriptive statistics on the variables used in the analysis were first tested. The descriptive statistics are presented in the table below.

Table 2: Descriptive Statistics

Variables	HDI	CO_2	RE	FFC
Mean	0.721667	4.019715	13.167536	6.983370
Median	0.711000	4.056938	13.090420	7.007647
Maximum	0.855000	5.340025	19.008345	7.586863
Minimum	0.598000	2.790932	8.2382720	6.330265
Standard error	0.085635	0.818349	2.7356805	0.392295
Skewness	0.148599	0.011633	0.2612694	-0.013676
Kurtosis	1.622475	1.572381	2.7443374	1.771113

The descriptive statistics in the table show the mean, median, maximum, minimum, standard error, skewness, and kurtosis values of the data used in the analysis. These values provide information on the distribution and central tendency of the dataset used in the analysis. After the descriptive statistics, stationarity analyses should be performed to choose the method to be used to determine the relationship between the series. In this context, ADF (Augmented Dickey Fuller) and PP (Philips Perron) unit root tests for the variables in the analysis are given in the table below.

Table 3: ADF And PP Unit Root Test Results

Unit Root Test	ADF		PP	
Variables	Level I(O)	Difference I(1)	Level I(O)	Difference I(1)
HDI	0.219950	-4.538354***	0.112614	-4.537824***
CO_2	-0.849147	-6.0111591***	-0.715013	-9.076142***
RE	-1.754655	-6.449209***	-1.653842	-6.586488***
FFC	-0.655867	-7.128975***	-0.825383	-8.069010***

***, **, * signs express 1%, 5%, 10% significance levels, respectively.

According to the results of the ADF and PP unit root tests in the table, the series are stationary in the difference. According to the results obtained from the unit root test, the Granger causality test can be used to test the causal relationship between variables. Accordingly, the results of the Granger causality test, which is used to analyse the causal relationship between variables, are given in table below.

Table 4: Granger Causality Test Results

Variables	Chi-Square Test	Causality Relationship
$D(CO_2)$=>D(HDI)	4.5219*	**Granger causality exists**
D(RE)=>D(HDI)	1.0237	There is no granger causality
D(FFC)=>D(HDI)	4.6676*	**Granger causality exists**
D(HDI)=>D()CO_2	1.2237	There is no granger causality
D(HDI)=>D(RE)	5.5495**	**Granger causality exists**
D(HDI)=>D(FFC)	2.7498	There is no granger causality

***, **, * signs express 1%, 5%, 10% significance levels, respectively.

According to the results of the Granger causality test in the table, it was concluded that there is a one-way causality relationship from carbon dioxide and fossil fuel consumption to the human development index, and a one-way causality relationship from the human development index to renewable energy consumption. According to the results of the unit root test, it was determined that the series were not stationary at their level values, but became stationary when their first differences were taken (I(1)). Since the series were cointegrated of the same order, the Johansen Cointegration Test was preferred to examine the long-term relationship between them. The number of cointegration vectors was determined by considering the Trace and Maximum Eigenvalue statistics. The analysis results showing the Johansen Cointegration relationship are presented in the table below.

Table 5: Johansen Cointegration Test Results

H0	Eigenvalue	Trace	%5 Critical Value	Max-Eigen	%5 critical Value
r=0	-	93.56	47.21	55.96	27.07
r≤1	0.8548	37.59	29.68	24.42	20.97
r≤2	**0.5693**	**13.16***	**15.41**	**9.22***	**14.07**
r≤3	0.2725	3.93	3.76	3.93	3.76

***, **, * signs express 1%, 5%, 10% significance levels, respectively.

When examining the Johansen cointegration test results in the table, both the Trace and Maximum Eigenvalue statistics reject the hypotheses that ‘there is no cointegration (r=0)’ and ‘there is at most 1 cointegration (r≤1)’ at the 5% significance level. However, the hypothesis that ‘there are at most 2 cointegration vectors (r≤2)’ cannot be rejected (13.16<15.41). These findings prove that there are 2 cointegration (long-term equilibrium) relationships between the variables included in the model. Within this framework, as the analysis revealed the existence of cointegration relationships between the variables, a Vector Error Correction Model (VECM) was established to analyse both the short-term and long-term relationships between the variables simultaneously. Akaike (AIC) information criterion was used to determine the most appropriate lag length in the VECM model. Consequently, as two cointegration vectors were identified in the analysis, the normalised long-term coefficients are presented in the table below.

Tablo 6: Normalised Long-Term Cointegration Coefficients

Independent Variables	Model 1 (HDI)	Model 2 (CO_2)
RE	0.0051*** *(0.0015)*	- 0.6120*** *(0.1045)*
FFC	- 0.1800*** *(0.0083)*	1.9208*** *(0.5596)*
Constant	-0.658	12.068

***, **, * signs express 1%, 5%, 10% significance levels, respectively.

The long-term equations obtained according to the VECM results in Table 5 are defined as follows:

Model 1: HDI = 0.0051YE- 0.1800FYT −0.658

Model 2: CO_2= -0.612YE + 1.921FYT +12.068

The findings of Model 1 indicate that a 1-unit increase in renewable energy in the long term leads to an approximate 0.005-unit positive increase in the Human Development Index (HDI). In contrast, a one-unit increase in fossil fuel consumption has a negative effect of 0.180 units on the human development index, and this relationship is statistically significant (p<0.01). When evaluating the results of the second model, it is noticeable that the direction of the relationship between the variables has changed. In this model, it was found that the renewable energy variable has a reducing (negative) effect on the dependent variable and an increasing (positive) effect on fossil fuel consumption, and that its coefficient is quite strong (1.921). The statistical significance of the coefficients in both models confirms the existence of long-term causality and interaction mechanisms between the variables.

Tablo 7: VECM Model Diagnostic Statistics

Equation	RMSE	R-Square (R2)	Chi-Square ($\chi 2$)	P-Value
ΔHDI	0.0061	**0.8347**	65.63	0.0000
ΔCO_2	0.2363	0.3806	7.98	0.9243
ΔYE	2.2576	0.4178	9.32	0.8596
ΔFYT	0.0553	0.5781	17.81	0.2725

When examining the model fit statistics, it is observed that the established VECM model has a very high explanatory power ($R^2 = 0.83$) for short-term changes in the HDI variable (ΔHDI). However, it was determined that the models for the other variables were not statistically significant ($p>0.05$). This situation indicates that the human development index variable plays an adaptive role in eliminating imbalances in the system, while the other variables may be 'weakly exogenous'. To ensure that the cointegration test results produce reliable and deviation-free results, there should be no autocorrelation, varying variance, and normal distribution problems in the model in the analysis. Therefore, the autocorrelation, varying variance, and normal distribution test results of the model established in the analysis are given in the table below.

Table 8: Autocorrelation, Varying Variance, and Normal Distribution Test Results

Test	Chi-square	Probability value
Breusch-Gordfrey test	20.62	0.1934
White test	18.92	0.1681
Jarque-Bera test	23.82	0.2030

There are no autocorrelation, varying variance, and normal distribution problems in the model established according to the results of the Breusch-Gordfrey autocorrelation test, White changing variance test, and Jarque-Bera normal distribution test in the table, and it can be said that the causality analysis produces reliable and stable results.

7. Conclusions

This study analyses the relationships between human development, energy consumption, and carbon dioxide emissions within the context of economic development and environmental sustainability in Turkey. The stationarity properties of the series were examined using the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. As the series are stationary at their first differences (I(1)), the long-term relationship between the variables was analysed using the Johansen Cointegration Test. The findings indicate the existence of two statistically significant cointegration vectors ($r \leq 1$) between the variables. This demonstrates a long-term and balanced relationship between energy consumption, environmental quality, and human development in Turkey. When evaluating the results of the Vector Error Correction Model (VECM), which was established to determine the coefficients of long-term and short-term relationships between the variables, the first model, where the Human Development Index (HDI) is the dependent variable, shows that an increase in renewable energy consumption has a positive and statistically significant effect on human development. In contrast, the effect of fossil fuel consumption on human development is negative and pronounced in terms of coefficient magnitude. This finding indicates that fossil fuel use in Turkey suppresses social welfare and human development through environmental damage, while renewable energy investments, although with low coefficients, have begun to contribute to social welfare. Examination of the model's diagnostic statistics shows that the Human Development Index plays a regulatory role in addressing imbalances in the system ($R^2 = 0.83$), while the other variables are exogenous. In conclusion, the empirical findings of this study reveal that reducing dependence on fossil fuels is essential for achieving sustainable development and full economic prosperity in Turkey. Fossil fuels degrade environmental quality and negatively affect human development. Increasing incentives for renewable energy sources will not only ensure environmental sustainability but also contribute to higher levels of human development. In this context, increasing investments in renewable energy can be considered a key policy tool for the Turkish economy to achieve a better balance in both environmental and social well-being by reducing dependence on fossil fuels. Furthermore, based on these results, it can be assumed that as social welfare and economic development increase in Turkey, investments in renewable energy production also rise. Therefore, although primary fuels are used in the production industry, it can be concluded that the trend towards renewable resources is increasing in parallel with the rise in social welfare. This demonstrates that the study's results are consistent with the policies implemented in the Turkish economy in recent years within the framework of sustainable development. Indeed, statistical indicators show that investments in renewable energy sources such as electricity and wind power have increased alongside economic growth and rising prosperity. Furthermore, the increase in renewable energy investments is crucial for achieving sustainable development and environmental sustainability, as well as reducing the country's dependence on fossil fuels, which is essential for attaining full economic independence.

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