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The Relationship Between Energy Consumption and Human Development Index: The Role of Electricity, Natural Gas and Oil Consumption

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Abstract: The objective of this study is to empirically analyze the effects of electricity, natural gas, and oil consumption on the Human Development Index (HDI) in Turkey and to offer policy recommendations within the scope of sustainable development. To this end, unit root tests were applied to the time series data for electricity, natural gas, oil consumption, and HDI covering the 1990–2022 period, followed by the ARDL cointegration test to reveal the model's long- and short-run effects. According to the cointegration test results, a statistically significant relationship was observed in the short run between the one-period lagged value of oil consumption and the current period value of electricity consumption. While the one-period lagged value of oil consumption negatively affected the HDI in the short run, the current period value of electricity consumption affected it positively. In the long run, a significant relationship was found only between HDI and electricity consumption, with electricity consumption having a positive effect on the HDI. The impact of oil consumption on the HDI is transitory and becomes evident in the subsequent period. Electricity consumption, on the other hand, creates a stronger positive effect on the HDI in the long run rather than the short run.

Keywords: Human Development Index, Energy Consumption, Sustainability, ARDL Cointegration Test

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1. Introduction

Since the dawn of human history, energy needs have been regarded as an indispensable element for the survival of the human race, the procurement of sustenance, and the facilitation of physical and biological development [1]. However, over the years, these rudimentary perspectives on the concept of energy have been supplanted by more complex considerations. The concept of energy gained a broad field of application, particularly with the Industrial Revolution. The energy demand, which became increasingly intricate following the Industrial Revolution, led to an intensified human dependence on energy in daily life. Factors such as rapid technological advancement, the growth trajectories of economies, population growth, and the subsequent rise in housing needs, transportation requirements, and industrialization have caused a precipitous increase in energy demand. Today, energy consumption is utilized as an indicator of the social and economic development of nations. Nevertheless, the chaotic environment following the Industrial Revolution caused countries to undergo a difficult economic period. During this era, nations entered a process of rapid growth and development, evaluating economic and social progress solely through the lens of economic growth [2-3].

Until the 1970s, the concept of development was largely conceptualized and evaluated solely through per capita national income. The reliance on per capita income alone to explain national welfare drew significant criticism. Foremost among these criticisms was the notion that the level of per capita national income remains insufficient in explaining development on its own. Consequently, after the 1980s, the concepts of development and advancement were integrated, transforming "development" into a concept that encompasses not only economic progress but also human development [4]. Following this shift, in the 1990s, the concept of human development began to be utilized as a welfare indicator for countries, transcending per capita national income. The concept of human development first emerged as data in 1990 under the title of the Human Development Index (HDI), introduced by the Pakistani economist Mahbub ul Haq. The Human Development Index (HDI) was first introduced in the 1990 Human Development Report published by the United Nations Development Programme (UNDP). The index is constructed based on three core dimensions: life expectancy, education, and income. Specifically, it combines indicators of life expectancy at birth, educational attainment, and gross national income per capita. The HDI is calculated as the geometric mean of these three dimensions and is published annually at the country level, providing a broader measure of development that incorporates education and health alongside national income [5-6-7-8].

The objective of this study is to empirically analyze the effects of electricity, natural gas, and oil consumption on the Human Development Index in Türkiye and to offer policy recommendations within the scope of sustainable development. The primary motivation for selecting Türkiye as the sample of this study lies in the parallel trajectory observed over the past three decades between the country's rising HDI performance and the structural transformation of its energy consumption patterns. As an emerging economy striving to achieve sustainable development goals, Türkiye's demand for and dependence on energy resources have steadily increased. In this context, Türkiye provides a relevant case for examining how major energy sources, namely electricity, natural gas, and oil, influence welfare, access to healthcare, and educational outcomes. A review of the existing literature indicates that most studies focus on the relationship between aggregate energy consumption and the HDI. To provide greater analytical depth and address this gap in the literature, the present study disaggregates total energy consumption and concentrates specifically on electricity, natural gas, and oil consumption.

In Türkiye, electricity, natural gas, and oil consumption constitute approximately 82% of total energy consumption. The gradual substitution of fossil fuels by electricity and the increasing share of renewable energy sources in electricity generation are of critical importance for energy independence [9-10]. Beyond energy independence, this situation positively affects the HDI through the dimension of a long and healthy life by minimizing the environmental impacts caused by fossil fuels [11]. Furthermore, the role of electricity in healthcare services, education, and economic activities is gaining increasing importance. It is evident that electricity plays a critical role in the HDI, as it enhances the living comfort and welfare levels of individuals in all areas of daily life [12-13]. The type of resources used in electricity generation in Türkiye is significant for the HDI. In a scenario where fossil fuels are heavily utilized in electricity production, environmental problems may arise.

Moreover, disruptions in energy supply or fluctuations in energy prices would adversely affect economic stability, thereby negatively impacting the HDI. In a scenario where the share of renewable energy sources in electricity generation is high, a positive effect on the HDI is expected by minimizing the negative impacts of environmental issues and energy dependency.

While the share of natural gas and oil resources in Türkiye's total energy consumption was 50% in 2000, this figure has risen to 62% today. This situation can negatively affect the HDI through health and quality of life by causing environmental issues [14]. The production of such intensely consumed resources also becomes vital. The limited production of natural gas and oil in Türkiye leads to nearly all of these İtwo resources being supplied through imports. The fact that Türkiye is a resource-poor country in terms of natural gas and oil reserves, combined with the intensive consumption of these two sources, poses a challenge for energy security. This situation could hinder the achievement of sustainable development goals by negatively affecting Türkiye's economic stability in the event of even the slightest problem in energy flow. While natural gas and oil consumption can have such negative effects on the HDI, positive effects can also be observed. Natural gas and oil are fundamental energy sources used in the manufacturing sector [15]. The growth of these sectors increases the income levels of individuals, leading to a rise in living standards and a positive impact on the HDI. Natural gas, on the other hand, meets heating needs, particularly in residential areas and health facilities. This situation is thought to positively affect the HDI by improving the quality of healthcare services and ensuring healthy living conditions [16].

In the subsequent sections of the study, a literature review related to the subject will be presented. Following the literature review, the effects of electricity, natural gas, and oil consumption on the Human Development Index will be examined in line with the study's objective. Subsequently, the dataset and the model will be introduced, followed by the methodology and econometric findings. In the conclusion section, the empirical findings will be discussed, and energy-specific policy recommendations will be made, taking into account the effects of electricity, natural gas, and oil resources on the Human Development Index.

2. Literature Review

Access to energy resources constitutes a critical issue for emerging economies such as Türkiye. Energy functions not only as a production input but also as a fundamental determinant of human development, as reflected in the Human Development Index (HDI), which incorporates education, healthcare, and living standards. In this regard, examining how the composition of energy consumption influences the HDI is essential for designing effective energy policies and translating them into broader social welfare gains.

Niu et al. (2013) analyze the causal relationship between electricity consumption and the HDI for 50 countries classified by income groups over the period 1990–2009, employing panel data techniques. Their empirical framework includes variables such as the HDI, GDP per capita, consumption expenditures, urbanization rate, life expectancy at birth, and adult literacy rate. The findings indicate that electricity consumption exerts a positive and statistically significant effect on the HDI in high-income countries [9].

Ouedraogo (2013) investigate the relationship between energy consumption, electricity consumption, and the human development index for 15 developing countries between 1988 and 2008 using panel data analysis. In this framework, the HDI was designated as the dependent variable, while total energy consumption, electricity consumption, and Brent crude oil prices were used as independent variables. It was observed that total energy consumption and electricity consumption had little effect on the HDI in the short run. In the long run, however, it was concluded that while there is a negative cointegration relationship between total energy consumption and the HDI, a positive cointegration relationship exists between electricity consumption and the HDI [14].

Wang et al. (2018) investigate the relationship between renewable energy consumption, economic growth, and the Human Development Index in Pakistan for the period 1990–2014. Their empirical model includes carbon emissions, renewable energy consumption, economic growth, trade openness, and urbanization as explanatory variables. The results suggest that renewable energy consumption and carbon emissions positively contribute to the HDI, while trade openness, economic growth, and urbanization have a negative effect on human development [17].

Adekoya et al. (2021) examine the effect of renewable energy consumption and carbon emissions on the human development index by dividing 126 countries into 8 regions for the period 2000–2014 through panel data analysis. It was observed that renewable energy consumption affects the human development index in most regions, though results vary by region. Specifically, it was concluded that renewable energy consumption negatively affects the HDI in the MENA, Central America, and Caribbean regions, while having a positive impact on the European region. Furthermore, carbon emissions were found to have a positive effect on the human development index across all regions [18].

Türkmen & Naimoğlu (2021) aimed to test the hypothesis of the necessity of energy use for poverty reduction and the improvement of life quality in Türkiye, considering the period 1990–2019 and utilizing variables such as energy consumption, energy prices, and the human development index. The findings indicate that energy consumption is a significant variable for increasing the human development index in the long run, whereas the index shows minimal response to energy price changes. In the short run, it was concluded that energy consumption affects the HDI positively in the current period but negatively in its lagged value, while energy prices remained ineffective [19].

Kaewnern et al. (2023) employ panel data analysis for a group of countries ranked among the top ten in the Human Development Index, namely Norway, Switzerland, Ireland, Germany, the People's Republic of China, Australia, Iceland, Sweden, Singapore, and the Netherlands, over the period 1996–2007. The study investigates the impact of economic growth, renewable energy consumption, research and development (R&D) expenditures, and total natural resource rents on the HDI. The empirical findings indicate that all independent variables exert a positive effect on human development. In addition, the results reveal a unidirectional causality running from the HDI to renewable energy consumption and R&D expenditures, as well as a bidirectional causal relationship between the HDI and economic growth [20].

Durgun (2023) observed the relationship between total energy consumption and the human development index in Türkiye using time series analysis, considering data from 1990 to 2021. According to the cointegration test results, a cointegration relationship was found between the variables. In the long run, the effect of energy consumption on the human development index is positive and significant. According to causality test results, there is a unidirectional causal relationship from energy consumption to the human development index in the long run [21].

Akpolat, A. G. and Bakırtaş, T. (2024) studied the BRICS countries together with Egypt, Iran, and Türkiye for the period 1990–2021. Using panel data analysis, they examined the relationship between renewable energy consumption, fossil fuel consumption, carbon emissions, and the Human Development Index (HDI). Their results show a U-shaped relationship between renewable energy consumption and the HDI. This means that renewable energy may have a negative or weak effect on human development at low levels, but its effect becomes positive after a certain point. They also found an inverted U-shaped relationship between fossil fuel consumption, carbon emissions, and the HDI. In other words, fossil fuels and carbon emissions may support human development at first, but after reaching a certain level, they start to harm it [22].

Akyazı, S. and Korkmaz, İ. (2024) examined the relationship between the green economy and the Human Development Index in Türkiye between 1990 and 2018. They used variables such as HDI, energy consumption, green patents, and carbon emissions. According to the Granger causality test results, the HDI is a Granger cause of energy consumption, green patents, and carbon emissions. This means that changes in human development help predict changes in these variables [23].

Kutlu, Ş. Ş. (2024) examined the effects of human development and renewable energy consumption on environmental sustainability in Türkiye for the period 1990–2020. The study used variables such as ecological footprint, the Human Development Index (HDI), renewable energy consumption, and industrial sector value-added. The findings show that, in the long run, human development improves environmental sustainability by reducing the ecological footprint [24].

Akın, F. and Dinçer, S. (2025) conducted a panel data analysis for newly industrialized countries, including Brazil, China, India, Indonesia, Malaysia, Mexico, the Philippines, South Africa, Thailand, and Türkiye, covering the period 1990-2022. The study analyzed the effects of renewable energy consumption and the Human Development Index on economic growth. The results show that both renewable energy consumption and the HDI have a positive and significant effect on economic growth. At the country level, renewable energy consumption positively affects growth in China, India, Indonesia, and Türkiye. The study also found a two-way (bidirectional) causality between the HDI and economic growth, and between the HDI and renewable energy consumption [25].

3. Econometric Analysis

In this section, information regarding the dataset and the model to be utilized in the analysis will be provided first. Subsequently, the econometric methodology will be discussed, followed by the econometric analysis phase in accordance with the objective of the study.

3.1. Dataset and Model

An econometric model has been established to test the relationship between the HDI and energy consumption. In the constructed model, the variables of the Human Development Index, electricity consumption, natural gas consumption, and oil consumption were employed to examine the impact of energy consumption on the HDI. The Human Development Index serves as the dependent variable, while electricity consumption, natural gas consumption, and oil consumption variables are utilized as independent variables. To reduce the risk of heteroscedasticity caused by the large scale and high variation in energy consumption data, the natural logarithms of these variables were taken. This transformation also helps the data become more stable. In contrast, since the Human Development Index (HDI) is already a normalized index ranging from 0 to 1, it was included in the model in its original level form. The econometric model of the study was tested using the following equation:

$$HDI_t = \beta_0 + \beta_1 LNELEC_t + \beta_2 LNNAT_t + \beta_3 LNOIL_t + \varepsilon_t \quad (1)$$

In the model, β_0 represents the constant term, β_1, β_2 and β_3 denote the partial regression coefficients of the model, and ε_t refers to the error term. Detailed information regarding the other variables is presented in Table 1.

Table 1. Information on Variables

Name	Description	Type	Period	Source
HDI	Human Development Index	-	1990-2022	UNDP
LNELEC	Electricity Consumption	Bin TEP	1990-2022	EİGM
LNNAT	Natural Gas Consumption	Bin TEP	1990-2022	EİGM
LNOIL	Oil Consumption	Bin TEP	1990-2022	EİGM

Reference: [26-27].

Data on electricity consumption, natural gas consumption, and oil consumption were obtained from the General Energy Balance tables of the General Directorate of Energy Affairs (EİGM), while the Human Development Index was sourced from the United Nations Development Programme (UNDP) statistical databases. The variables utilized in the study consist of annual data covering the period 1990–2022, each comprising 33 observations.

Table 2. Descriptive Statistics of Variables

	HDI	LNELEC	LNNAT	LNOIL
Mean	0.7217	4.0443	3.9045	4.4615
Median	0.7110	4.0874	4.0430	4.4410
Maximum	0.8550	4.3882	4.4752	4.6457
Minimum	0.5980	3.5941	2.8520	4.2950
Standard Deviation	0.0856	0.2463	0.4449	0.1024
Skewness	0.1486	-0.2847	-0.5766	0.5002
Kurtosis	1.6225	1.8504	2.3866	2.2641
Jarque- Bera	2.7306	2.2629	2.3462	2.1210
Prabability	0.2553	0.3226	0.3094	0.3463
Observations	33	33	33	33

Table 2 presents the descriptive statistics for the variables. Between 1990 and 2022, the average Human Development Index value for Türkiye was 0.7217. Considering this multi-year average, it is possible to state that Türkiye is among the countries exhibiting high human development. The standard deviations of the series are notably low, indicating that the majority of the data points are clustered around the mean. Among the energy sources, natural gas exhibits the highest standard deviation at 0.4449, whereas the series with the lowest standard deviation is oil, at 0.1024.

3.2. Econometric Methodology

The unit root tests developed by Dickey and Fuller (1979) are applied not only to first order autoregressive processes but also to higher order autoregressive processes. A first order autoregressive model is constructed as follows [28].

$$Y_t = \Phi_1 Y_{t-1} + \varepsilon_t \tag{2}$$

Here, the error term (ε_t) is expected to be a clean sequence. However, if the variables do not fit the first order autoregressive model, then contrary to what is expected, there will be autocorrelation in the error term. Therefore, this problem of autocorrelation in the error terms should be eliminated. Dickey and Fuller (1981) developed the Dickey and Fuller (1979) unit root test to eliminate the autocorrelation problem in the error term, and lagged values of the dependent variable were added to the model. This was an attempt to eliminate the autocorrelation problem in the error term. This model is called the Augmented Dickey-Fuller unit root test [28-29-30].

Augmented Dickey-Fuller equations are written as follows to test for the presence of a unit root in the series:

$$\triangle Y_t = \delta Y_{t-1} + \sum_{j=1}^{p} \delta_i \triangle Y_{t-j} + \varepsilon_t \tag{3}$$

$$\triangle Y_t = \mu + \delta Y_{t-1} + \sum_{j=1}^{p} \delta_i \triangle Y_{t-j} + \varepsilon_t \tag{4}$$

$$\triangle Y_t = \mu + \beta t + \delta Y_{t-1} + \sum_{j=1}^{p} \delta_i \triangle Y_{t-j} + \varepsilon_t \tag{5}$$

When we look at these three equations, equation (3) refers to the test equations without constant term and trend, equation (4) includes constant term, and equation (5) includes both constant and trend. In this case, these tests are called Augmented Dickey-Fuller unit root tests [31-32].

In the Dickey-Fuller unit root test, it is assumed that the distribution of shocks is statistically independent and their variance is constant. In other words, it is assumed that there is no autocorrelation between shocks. Phillips-Perron (1988) developed a nonparametric unit root test in their study. In this study, Phillips-Perron improves these assumptions developed by Dickey-Fuller and Augmented Dickey-Fuller and makes a new assumption about the distribution of randomly occurring shocks. Three different equations can be developed for the Phillips-Perron unit root test. However, a simple equation for the Phillips-Perron test can be given as follows [33].

$$Y_t = \mu + \Phi_1 Y_{t-1} + \varepsilon_t \tag{6}$$

$$(1 - \Phi_1 L) Y_t = \mu + \varepsilon_t$$

In this equation, the unit root for the model is found with $1/\Phi_1$. When $\Phi_1 = 1$, the series contains unit root, which means that the series is non-stationary. In the Dickey-Fuller unit root test, the τ (tau) test will be used, while in the Phillips-Perron unit root test it will be expressed as Z_a. The formula used for the PP unit root test is given below.

$$Z_a = T(\Phi_1 - 1) - CF \tag{7}$$

Here CF is used as correction factor. In this context, if the test statistic calculated in equation (7) is greater than the critical value, it is concluded that the series contains unit root, that is, it is non-stationary [34].

Zivot Andrews (1992) constructed the test with the assumption that the break time is unknown. While Perron (1989) estimates the break time as an exogenous variable in the model, in Zivot Andrews approach, the break time is estimated as an endogenous variable in the model. According to Zivot Andrews, estimating the break time as an exogenous variable in the model will change the test results in the direction of no unit root. In the Zivot Andrews approach, the break time is assumed to be at any point. Zivot Andrews unit root test Model A (Intercept) allows for a break in level, Model B (Trend) allows for a break in trend and Model C (Intercept and Trend) allows for a break in both level and trend [35-36].

Model A $$Y_t = \mu + \beta t + \Phi_1 Y_{t-1} + \gamma_2 DU_t(\lambda) + \sum_{j=1}^{p} \delta_j \triangle Y_{t-j} + \varepsilon_t \quad (8)$$

Model B $$Y_t = \mu + \beta t + \Phi_1 Y_{t-1} + \gamma_3 DUM_t(\lambda) + \sum_{j=1}^{p} \delta_j \triangle Y_{t-j} + \varepsilon_t \quad (9)$$

Model C $$Y_t = \mu + \beta t + \Phi_1 Y_{t-1} + \gamma_2 DU_t(\lambda) + \gamma_3 DUM_t(\lambda) + \sum_{j=1}^{p} \delta_j \triangle Y_{t-j} + \varepsilon_t \quad (10)$$

Here, DU_t denotes a dummy variable at the level, while DUM_t denotes a break in slope. μ is the intercept and ε_t is the error term.

In Johansen and Engle-Granger cointegration tests, variables are expected to be stationary at the same degree. In addition, ignoring lagged values of variables in Johansen and Engle-Granger cointegration tests leads to specification errors. Pesaran and Shin (1995) and Pesaran et al. (2001) proposed an autoregressive distributed lag (ARDL) model instead of using equations for cointegration relationship. Thus, the ARDL model has started to be used as a model that allows us to examine the cointegration relationship between variables that are stationary of different degrees. The ARDL model has advantages such as allowing us to perform cointegration tests on variables that are stationary at different degrees and providing statistically more reliable results by using the unconstrained error correction model [37-38]. The following process is followed to explain the ARDL model.

$$Y_t = a + \sum_{j=1}^{k} a_i Y_{t-j} + \sum_{j=0}^{k} \beta_i X_{t-j} + \varepsilon_t \quad (11)$$

After determining the lag length of the model, the bounds test is applied to determine whether there is a cointegration relationship between the variables. As a result of the bounds test, the F-statistic value is obtained. When this value is compared with the lower and upper critical values, it is concluded whether there is a cointegration relationship between the series. If the F-statistic value obtained here is greater than the upper critical value, there is a cointegration relationship between the variables, if it is less than the lower critical value, there is no cointegration relationship between the series, and if it is between the lower and upper critical values, no comment can be made on whether there is a cointegration relationship between the series.

3.3. Econometric Findings

To reveal the long-term and short-term relationships between the series, stationarity tests will be conducted first. The integration levels of the series will be determined through stationarity testing, and the appropriate cointegration method will be selected based on these results to perform the long-term and short-term analysis of the model.

3.4. Unit Root Test Results

In econometric analysis, non-stationary series lead to various issues, most notably the problem of spurious regression. In a model suffering from spurious regression, the R^2 value appears higher than its actual value, which calls the reliability of the study into question. Therefore, unit root tests are a prerequisite for the model to yield statistically more reliable results. This prerequisite also plays a decisive role in selecting the specific analytical methods to be applied to the model. In addition to traditional unit root tests, this study also utilizes unit root tests that account for structural breaks. The hypotheses for the unit root tests are formulated as follows:

H_0: The series contains a unit root (the series is non-stationary).

H_1: The series does not contain a unit root (the series is stationary).

Table 3. Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) Unit Root Test Results

	ADF				**PP**			
	Level		**First Difference**		**Level**		**First Difference**	
	Intercept	Intercept and Trend	Intercept	Intercept and Trend	Intercept	Intercept and Trend	Intercept	Intercept and Trend
HDI	0.2200	-1.9134	-4.5384[a]	-4.4714[a]	0.1126	-2.1734	-4.5378[a]	-4.4735[a]
LNELEC	-2.4826	-0.9552	-4.5574[a]	-5.2453[a]	-7.3937[a]	-0.1016	-4.5746[a]	-11.7205[a]
LNNAT	-3.5520[b]	-3.7102[b]	-4.4006[a]	-4.6965[a]	-4.2885[a]	-4.1301	-4.4994[a]	-8.2757[a]
LNOIL	-0.5180	-1.9898	-6.0602[a]	-5.9399[a]	-0.4703	-1.9963	-6.0559[a]	-5.9368[a]
Critical Values								
1%	-3.6537	-4.2733	-3.6617	-4.2846	-3.6537	-4.2733	-3.6617	-4.2846
5%	-2.9571	-3.5578	-2.9604	-3.5629	-2.9571	-3.5578	-2.9604	-3.5629

Note: The optimum lag length in the ADF Unit Root Test is determined according to the Schwarz Information Criterion and the optimum bandwidth in the Phillips-Peron Unit Root Test is determined according to the Newey-West Bandwidth method. The letters a and b indicate that the series is statistically significant at the 1% and 5% significance level, respectively.

Table 3 presents the results of the traditional unit root tests. According to the ADF and PP unit root tests, the null hypothesis was rejected for the HDI and LNOIL variables after taking their first differences, indicating that these series are stationary. For the LNNAT series, both tests concluded that the variable is stationary at its level value. Regarding the LNELEC series, while the ADF test indicated stationarity at the first difference, the PP test suggested that the series is stationary at levels. Consequently, based on the ADF and PP unit root test results, it was concluded that the HDI and LNOIL series are integrated of order one I(1), whereas the LNNAT and LNELEC series are integrated of order zero I(0).

Another reason for the non-stationarity of series containing a unit root is that shocks to the series leave a permanent effect. Put differently, in the presence of structural breaks, traditional unit root tests like ADF and PP, which do not account for such breaks, tend to yield results favoring the acceptance of the null hypothesis (i.e., that the series is non-stationary). Therefore, in addition to traditional unit root tests, Zivot-Andrews and Lee-Strazicich unit root tests, which incorporate structural breaks, were applied to the series.

Table 4. Results of Zivot-Andrews and Lee-Strazitch Unit Root Test with Breaks

	Zivot-Andrews				**Lee-Strazitch**			
	Level		**First Difference**		**Level**		**First Difference**	
	Model A	Model C	Model A	Model C	Model A	Model C	Model A	Model C
HDI	-3.66	-4.55	-5.61[a]	-6.22[a]	-2.412	-10.045[a]	-4.518[a]	-7.305[a]
Structural Break	2010	2013	2016	2019	2002 2015	2006 2011	2006 2017	2008 2011
LNELEC	-2.99	-3.20	-5.64[a]	-5.54[b]	-2.193	-5.215	-5.533[a]	-6.359[b]
Structural Break	1999	2006	2004	2004	2013 2018	1999 2004	1997 2005	1997 2000
LNNAT	-4.99[b]	-4.26	-5.34[a]	-6.21[a]	-1.471	-6.253[b]	-4.00[b]	-7.727[a]
Structural Break	2003	2005	1998	2003	2011 2017	1998 2003	1996 2001	2001 2008
LNOIL	-5.46[a]	-4.64	-3.65	-5.38[b]	-3.075	-9.410[a]	-6.482[a]	-7.145[a]
Structural Break	2015	2015	2011	2015	2000 2014	1999 2013	1996 2011	1998 2012
Critical Values								
1%	-5.34	-5.57	-5.34	-5.57	-4.073	-6.821	-4.073	-6.821
5%	-4.93	-5.08	-4.93	-5.08	-3.563	-6.166	-3.563	-6.166

Note: The letters a and b indicate that the series is statistically significant at 1% and 5% significance level, respectively.

According to the results of both unit root tests that account for structural breaks presented in Table 4, the null hypotheses for the LNNAT and LNOIL series were rejected, concluding that they are stationary at their level values. While the ADF and PP tests suggested that the LNOIL series was non-stationary at levels, the Zivot-Andrews (ZA) and Lee-Strazicich (LS) tests—which incorporate structural breaks—asserted that the series is stationary at levels. In fact, while the LNOIL series is stationary at its level value, it was observed that a "spurious non-stationarity" existed due to the structural breaks within the series. According to the ZA test, the LNELEC and HDI series became stationary after their first differences were taken. Regarding the LS test, which accounts for two breaks, the LNELEC series became stationary at the first difference, whereas the HDI series was found to be trend-stationary at its level value. Consequently, the ZA and LS break-incorporating unit root tests yielded results consistent with the ADF and PP tests, with the exception of the LNOIL series.

The ZA and LS unit root test results in Table 4 indicate that the variables experienced structural breaks in similar years. The most striking structural break date in the table is 2011. This year represents a period when the Turkish economy grew by approximately 9%, and industrial production along with household welfare reached peak levels. This high growth performance created a break in the LNELEC, LNNAT, LNOIL, and HDI series. For the LNELEC and LNNAT series, break dates are clustered around 2003, 2004, and 2005. The implementation of the Energy Market Law in 2003 led to the liberalization of the energy sector and its rapid expansion. Particularly after 2003, the expansion of natural gas infrastructure for the purpose of resource diversification led to a rapid increase in the share of natural gas in energy consumption. This process, which began with the liberalization of the energy sector, structurally influenced the electricity and natural gas consumption series.

The ZA unit root test identifies 2015 as the break date for the LNOIL series. In 2015, there was a surge in US shale oil production. Meanwhile, OPEC did not reduce oil production as part of its strategy to protect market share. The simultaneous occurrence of these two situations caused an unprecedented supply glut in global energy markets. Concurrently, developments such as the decline in growth rates in Asian and European countries and the subsequent decrease in energy demand led to a drop in oil prices of approximately 80 dollars/barrel. The fall in oil prices resulted in lower production and logistics costs, creating a structural break for the LNOIL series in 2015.

3.5. ARDL Cointegration Bound Test Results

Based on the unit root test results, the ARDL (Autoregressive Distributed Lag) Cointegration Bound Test was employed to examine the long-term and short-term relationships between the variables. In the ARDL bound test, the primary requirement is to determine the optimal lag length of the model. Prior to identifying the optimal lag, the maximum lag length to be utilized in the model must be established. The accurate specification of the lag length is of vital importance for the reliability of the model. The determination of the maximum lag length varies depending on the data type and the sample size used in the study. Due to data constraints and the use of annual data, the maximum lag length in this study was set to 2, and the Schwarz Information Criterion (SIC) was utilized for model estimation. After determining the maximum lag length and the information criterion, the most appropriate model for the ARDL cointegration bound test was identified as the ARDL(1, 0, 0, 1) model. The hypotheses for the cointegration test are formulated as follows:

H_0: There is no cointegration relationship between the series

H_1: There is a cointegration relationship between the series.

Once the appropriate model is determined in the ARDL cointegration test, a Bound Test is applied to establish whether a cointegration relationship exists between the variables. In the bound test, if the F-statistic value is greater than any of the upper bound critical values, the null hypothesis is rejected, and it is concluded that a long-term cointegration relationship exists between the variables.

Table 5. ARDL (1,0,0,1) Model Bound Test Results

			Critical Values	
k	**F-Statistic**	**Significance Level**	*Lower Bound (I0)*	*Upper Bound (1)*
3	10.0420[a]	%1	3.65	4.66
		%5	2.79	3.67

Note: *k* denotes the number of independent variables. The letters *a* and *b* indicate statistical significance at the 1% and 5% levels, respectively. The lower and upper bound critical values were obtained from Table CI(ii) Case II in the study by Pesaran et al. (2001), [38].

Table 5 presents the results of the ARDL (1,0,0,1) model bound test. Since the calculated F-statistic value exceeds the upper bound critical value at the 1% significance level, the null hypothesis is rejected. Consequently, it is concluded that a cointegration relationship exists between electricity consumption, natural gas consumption, oil consumption, and the Human Development Index during the period under study.

Table 6. ARDL (1,0,0,1) Model Long-Run and Short-Run Estimation Results

Long-Run Coefficients				
Variable	*Coefficient*	*Standard Error*	*t-Statistic*	*Probability*
LNELEC	0.7925[a]	0.2219	3.5719	0.0013
LNNAT	-0.1627	0.1124	-1.4478	0.1588
LNOIL(-1)	-0.3635	0.2698	-1.3473	0.1887
C	-0.1911	0.8415	-0.2271	0.8220
Short-Run Coefficients				
Variable	*Coefficient*	*Standard Error*	*t-Statistic*	*Probability*
HDI(-1)	-0.2090[b]	0.0910	-2.2960	0.0303
LNELEC	0.1656[b]	0.0639	2.5919	0.0157
LNNAT	-0.0340	0.0267	-1.2720	0.2151
LNOIL(-1)	-0.0760[b]	0.0358	-2.1207	0.0440
C	-0.0399	0.1883	-0.2122	0.8337
D(LNOIL)	0.0034	0.0525	0.0650	0.9487
DUMMY	-0.0076[b]	0.0036	-2.1139	0.0447
ECT (-1)	-0.2090[a]	0.0274	-7.6318	0.0000
Diagnostic Test Results				
R^2			0.9966	
Adjusted R^2			0.9958	
Breusch-Godfrey Serial Correlation Test			3.1678 (0.2052)	
Jarque-Bera Normality Test			2.2517 (0.3243)	
F-statistic			1216.6 (0.0000)	
Breusch-Pagan-Godfrey Heteroscedasticity Test			8.2465 (0.2206)	
Ramsey RESET Test			0.5187 (0.4787)	

Note: The letters *a* and *b* denote that the series is statistically significant at the 1% and 5% levels, respectively. The values in parentheses represent the probability (p-values).

The long-run and short-run coefficient estimations of the ARDL (1,0,0,1) model are presented in Table 6. Upon examining the long-run coefficients, a cointegration relationship was previously identified between electricity, natural gas, and oil consumption and the HDI. When evaluating the long-run coefficients in the model, the one-period lagged value of oil consumption and the current-period value of natural gas consumption were found to be statistically insignificant. This indicates that a reliable and distinct relationship could not be established between oil and natural gas consumption and the HDI. Instead, this relationship manifests through indirect effects rather than direct ones. In essence, this suggests that the long-term impact of oil and natural gas on welfare is transmitted through electricity generation and their roles as intermediate inputs.

Conversely, the long-run relationship between electricity consumption and the HDI was found to be statistically significant at the 1% level. In other words, while other variables are held constant (ceteris paribus), a 1% increase in electricity consumption results in a 0.7925% increase in the HDI in the long run. This finding demonstrates that electricity is not merely a technical energy input; it functions as a fundamental leverage for the HDI, directly facilitating everything from healthcare services and the digitalization of education to high-value-added production.

In the short run, a positive cointegration relationship was identified between electricity consumption and the HDI, consistent with the long-run findings. While other variables are held constant, a 1% increase in electricity consumption results in a 0.1656% increase in the HDI. This indicates that while increases in electricity consumption are immediately reflected in the HDI, the impact remains more limited compared to the long-run effect. Furthermore, while only electricity consumption showed a statistically significant relationship with the HDI in the long run, the one-period lagged value of oil consumption was found to be statistically significant at the 5% significance level in the short run. However, the relationship between the lagged value of oil consumption and the HDI is negative. Specifically, ceteris paribus, a 1% increase in the one-period lagged value of oil consumption leads to a 0.0760% decrease in the HDI. It is considered that as the consumption of import-dependent resources like oil increases, although short-term economic growth may be achieved, this situation negatively affects purchasing power (the income component of the HDI) in the subsequent period through the channels of current account deficits and inflation.

Furthermore, the coefficient of the dummy variable, included exogenously to represent the identified structural break, was found to be negative and statistically significant at the 5% level. This result indicates that the period of structural break identified in the model (the shocks between 2005-2012) exerted downward pressure on the HDI. The Error Correction Term (ECT) was found to be negative and statistically significant at the 1% level, as expected. This confirms that the error correction mechanism is operational and that short-term deviations occurring in the model converge back to equilibrium in the long run. The error correction parameter was estimated at -0.2090. In other words, it is observed that 20.90% of a short-term deviation will be corrected in the following year, returning to long-run equilibrium. This implies that the effect of a deviation will completely dissipate after approximately five years.

According to the diagnostic test results, it was determined that the model does not suffer from issues such as serial correlation, heteroscedasticity, or functional form specification errors. Furthermore, the results indicate that the model's residuals exhibit a normal distribution and that the model possesses high explanatory power.

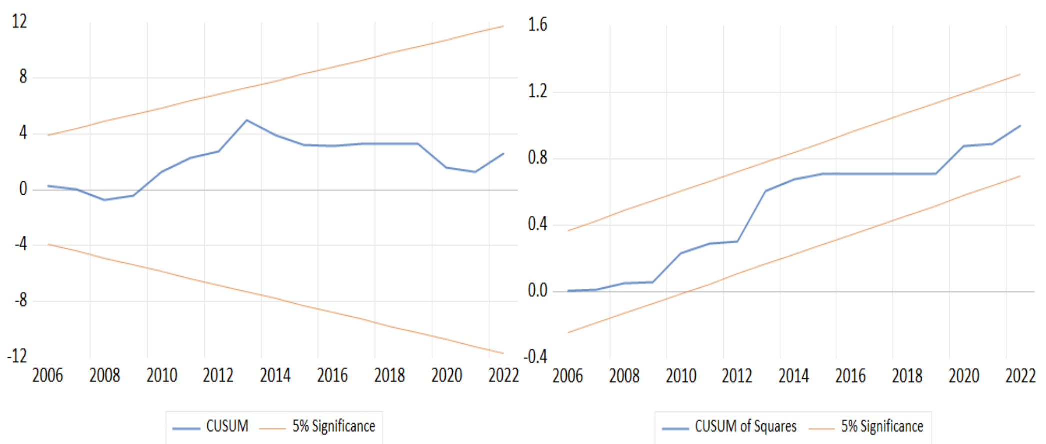

Figure 1. CUSUM and CUSUM-SQ Test Results (Status Prior to the Dummy Variable)

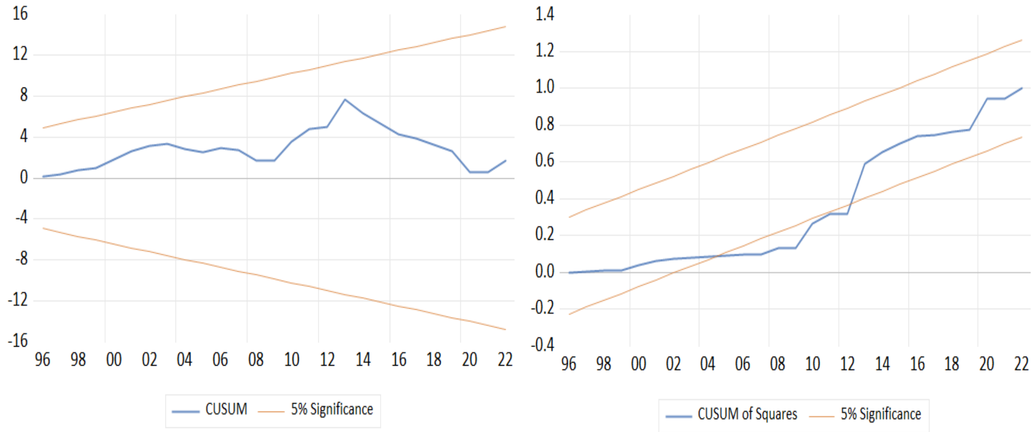

Figure 2. CUSUM and CUSUM-SQ Test Results (Status Post-Dummy Variable)

CUSUM-SQ tests were employed. The CUSUM-SQ test indicated a structural break between 2005 and 2012, as the statistics moved outside the critical boundaries (reference lines). To mitigate the effects of this structural break, a dummy variable was added to the model as an exogenous regressor. Following the inclusion of the dummy variable, both CUSUM and CUSUM-SQ tests demonstrated that the model's residuals remained within the reference lines, indicating that the model exhibits a stable structure. The CUSUM and CUSUM-SQ graphs before and after the inclusion of the dummy variable for the period in question are presented in Figure 1 and Figure 2.

4. Conclusion

When examining the literature on energy consumption and development, it is observed that studies predominantly focus on the economic dimension of development. Evaluating the concept of development solely through its economic aspect overlooks the dimension of human welfare, leading to an incomplete assessment of development. Consequently, studies focusing on energy consumption in relation to the Human Development Index (HDI), which considers all dimensions of development, have begun to contribute significantly to the literature. In this study, the relationship between electricity, natural gas, and oil consumption and the HDI in Türkiye over the 1990–2022 period was tested using ADF, PP, ZA, and LS unit root tests and the ARDL cointegration methodology.

According to the ARDL cointegration test results, a cointegration relationship was identified in the short run between the one-period lagged value of oil consumption, the current-period value of electricity consumption, and the HDI. In the long run, it was concluded that a cointegration relationship exists only between electricity consumption and the HDI. No cointegration relationship was detected between natural gas consumption and the HDI. In the short run, the effects of changes in oil consumption on the HDI manifest in the subsequent period. Although this effect negatively impacts the HDI in the short run, it is observed that this influence disappears in the long run. In this context, an increase in oil consumption creates a temporary negative effect on the HDI, affecting the index with a lag. There may be several reasons why oil consumption lacks a significant impact on the HDI in the long run or loses its influence over time. While the effects of oil consumption are felt in the short term, factors such as technological advancements and the transition to renewable energy sources in the long run may offset the impact of oil on the HDI. Alternatively, increasing societal awareness regarding environmental issues over time may lead to the elimination of the short-term negative effects of oil consumption on the HDI in the long-term equilibrium.

A robust cointegration relationship was identified between electricity consumption and the HDI. While the positive impact of electricity consumption on the HDI is limited in the short run, this effect becomes significantly more pronounced in the long run. In the short run, electricity consumption creates a positive—albeit limited—impact on the HDI by meeting instantaneous energy needs in healthcare, education, and daily life. Investments in electrical infrastructure and the successful integration of renewable energy sources into electricity generation enable electricity consumption to exert a more permanent and substantial positive influence on the HDI in the long run compared to the short run. The fact that improvements in electrical infrastructure, integration of renewable energy sources, and the associated economic transformations require time limits the short-run impact of electricity consumption on the HDI. However, the realization of these systemic changes over the long term causes the positive impact of electricity consumption on the HDI to become stronger and more significant.

This study demonstrates that the consumption of resources such as oil and natural gas, which have high import dependency in Türkiye, poses a challenge not only to energy security but also to the achievement of Türkiye's sustainable development goals. To attain these targets, policy-makers in Türkiye should prioritize focusing on electricity resources rather than oil and natural gas. In this context, prioritizing policies such as improving energy efficiency, transitioning to renewable energy sources, expanding access to electricity, shifting energy consumption habits, and reducing carbon emissions will play a crucial role in enhancing both the HDI and energy security. To promote energy efficiency, it is essential to raise public awareness and implement regulations aimed at increasing efficiency in sectors such as housing, industry, and transportation. Furthermore, technologies with high energy efficiency should be supported through tax incentives, favorable credit facilities, and subsidies. Incentive mechanisms must be developed to increase investments in renewable energy and to facilitate technological advancement. Simultaneously, Türkiye needs to set ambitious targets to increase the share of renewable energy sources in its electricity generation mix. Strengthening and expanding the electrical infrastructure, particularly by facilitating access in underserved areas, will also improve access to vital services such as education and healthcare in those regions. This situation will create a positive impact on the HDI. One of the most critical policies to be prioritized is the transformation of individual energy consumption habits. Raising public awareness is a task that must be carried out in tandem with energy conservation and environmental sustainability. Through education provided at homes, schools, and workplaces, society should be sensitized to environmental pollution and energy efficiency to foster long-term sustainable habits. Regarding the reduction of oil and natural gas consumption, the progressive taxation system—where higher consumption levels incur higher costs—should be maintained to encourage a shift in energy consumption patterns. The industrial sector also plays a pivotal role in the reduction of carbon emissions. While necessary awareness-raising activities must be conducted at the societal level, it is essential to develop and rigorously implement an Emissions Trading System (ETS) for the industrial sector.

When we compare our results with previous studies, our findings are similar to those of Niu, Shuai et al. (2013) and Ouedraogo, Nadia S. (2013), especially in showing that electricity consumption has a strong and positive effect on the Human Development Index (HDI). However, while Akpolat, A. G. and Bakırtaş, T. (2024) find an inverted U-shaped relationship between fossil fuels and the HDI, our results differ from theirs regarding natural gas consumption. In our study, natural gas and oil consumption do not have a direct long-term effect on human development in Türkiye. Instead, their impact appears to be indirect.

Although this study provides important findings on the relationship between energy consumption and the HDI in Türkiye, it has some limitations. First, the analysis covers only the period 1990–2022 and focuses on three main energy sources. Due to data limitations, renewable energy could not be included as a main variable in the econometric model. Future research could expand this study by using panel data analysis at the regional level within Türkiye or by comparing different groups of countries.

5. Patents

This research did not result in any patents.

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