Chapter 4

Are Energy Intensity, Total Primary Energy Consumption, Renewable Energy Consumption, and CO_2 Emissions a Driver for Economic Growth? Evidence from Turkiye

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Abstract

This primary purpose of this study is to investigate the impact of energy intensity (EI), total primary energy consumption per capita (EC), renewable energy consumption (REW) and CO_2 emissions, which are among the energy security elements, on GDP in Turkiye. Additionally, population (POP) and trade openness (TO) rates are control variables in the model. The analysis of the study consists of annual data from 1980 to 2022. The fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) approaches were used in this study to estimate long-term models. The study also employed the canonical cointegrating regression (CCR) method as a robust estimator. The estimated results of the study indicate that energy security has strongly affects on GDP in Turkiye. Accordingly, primary energy consumption, renewable energy consumption, and CO_2 emissions have positive effects on GDP. In addition, energy intensity affects GDP negatively, as expected. An energy policy that supports low energy intensity and high renewable energy consumption can be a pioneer of sustainable growth. However, the positive impact of primary energy consumption and CO_2 on GDP indicates that environmental degradation may increase in Turkiye's economic growth process. In other words, economic growth also depends on factors that cause energy insecurity. Therefore, it is important to develop policies that support energy security (high renewable energy consumption, low carbon emissions, low energy intensity, and low primary energy consumption). Moreover, as expected, trade openness and population support economic growth in Turkiye.

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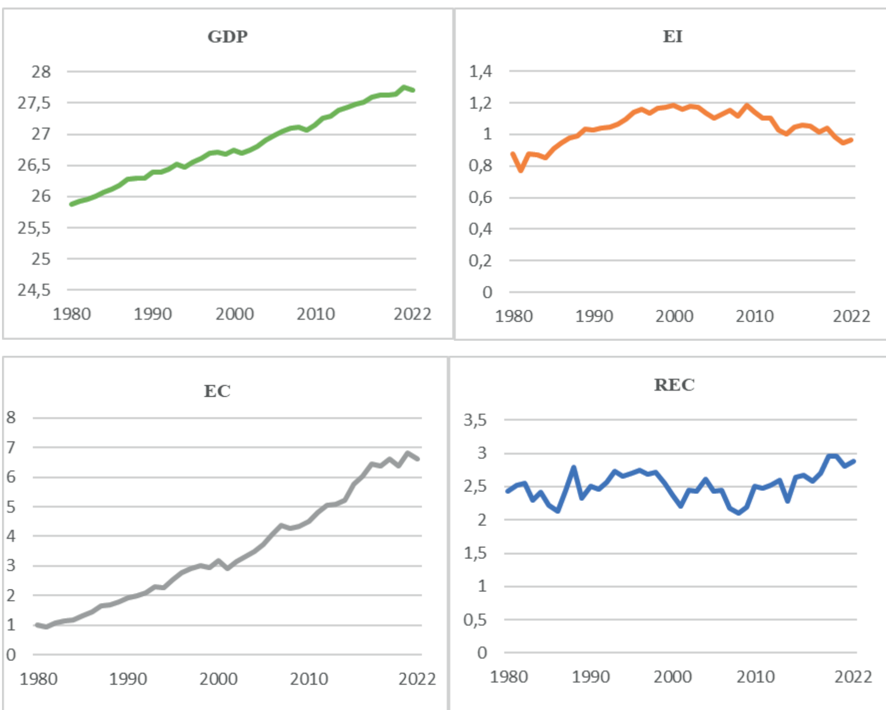
Introduction

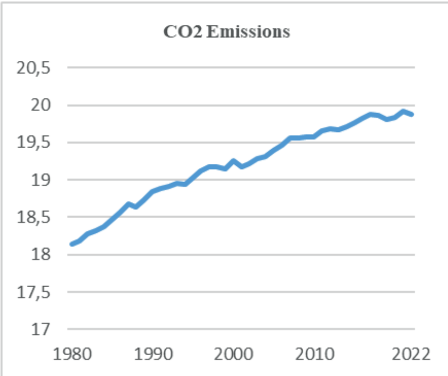
Energy security (ES) is significant to all stakeholders in an economy, especially politicians, consumers, and operators (Ang et al., 2015). Energy and ES are among the dynamics of sustainable development. ES refers to uninterrupted energy supply for sustainable growth. Therefore, there is a strong relationship between energy consumption and economic growth. In this direction, studies on the relationship between energy consumption and growth have gained momentum in the economic literatüre (Beckermen, 1992; Stern, 1993; Grossman ve Krueger, 1995; Apergis and Payne, 2009a,b; Belloumi, 2009; Pao, 2009; Wolde and Menyah, 2010; Stern, 2011; Bekhet et al., 2017; Stern, 2019; Kahia et al., 2017; Khan et al., 2020; Rahman and Velayutham; Support and Sinha, 2020).

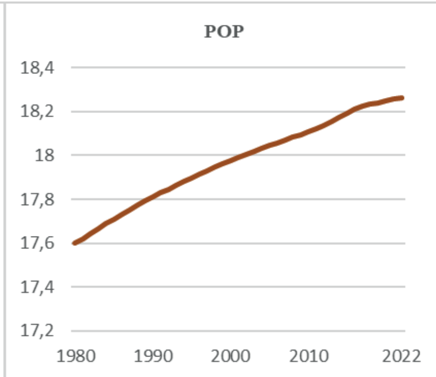
In addition to the importance of energy consumption on economic growth, the environmental impacts of the energy sector are also quite high (Kaynak et al., 10:2011). In the literature, studies on the relationship between energy consumption, economic growth and the environment are basically divided into three parts (Zhang and Cheng, 2009). The first part research area focuses on economic growth and environmental pollutants. The second part research area focuses on the relationship between energy consumption and output. The last research area combines the first two research areas and focuses on the relationship between economic growth, energy use, and environmental pollutants (Ozturk and Acaravcı, 2010). Because many countries are trying to meet their energy demand while struggling with increasing greenhouse gas emissions (Apergis et al., 2010). As a result of these efforts, the share of energy consumption from fossil energy sources in total energy consumption decreased from 94% to 80% (WDI, 2023). Carbon emissions caused by fossil-based energy consumption have increased from 15 billion tons to 37 billion tons in the last 50 years (Ritchie, 2022). In the same period, GDP increased more than four times. This indicate that environmental pollution increases together with economic growth. The economic effects of global warming and climate change as a result of increasing greenhouse gas emissions have become a popular subject of study (Zhang and Cheng, 2009; Ozturk and Acaravcı, 2010). During the same period, CO2 emissions in Turkey increased 10 times and reached 440 million tons from 42 million tons annually. The increased rate of carbon emissions in Turkey is five times higher than the world average. At the same time, Türkiye provides 1.2% of global total CO2 emissions. This situation also raises concerns about the environmental effects of energy consumption in Turkey. However, Turkey is a fast-growing and developing country, so rapid increases in emission volumes can be considered reasonable. Because

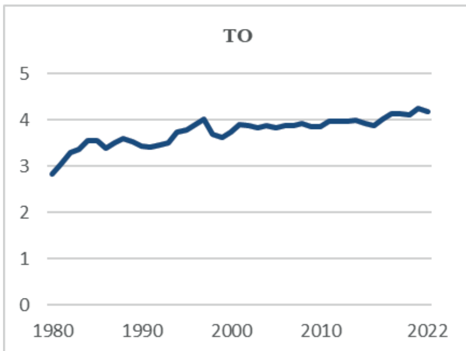
CO_2 emissions are increasing rapidly in countries with similar development levels as Turkey. Increasing energy consumption and CO_2 in Turkey also positively affects economic growth. According to the information in Table 1, it is seen that the increase in GDP in Turkey is parallel to the energy consumption. However, in addition to the increase in production and energy consumption, it is seen that CO_2 also increase significantly. In addition, since population growth provides the labor force required for production, population growth also moves together with economic production. Another point that draws attention here is that the REC shows high volatility. While this rate gradually increased between 1980 and 2000, it started to decrease after the 2000s. But this rate started to raise again after 2017. REC (% total energy consumption) is currently around 17%. This rate is expected to reach 23.7% in 2035 (T.R. Ministry of Energy and Natural Resources, 2022). EI started to decline after the 2000s. In other words, the amount of energy required for one unit of production has started to decrease. Using less energy for the same amount of production is a positive situation for a sustainable environment and economy. Therefore, low energy intensity, low carbon emissions and high renewable energy consumption are very important in the sustainable development process of an economy.

Table 1: Real GDP, EI, EC, REC, CO2, POP and TO (Natural Logarithm of All Variables)









The demand for renewable energy has begun to increase to reduce the environmental impacts resulting from such a rapid increase in fossil energy consumption. In this regard, academic studies on the relationship between clean energy and growth have gained momentum in recent years and renewable energy has become a popular topic (Pao ve Fu, 2013; Ocal ve Aslan, 2013; Kahia vd., 2017; Ntanos vd., 2018; Rahman ve Velayutham, 2020). Renewable energy is a more environmental energy source (Ocal and Aslan, 2013) and is also an alternative energy source for ES. For this reason, investments in renewable energy resources have begun to increase rapidly around the world, especially in developed countries.

It is difficult to give a single definition of ES (Alhajiji, 2007). Because ES included oil supply and fossil fuels in the 1970s. However, in later periods, with the widespread use of natural gas in the world, the scope and definition of ES changed (Jenny, 2007). Thus, ES has been associated with areas such as transportation, terrorism, environment, economy, natural disasters, prices, sustainability, social life and politics. Therefore, the basis of ES is based on efforts to ensure sustainable energy supply in all cases.

As studies on ES increase, the scope of ES has expanded. In this direction, a large literature focusing on the definition of ES has been created (Yergin, 1988; Bieleck, 2002; Yergin, 2006; Bahgat, 2006; Kruyt et al., 2009; Sovacool et al., 2010; Chester, 2010; Winzer, 2012; Cherp and Jevel, 2014; Andg et al., 2015). Considering the scope, definition and impact of ES, it is divided into four areas in the literature (CIEP, 2004; Chevalier, 2005; APERC, 2007; IEA, 2007d). These four areas are: Availability, Accessibility, Affordability, Acceptability. Availability refers to the physical existence and usability of energy in an economy. Accessibility refers to the accessibility of energy resulting from the distance between the production and consumption of energy. Therefore, acceptability is a geopolitical indicator. Affortability refers to a country's ability to purchase energy at affordable prices. In this respect, the Affortability element is an economic indicator. Finally, acceptability refers to the environmental impact and sustainability of ES. Therefore, acceptability is an environmental indicator (Kruyt et al., 2009). Fang et al., (2018), Le and Nguyen (2019) and Lee (2022) mentioned the develop-ability feature of ES in their studies. Accordingly, the develop-ability element indicates a low-carbon, clean and optimized energy system. This indicator expresses the environmental impacts resulting from energy production and use. Based on Fang et al., (2018), Le and Nguyen (2019) and Lee et al., (2022), this study investigates the impact of indicators of ES (acceptability and develop-ability) on growth.

This study aims to investigate the impact of energy intensity, total primary energy consumption, renewable energy consumption, and total CO2 on GDP in Turkey. Additionally, total population and trade openness were included in the model as control variables. FMOLS and DOLS were used for the long-term prediction of the model. Robustness analysis was performed with the CCR technique to test the consistency of the results of FMOLS and DOLS. The following parts of the study are as follows; Literature Review, Data, Model and Methodology, Empirical Results and Discussions, and Conclusion.

2. Literature Review

There are many studies the impact of energy consumption on growth. Studies investigating the effect of energy intensity on GDP are very few. However, energy intensity is an important element of sustainable ES. In this direction, studies based on energy intensity have begun to increase in recent years. In this section, academic studies on the impact of energy intensity, energy consumption, and CO2 emissions on growth are examined.

Chien and Hu (2008) examined the impact of REC on GDP in 116 countries using the SEM method. According to the results of the study, REC has a positive effect on GDP. Azam et al., (2021) examined the impact of natural gas, renewable energy, and nuclear energy consumption on growth and CO2 in the 10 countries with the highest CO2 emissions in the world using the panel FMOLS method. According to analysis results, natural gas does not contribute to CO2 and growth. However, renewable energy and nuclear energy consumption have a positive impact on GDP. Almulali (2014) examined the impact of nuclear energy consumption on GDP using the FMOLS method in the 30 countries. The results of the study indicated that the effect of nuclear energy consumption on GDP is positive.

Almulali and Sab (2012) examined the impact of energy consumption on GDP in Sub-Saharan African countries using the panel cointegration method. According to the analysis results, energy consumption positively affects GDP growth. Lise and Montfort (2007) discussed the relationship between EC and growth in Turkey. According to the results of the study, EC affects GDP growth. Ocal and Aslan (2013) examined the impact of renewable energy consumption on GDP using the ARDL method in Turkey. According to the results of the study, the long-term effect of renewable energy consumption on GDP is negative. Öztürk and Acaravcı (2010) examined the long-term impact of energy consumption and CO2 on GDP in Turkey using the ARDL method. According to the long-term results of the study, the impact of energy consumption on GDP is positive, but the impact of CO2 on GDP is negative. Say and Yucel (2009) examined the effect of energy consumption on GDP using the OLS method. The authors stated that energy consumption positively affects GDP. Doğan (2015) examined the impact of electricity consumption from renewable and non-renewable energy sources on growth in Turkey using the ARDL method. According to this, electricity consumption from renewable energy sources has a positive impact on growth. In addition, the analysis results indicated that electricity consumption from non-renewable energy sources has a positive effect on growth.

Dogan (2016) investigated the impact of renewable and non-renewable energy consumption on economic growth in Turkey using the ARDL method. The results of the study indicated that the impact of renewable energy consumption on growth is positive and non-renewable energy consumption is negative. Apergis and Payne (2010) investigated the impact of energy consumption on growth in 13 Eurosian countries using the FMOLS method. According to the results of the study, the impact of energy consumption on growth is positive. Apergis and Payne (2011) examined the impact of renewable energy consumption on growth in 20 OECD countries using the FMOLS method. According to the results of the study, the impact of renewable energy consumption on growth is positive. Al-Mulali (2011) examined the impact of CO2 emissions and oil consumption on growth in MENA countries using panel cointegration and Granger causality methods. According to the results of the study, CO2 emissions and oil consumption have a positive effect on economic growth in the long term. Balli et al., (2019) examined the impact of tourism revenues and CO2 emissions on growth in Mediterranean countries with CCMGE and AMG methods. The results of the study indicated that tourism revenues and CO2 emissions positively affect growth.

Mahmoodd and Ahmad (2018) investigated the relationship between energy intensity and growth in European countries. The results of the study indicated that there is a negative relationship between energy intensity and growth. Agovino et al., (2019) investigated the relationship between energy intensity and growth in European countries using the ARDL method. Accordingly, there is a negative relationship between energy intensity and growth in the long term. Hundie and Daksa (2019) examined the relationship between energy intensity and growth in Ethiopia using the ARDL and FMOLS methods. Accordingly, there is a negative relationship between energy intensity and growth. Jiang et al., (2014) examined the impact of various indicators, especially income, on energy intensity in 29 cities of China using the ARDL method. Accordingly, income affects energy intensity positively. Lee and Nguyen examined the impact of ES indicators on growth in 74 countries using the PCSE and FGLS methods. According to the results of the study, while ES affects economic growth positively, energy insecurity affects growth negatively.

3. Data, Model and Methodology

In this study, GDP is considered a proxy variable for economic growth. So the term economic growth is used more in the study instead of GDP. The effect of energy intensity on growth has not been adequately examined in the previous energy-economy literature. Especially in studies focusing on Turkey, the relationship between energy consumption and GDP has been mostly discussed. However, energy intensity is among the most important environmental elements of sustainable ES. This study aims to contribute to this gap in the literature.

EI is among the acceptability indicators of ES. EI is the ratio of energy supply to gross domestic product measured in purchasing power parity.

In other words, energy intensity refers to the amount of energy used to produce one unit of output. Therefore, EI contains important information about the efficiency of the economy, the environmental effects of growth, and sustainability. For example, EI is gradually decreasing in developed economies. For this reason, in developed economies, while energy supply security increases, the environmental impacts caused by energy use decrease. Because, thanks to technological developments, the amount of energy used to produce a unit of output is gradually decreasing in developed countries. The decrease in EI in production leads to a decrease in environmental degradation. Reducing EI also contributes to reducing countries' energy import costs. Therefore, for a sustainable economy and ES policy in Turkey, energy intensity in economic production must be taken into account. In other words, a sustainable ES policy that covers energy intensity is important for the Turkish economy. Additionally, primary energy consumption per capita, renewable energy consumption and CO2 emissions are also included in the model. Thus, this study investigates the impact of four different indicators of ES on economic growth in Turkey. Trade openness rate and total population were included in the model as control variables. The long-term model was estimated using FMOLS (fully modified ordinary least square) and DOLS (dynamic ordinary least square) methods. Additionally, robustness analysis was performed using the Canonical Cointegrating Regression (CCR) method.

This study investigates the impact of energy intensity (EI), total primary energy consumption (EC) per capita, renewable energy consumption (REC), CO2 emissions (CO2), trade openness (TO), and population (POP) on the gross domestic product (Y). The annual data used in the study is from 1980 to 2022. Descriptive information about the variables is in Table 2. EI and REC are included in the acceptability element of ES. Accordingly, EI and REC indicators indicate the economic and environmental impact of energy consumption. EC and CO2 are included in the develop-ability of ES, and these elements are considered the most important performance of ES (Fang et al., 2018; Le and Nguyen, 2019; Lee et al., 2022). EI, E, and CO2 emissions are negative indicators of ES. Accordingly, increasing EI causes to increase in the amount of energy required to produce one unit of output. In this case, economic growth and energy consumption cause more environmental impact. Similarly, increasing EC and CO2 emissions from fossil fuels can cause great harm to the environment. Increases in these elements, which lead to energy insecurity, harm the establishment of a low-carbon energy system. In this case, economic growth and EC cause more environmental impact. Similarly, increasing per capita EC and CO2 emissions from fossil fuels can cause great harm to the environment. Increases in these elements, which lead to energy insecurity, harm the establishment of a low-carbon energy system. Therefore, growth in EI, EC and CO2 leads to a weakening of a country's ES. On the other hand, REC is a positive indicator of ES. In other words, the increase of the energy resources in a country leads to the development of that country's sustainable energy policy. As a result, the development of a country's ES and uninterrupted energy supply system contributes to the economic, political, social and environmental development of that country.

Table 2: Variable definitions and Data Source

Variable	Definition	Source
Y	Natural logarithm of GDP, constant (2015:100)	WDI
EI (Acceptability)	Natural logarithm of the energy intensity of primary energy (MJ/$2017 PPP GDP))	EIA
EC (Develop-ability)	Natural logarithm of primary energy consumption per capita (BTU)	EIA
REC (Acceptability)	Renewable energy consumption (% of total final energy consumption)	WDI
CO_2 (Develop-ability)	Natural logarithm of total CO2 emissions (TONS)	WDI
TO	Natural logarithm of trade opennes	WDI
POP	Natural logarithm of total population	WDI

Pkrovski (2003), Oh and Le, (2004), Lee and Chang, (2007), Stern (2011), Sharma (2010), Apergis (2010), Borhan (2012), Ayres et al., (2013), Rahman et al., (2017), Koçak and Şarkgüneşi (2017), Rahman et al., (2020) was followed for the empirical model of this study examining the relationship between energy and GDP. In each of these studies, different variables were included in the model. But all of them are based on the Cobb-Douslas (1928) production function. In this study, based on Le and Nguyen (2019), the model investigating the effect of ES on growth is as follows:

$$Y = f(EI, EC, REC, CO2, TO, POP) \quad (1)$$

$$Y_t = \beta 0 + \beta 1EI_t + \beta 2EC_t + \beta 3REC_t + \beta 4CO2_t + \beta 5TO_t + \beta 6POP_t + \varepsilon_i \quad (2)$$

β0 in equation 2 is a constant coefficient. $\beta_{1\text{-}6}$ is a coefficient expressing the effect of the relevant variable on Y. ε refers to the error term coefficient. t indicates the relevant period. Y is GDP calculated at 2015 prices. EI is energy intensity (MJ/$2017 PPP GDP). EC is the total primary energy consumption per person. REC expresses the share of renewable energy consumption in total final energy consumption. CO2 is the total carbon dioxide emissions (millions of tons). TO is the trade openness ratio that gives the share of total exports and imports in GDP. Finally, POP represents the total population.

FMOLS (Phillips and Hansen, 1990) and DOLS (Stock and Watson, 1993) methods have been widely preferred in the energy-economy literatüre (Ferhani and Rejeb, 2011; Khan et al., 2013; Steimikiene and Kasperowicz, 2016; Bhattacharya, 2016; Rahman et al., 2020; Doganalp et al., 2021; Wen et al., 2021). FMOLS and DOLS methods provide more robust results than the standard OLS technique. These methods provide asymptotic results by taking into account the serial correlation effect and the endogeneity problem arising from the cointegration relationship (Narayan & Narayan, 2005; Tursoy & Faisal, 2018;). FMOLS technique refers to a non-parametric approach and gives consistent results in models with small sample sizes. For this reason, the FMOLS method is among the most flexible long-term estimators that control endogeneity and autocorrelation in the model (Khan et al., 2018; Hafeez et al., 2018; Rahman et al., 2020; Zimon et al., 2023). In other words, these methods capture serial correlation by allowing asymptotic consistency. If there is a long-run cointegration relationship in the model, FMOLS and DOLS methods can be used (Adebayo et al., 2021). Therefore, in this study, since there is a cointegration relationship between the variables and the number of observations is 42, long-term estimation was made using FMOLS and DOLS methods. According to these techniques, the common co-integration order of the variables should be I(1). The FMOLS model adapted for this study is as follows;

$$Y_t = \beta 0 + \beta 1EI_t + \beta 2EC_t + \beta 3REC_t + \beta 4CO2_t + \beta 5TO_t + \beta 6POP_t + \sum_{i=q}^{\rho} \lambda 1\Delta EI_{t-1} + \sum_{i=q}^{\rho} \lambda 2\Delta EC_{t-1} + \sum_{i=q}^{\rho} \lambda 3\Delta REC_{t-1} + \sum_{i=q}^{\rho} \lambda 4\Delta CO2_{t-1} + \sum_{i=q}^{\rho} \lambda 5\Delta TO_{t-1} + \sum_{i=q}^{\rho} \lambda 6\Delta POP_{t-1} + \varepsilon_i \quad (3)$$

The t in equation 3 is the indicator of time. ρ is the number of lags. Δ is the difference operator of the model.

The empirical order of the study follows: First of all, it is important to determine the stationarity level of variables in time series analysis. For this reason, Augmented Dickey and Fuller (ADF) (1979), and Phillips-Perron (PP) (1988) tests were applied to determine the stationarity level of the variables. The null hypothesis of ADF and PP tests states that the variable is not stationary. In this study, according to ADF and PP methods, the co-integration order of all variables is I(1), and thus it was decided to apply the Johansen (1988) cointegration test. Co-integration relationship in non-stationary series is generally determined by cointegration methods such as Johansen (1988-1991) and Engle-Granger (1987). In the Johansen technique, the order of integration of all variables is determined. Then, the significance of trace and max-eigen statistics expressing the cointegration relationship in the model is checked (Irshad and Ghafoor, 2023). If the probability values of trace and max-eigen test statistics are significant and support each other, it is accepted that there is at least one long-term cointegration relationship in the model. The null hypothesis of the Johansen cointegration technique states that there is no cointegration relationship in the model. As a result, in this study, after it was determined that there was a Johansen cointegration relationship between the variables, long-term estimation was made using FMOLS and DOLS estimators. Additionally, a robustness analysis was applied to check the consistency of the results of FMOLS and DOLS techniques. For this reason, the CCR technique, which is a robust prediction technique, has been applied.

Table 3: Description Statistics and Correlation Matrix

Variable	Y	EI	EC	REC	CO2	TO	POP
Mean	26.81741	1.049844	3.500864	2.521190	19.19472	3.749391	17.97201
Median	26.74871	1.054312	3.153539	2.525945	19.21434	3.843626	17.99101
Maximum	27.75416	1.184790	6.813173	2.957767	19.91629	4.260352	18.26217
Minimum	25.87849	0.770108	0.942223	2.105548	18.13582	2.838483	17.60172
Std. Dev.	0.555081	0.103981	1.834301	0.214917	0.526899	0.302528	0.197001
Skewness	0.069096	-0.703542	0.359245	-0.020158	-0.406303	-0.834051	-0.230410
Kurtosis	1.868307	2.774740	1.906896	2.471464	2.071422	3.619619	1.923983
Jarque-Bera	2.328856	3.638206	3.065726	0.503415	2.727965	5.673303	2.454886
Probability	0.312101	0.162171	0.215917	0.777472	0.255641	0.058622	0.293041
Sum	1153.149	45.14328	150.5372	108.4111	825.3731	161.2238	772.7966
Sum Sq. Dev.	12.94083	0.454109	141.3158	1.939946	11.66013	3.843974	1.629997
Observations	42	42	42	42	42	42	42
Y	1						
EI	0.35894	1					
EC	0.9924	0.27909	1				
REC	0.36270	-0.04036	0.38731	1			
CO2	0.98388	0.51125	0.96009	0.30058	1		
TO	0.89010	0.49471	0.89988	0.33165	0.90707	1	
POP	0.99149	0.46187	0.97422	0.32901	0.99451	0.90944	1

Description statistics and correlation matrix results are given in Table 3. Probability results of Jarqu-Bera statistics indicate that all variables are normally distributed. The variable with the highest standard error is EC, while the variable with the lowest standard error is EI. Accordingly, volatility in EC is much higher than other variables. Y and EC have a right-tail feature, while the other variables have a left-tail feature. EC has the longest right tail, while TO has the longest left tail. Correlation matrix results indicate that there is a strong and positive correlation relationship between Y and other variables. Accordingly, EC, POP and CO2 have the strongest positive correlation relationship with Y. EI is the variable with the lowest correlation with Y.

4. Empirical results and discussions

In this part of the study, the results of ADF-PP tests, Johansen cointegration test, and FMOLS-DOLS-CCRM methods are included.

Table 4: Unit Root Test Results

	ADF		PP	
Variable	*Level*	*1.different*	*Level*	*1.different*
Y	-2.9606	-6.9184*	-2.9698	-6.9386*
EI	-1.3383	-6.1571*	-0.5227	-10.4616*
EC	-1.8305	-3.8180**	-2.3175	-7.7905*
REC	-2.5279	-5.8704*	-3.0366	-7.8768*
CO2	-1.8139	-5.7751*	-1.6274	-7.0959*
TO	1.1723	-5.5292*	1.6872	-5.6510*
POP	-1.6777	-3.7753**	-1.2005	-3.2390**

Note: * and **, indicate significance level at 1% and 5%. For the ADF test, the Schwarz Information Criterion is taken into account. For PP testing, Bartlet Kernel is taken into account. The results refer to the model with trend and constant.

Table 4 shows the unit root results of ADF and PP tests. Accordingly, all variables are not stationary at the level they are but stationary at first difference. In other words, there is a strong cointegration relationship in the model. Since the common integration order of the variables is I (1), it was decided to make the long-term forecast using FMOLS and DOLS methods.

Table 5: Johansen Cointegarion Test Results

Hypothesized No. Of CE(s)	Stat. from trace test	Prob.	Stat. from max-eigen test	Prob.
None *	356.9464	0.0000	114.6971	0.0000
At most 1 *	242.2493	0.0000	60.17230	0.0012
At most 2 *	182.0770	0.0000	52.79373	0.0015
At most 3 *	129.2833	0.0000	42.06714	0.0057
At most 4 *	87.21613	0.0000	33.70975	0.0101
At most 5 *	53.50638	0.0002	24.60209	0.0234
At most 6 *	28.90429	0.0025	18.27779	0.0207
At most 7 *	10.62650	0.0262	10.62650	0.0262

Trace and max-eigen test results of the Johansen cointegration technique are given in Table 5. Accordingly, there is a strong cointegration relationship in the model. The results of unit root tests and Johansen test results support each other.

Table 6: FMOLS, DOLS and CCR

Dependent Variable: Y	FMOLS	DOLS	CCR
EI	-0.6486* (0.0647)	-0.6820* (0.0908)	-0.6142* (0.0540)
EC	0.0546* (0.0137)	0.0523** (0.0183)	0.0641* (0.0112)
REC	0.0455* (0.0130)	0.0443*** (0.0156)	0.0437** (0.0119)
CO2	0.6128* (0.0592)	0.6208* (0.0711)	0.5862* (0.0505)
TO	0.0498** (0.0226)	0.0608** (0.0260)	0.0367*** (0.0183)
POP	0.7198* (0.1656)	0.7176* (0.2098)	0.7257* (0.1529)
Cons	2.2966 (2.3621)	2.1943 (3.0829)	2.6922 (2.1620)

***Note:** *, ** and *** indicate the 1%, 5% and 5% significance level, respectively. The values of the variables in parentheses indicate standard errors.*

Long-term results of FMOLS and DOLS methods are given in Table 6. At the same time, the results of the CCR estimator are included as a robustness test. The results of the three techniques support each other and it appears that the results are consistent. First, energy intensity (EI) has a negative impact on GDP according to the three techniques. This means; If energy density decreases, the amount of energy required for one more unit of production gradually decreases. Producing more with the same amount of energy has positive results on the economy and the environment. This causes production efficiency and GDP to increase. The negative relationship between EI and Y indicates the impact of ES on economic growth. In other words, increasing ES in Turkey supports economic growth. Thus, reducing environmental disasters caused by energy can support economic growth. The impact of renewable energy consumption (REC) on growth also supports this hypothesis. Accordingly, the increase in renewable energy consumption (REC) in Turkey positively affects economic growth. In other words, if Türkiye turns more towards clean energy sources, the GDP growth may increase further. The effect of EI and REC on Y indicates that ES supports growth in Turkey. In particular, the fact that EI is the strongest variable determining Y (excluding population) indicates the strong effect of ES on growth. However, primary per capita energy consumption (EC) and CO_2 emissions indicate that energy insecurity also supports growth. Accordingly, increasing EC and CO_2 will ultimately lead to positive results on growth in Turkey. The reason for this is that the share of energy consumption from fossil fuels in total energy consumption in Turkey is more than 85%. Turkey's economy has a high dependence on fossil energy fuels. In other words, more energy consumption per person causes more CO_2 emissions. Therefore, the dependence of economic growth on fossil fuels causes environmental degradation to move in parallel with economic growth. CO_2 emissions are also the third largest variable determining Y. Economic growth in Turkey is dependent on both variables that cause environmental degradation and variables that cause environmental improvement. Therefore, supporting ES, increasing the use of clean energy, reducing energy intensity, reducing carbon emissions from fossil fuels, and developing new policies in this direction are important for the environment and economy. Otherwise, while the economy grows in Turkey, environmental disasters may increase more than environmental improvements. Because both ES and energy insecurity elements are the driving force of growth in Turkey. However, supporting factors that lead to environmental improvement and ES without harming economic growth will also have a positive impact on growth.

The effects of TO and POP on Y are positive as expected. Approximately 60% of the Turkish economy consists of foreign trade. But Türkiye is a country with a foreign trade deficit and a current account deficit. This means that imports are excessive and foreign direct investments (FDI) are insufficient. For this reason, Turkey needs more support for exports and FDI in a permanent and productive growth process. High population (POP) is an important workforce opportunity for Türkiye. Especially when compared to developed countries, Türkiye has a young and dynamic population profile. Therefore, the effect of POP on Y is positive and quite strong. More workforce means more potential growth. However, the difference between potential growth and real growth causes the workforce to remain idle, and sustainable growth is damaged by this situation. In addition, economic growth must be adequately reflected in real wage increases. Because Turkey is a country with both a high growth profile and high inflation. The fact that inflation has increased especially in recent years causes significant losses in real wages. The share of the workforce in production is gradually decreasing (TUIK, 2023). These results show that the production efficiency of the workforce may decrease in the future.

In addition, the CCR results applied as a robustness test also support the results of the FMOLS and DOLS methods. Accordingly, the results of FMOLS and DOLS techniques are robust.

Finally, the results of this study coincide with the results of studies in the literature, especially Le and Nguyen (2019). The negative relationship between energy intensity and growth coincides with the results of studies such as Mahmood and Ahmad (2018), Mendiluce et al., (2010), and Miketa (2001). The positive relationship between energy consumption (renewable energy consumption) and growth coincides with the results of studies such as Chien and Fu (2007), Tiwari (2011), Fang (2011), Pao and Fu (2013), Taghwaee et al., (2016), Rehman et al (2021), Khan et al., (2021), Rehman et al., (2021) and Wang et al, (2022). The positive relationship between CO2 and growth is similar to the results of studies such as Xepapadeas (2005), Say and Yucel (2006), Ang (2008), Fodha and Zaghdoud (2010), Al-Mulali and Sab (2012), Bozkurt and Akan (2014) and Azam et al., (2015). The positive relationship between trade openness and growth is similar to the results of studies such as Hye et al., (2016), Keho (2017), Malefane (2018), Raghutla (2020), and Rehman et al., (2021). The positive relationship between population and growth is similar to the results of studies such as Ali et al., (2013), Gaag and Beer (2015), Tartiyus et al., (2015), and Kuhe (2019).

5. Conclusion and Policy Recommendations

This study investigated the impact of energy intensity, primary energy consumption, renewable energy consumption, CO2 emissions, trade openness, and population on GDP. Energy intensity, primary energy consumption, and CO2 emissions are negative indicators of ES. Renewable energy consumption is a positive indicator of ES. Therefore, in this study, the impact of ES on sustainable growth in Turkey was investigated under the shadow of trade openness and population. For this purpose, ADF-PP unit root tests, Johansen cointegration test, and FMOLS-DOLS-CCR long-term techniques were used.

Türkiye's economy largely depends on non-renewable energy sources. Because the rate of fossil fuels in total energy consumption is around 85%. For this reason, CO2 emissions in Turkey have increased more than 10 times in the last 50 years. At the same time, the share of renewable energy consumption in total energy consumption has gradually decreased. In the same period, total GDP in Turkey (2015:100) increased approximately 10 times. This indicates that economic growth in Turkey moves together with fossil-based energy consumption, which leads to environmental degradation. However, this situation harms sustainable ES in Turkey. Therefore, Turkey needs an uninterrupted, environmentally supported, efficient, economic and social ES system.

The empirical analysis results of the study are remarkable. Accordingly, factors that both increase ES and decrease ES positively affect growth in Turkey. In other words, the decrease in energy intensity and the increase in the use of renewable energy resources positively affect the GDP in Turkey. Accordingly, the decrease in the energy used to obtain a unit of output and the increase in the use of clean energy resources positively affect both economic growth and ES in the long term. But while primary energy consumption and CO2 emissions harm ES, they support economic growth. Because fossil-based energy use is quite high. Therefore, as a result of the increase in the consumption of fossil energy resources, CO2 emissions gradually increase. Turkey's economy is very sensitive to fossil energy resources and therefore CO2 emissions. As a result, while Turkey's economy grows, environmental disasters increase and ES decreases. This dilemma between growth and ES points to the necessity of a sustainable ES system in Turkey. However, due to the high use of fossil-based energy consumption in Turkey, policies that support ES are expected to be high-cost. In other words, high investments are needed to support elements that increase ES. For a sustainable economy and ES policy in Turkey, policymakers need to focus on policies that contribute to ES with the support of internal and external resources. Finally, trade openness and population also positively affect GDP in the long term. Approximately 60% of the Turkish economy consists of foreign trade. In addition, it is known that the economy in Turkey, which has a young and dynamic population, has a sufficient workforce. However, in Turkey, which has a high growth potential as well as being exposed to high inflation from time to time, the real wage losses faced by the workforce negatively affect the efficiency of growth. In addition, foreign trade deficits and current account deficits indicate that a significant part of economic growth serves to finance the current account deficit. Therefore, for sustainable growth in Turkey, it seems that policies that support FDI, foreign capital, and high-value-added exports are needed.

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