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Do Increases and Decreases in Non-renewable Energy Consumption Have the Same Effect on Growth in Türkiye?

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Türkiye'de Yenilenemeyen Enerji Tüketimindeki Artış ve Azalışların Ekonomik Büyüme Üzerindeki Etkisi Aynı Mıdır?

Abstract

This study examines the relationship between fossil energy consumption (FEC) and economic growth by applying the non-linear ARDL method in the Türkiye sample. This relationship was addressed in 3 different models to eliminate the multicollinearity between the oil, natural gas, and coal variables that make up the FEC. According to the analysis results, all models have an asymmetric cointegration between the variables. In all models, the effect of decreases in energy consumption on economic growth is more dominant than increases in the long run. According to the causality results, the neutrality hypothesis is valid for coal consumption, the feedback hypothesis is valid for natural gas consumption, and the growth hypothesis is valid for oil consumption.

Keywords : Energy Consumption, Non-linear Cointegration, Growth, NARDL, Non-Renewable Energy.

JEL Classification Codes : B22, Q43, Q47.

Öz

Bu çalışmada fosil enerji tüketimi (FEC) ile ekonomik büyüme arasındaki ilişki Türkiye örnekleminde doğrusal olmayan ARDL yöntemi uygulanarak incelenmiştir. Bu ilişki, FEC'i oluşturan petrol, doğal gaz ve kömür değişkenleri arasındaki çoklu doğrusal bağlantıyı ortadan kaldırmak için 3 farklı modelde ele alınmıştır. Analiz sonuçlarına göre oluşturulan tüm modellerde değişkenler arasında asimetrik bir eşbütünleşme bulunmaktadır. Tüm modellerde, enerji tüketimindeki azalmaların ekonomik büyüme üzerindeki etkisi, uzun dönemdeki artışlardan daha baskındır. Nedensellik sonuçlarına göre kömür tüketimi için yansızlık hipotezi, doğal gaz tüketimi için geri besleme hipotezi ve petrol tüketimi için büyüme hipotezi geçerlidir.

Anahtar Sözcükler : Enerji Tüketimi, Asimetrik Eşbütünleşme, Büyüme, NARDL, Yenilenemez Enerji.

1. Introduction

Türkiye is a developing country located in Europe and Asia continents. Furthermore, this country has neighbouring countries with rich energy resources. As the economy is overgrowing, it is assumed that this economic growth of Türkiye will last with a similar tendency in the hereafter. Türkiye has grown by an average of 5,9% in the last ten years and 4,5% in the previous 50 years. Except for 2018 and 2019, it has an average growth rate above the European Union and the world average since 2001 (Göksu, 2021: 70-71). In Türkiye, the rapid increase in the population (approximately 85 million) and the economy's steady growth have led to increased energy demand and foreign dependency on energy in the last two decades. Even though Türkiye has tripled its renewable energy generation in the previous decade, the massive dependence on imports for fossil fuels, predominantly gas and oil (99% and 93%, respectively) (International Energy Agency, 2021: 11) still is one of the essential issues of the Türkiye economy.

When the changes in the growth and development goals of the countries in the historical process were examined, the increase in GDP first came to the fore in economic policies. Following this goal, countries focused on increasing their GDP per capita. The inadequacy of per capita income to show the level of human welfare has led to a shift to the "Human Development Index", which includes non-monetary indicators such as education and health as well as income. After that comes an evolving paradigm shift with the "Millennium Development Goals" and, finally, the "Sustainable Development Goals" (SDGs). The SDG aims to increase the well-being of all humanity, including all societies, to reduce poverty, protect social and cultural values, and prevent environmental destruction, which is included in the sustainable development agenda. Türkiye, like many other countries, wants to advance in these goals. However, Türkiye has advantages and disadvantages in achieving these goals. Dependence on foreign countries for non-renewable energy, inadequacy in using clean energy in the production process, and targeting high growth rates despite high inflation in recent years continue to put pressure on environmental problems. On the other hand, because more than half of the country's borders are surrounded by seas, the number of sunny days and wind-rich regions is an opportunity for clean energy and sustainable development goals.

The oil crisis in the 70s threatened countries' energy resources and made them understand the importance of diversifying their energy sources. This awakening has brought about different debates about the importance of energy for the Gross Domestic Product (GDP). The ongoing debate revolves around whether energy, deemed an essential production element, functions as a direct or intermediate production factor. Ghali and El-Sakka (2004) encapsulate this discourse through two perspectives: The neo-classical economists' standpoint posits energy's neutrality concerning economic growth, termed the 'neutrality hypothesis.' Conversely, ecological economists share an alternative view, asserting that energy is the primary factor of production. In this view, energy is characterised as a limiting factor in the scope of economic growth. The neo-classical economic growth model, commonly called the Solow growth model, significantly contributes to classical economics by providing analytical insights and establishing a foundational theoretical framework. This model emerged in response to the Harrod-Domar growth model, which attempted to extend Keynesian short-term static analysis into the long-term, addressing the complexities of dynamic growth issues.

This study, handled within the ecological economics framework, investigates whether non-renewable energy sources are inevitable for the Turkish economy. Tuğcu and Topçu (2018) criticised the literature on energy economics, which mainly uses linear methods in the energy-growth relationship and bypasses the possible asymmetry between the variables. At the end of their studies, they underlined that asymmetric methods should be considered empirical methodology for future studies. This approach constitutes the primary motivation source of the study. This research can be qualified as a complement to earlier empirical studies on energy economics. However, the present study differs from the current literature because we explore the affinity between growth and fossil energy consumption (FEC) with the asymmetric approach for Türkiye. This study will separately analyse the impact of increases and decreases in FEC upon economic growth. Ergo, the study’s primary question is whether the increases and decreases in FEC have the same effect on the Türkiye economy. Another sub-question related to this question is whether producers or consumers predominantly use FEC. If increases in FEC increase per capita income, it shows that the resources are predominantly used for production by the producers; on the contrary, it indicates that they are predominantly used for consumption by the consumers. Operating non-linear auto-regressive distributed lag (NARDL) models in 1972-2020 annual data, we introduce whether growth is connected to or not energy in the Türkiye sample. This study will present a new vision for policymakers to design fundamental policies balancing FEC and growth. In the subsequent sections of the research, following a concise examination of empirical literature in Section 2, Section 3 outlines the presentation of data and empirical methodology. Section 4 encompasses the exposition of findings and ensuing discussions, whereas Section 5 encapsulates the conclusive remarks.

2. Literature Review

Many studies have dissected the nexus between FEC and economic growth (EG), especially since the 1970s. The study of Kraft and Kraft (1978) can be considered one of the pioneering studies in energy economics. The study covering the years 1947-1974 in the sample of the US economy embraces the “linear” and “supply side” methods. As a result of the analysis performed with Sims’s causality test method, a two-way Granger causality relationship was found between gross national income and FEC.

Progress in applied econometrics, especially concerning unit root and co-integration tests, has prompted rich empirical literature on energy economics in recent years (Smyth & Narayan, 2015: 351). In recent years, Apergis & Payne (2010a); Belke et al. (2011); Tang et al. (2016); Alper & Alper (2017); Shahbaz et al. (2018); Benkraiem et al. (2019); Abbasi et al. (2021); Khan et al. (2021); Alam (2022); Uçan et al. (2022) can give examples of the linear co-integration method. In contrast, we can give examples of studies conducted with the non-linear co-integration method by Shahbaz et al. (2017), Tugcu & Topcu (2018), Benkraiem et al. (2019), Shastri et al. (2020), Awodumi & Adewuyi (2020) studies.

Using linear methods, Apergis and Payne (2010a) examined the relationship between coal consumption and economic growth for 25 OECD countries and found that they were cointegrated. In this study, the real gross fixed capital formation and labour force coefficients are positive, while the coefficients for coal consumption are negative. A bidirectional causality exists between coal consumption and short- and long-term economic growth. Using the panel data analysis method, Uçan et al. (2022) obtained similar findings for 15 developed countries, examining the relationship between energy consumption and economic growth. While Abbasi et al. (2021) and Alam (2022) obtained similar findings for non-renewable energy consumption, Khan et al. (2021) obtained similar findings by considering renewable and non-renewable energy consumption.

If the studies conducted with asymmetric methods in economic literature are examined in detail, Tuğcu and Topçu (2018) studies are remarkable. The study investigated the nexus between energy consumption (EC) and EG in G7 countries from 1980 to 2014. The non-linear ARDL approach and Hatemi-J asymmetric causality procedure were employed in the study. Researchers found that EC and EG in the G7 countries are cointegrated. The causality results support the asymmetric cointegration relationship and differ in energy types. Another study with asymmetric methods by Luqman M. et al. (2019) investigated the effects of renewable and nuclear energy on EG in Pakistan. As a result, they provided evidence of asymmetric cointegration between variables. In addition, they determined that shocks to nuclear and renewable energy variables will positively affect EG. Another study using asymmetric methods was conducted by Awodumi and Adewuyi (2020). Researchers used asymmetric methods to examine the relationship between non-renewable EC, EG, and carbon emissions for Africa's top oil-producing economies between 1980 and 2015. They conclude that per capita consumption of both oil and natural gas has an asymmetric effect on EG and per capita carbon emissions in all selected countries except Algeria.

In the energy economy, studies generally can be classified into three approaches: the supply side, the demand side, and the supply-demand side. The supply-side method analyses the impact of EC and output within conventional production (Landwehr & Jochem, 1997; Sari & Soytas, 2007; Bloch et al., 2015; Alam & Murad, 2020; Amin et al., 2020; Hasanov, 2021). The demand side method examines the nexuses between energy prices, EG, and EC (Narayan & Singh, 2007; Rafiq & Salim, 2009). In addition, some approaches include both energy supply and demand (Zhong, 2018; Bloch et al., 2012).

In addition, these studies were conducted in different countries or groups using different variables and methods, and they can be classified under four hypotheses. These are neutrality, growth, conservation, and feedback hypotheses (Payne, 2010a; Bildirici & Bakirtas, 2014; Omri, 2014; Apaydın et al., 2019). First, the "neutrality hypothesis" (Ouédraogo, 2010; Payne, 2010b; Dogan, 2015) states no relationship between GDP and

FEC. Second, the “conservation hypothesis” (Le Quang, 2011; Hwang & Yoo, 2014; Kumari & Sharma, 2016; Güllü & Yakışık, 2017) suggests that EC has either no or only a minor impact on growth, especially in countries with low energy dependence. Third, according to the “growth hypothesis” (Masuduzzaman, 2012; Azam et al., 2021; Zhang et al., 2021), EC enhancement may positively affect growth, while reducing EC negatively affects growth. Finally, according to the “feedback hypothesis” (Apergis & Payne, 2010b; Bildirici, 2012; Al-Mulali et al., 2014; Ahmad et al., 2016), there is a bidirectional nexus between growth and EC. The following studies illustrate these hypotheses.

Doğan’s (2015) study is an example of the “neutrality hypothesis”. The study analysed the relationships between EG and electricity consumption generated from renewable and non-renewable sources in Türkiye. Although the variables are cointegrated, the researcher determined that the “neutrality hypothesis” is valid in Türkiye in the short run. When the study of Kumari & Sharma (2016), which is among the studies supporting the “conservation hypothesis,” was examined in detail, the researchers found no cointegration relationship between the variables. In addition, finding a one-way Granger causality relationship from EG to electricity consumption is empirical evidence for the conservation hypothesis. Shastri et al. (2020) indicate in their study for India that the relationship between EG and EC is asymmetrical. The non-linear causality test results detected a unidirectional causality running from non-renewable EC and renewable EC to EG. Therefore, according to the researchers, the “growth hypothesis” is valid for India. Ha and Ngoc (2021) investigated the relationship between EC and EG in Vietnam using the NARDL cointegration approach. They found that the effects of electricity consumption on EG are asymmetrical. They also found that the effect of decreases in electricity consumption is more remarkable than increases. This result is the opposite for oil consumption. The study supports the “feedback hypothesis” for Vietnam regarding causality.

As underlined in the explanations above, although extensive energy economy literature discusses the correlation between FEC and EG by applying linear methods, non-linear methods are relatively inadequate, especially for Türkiye. With the present study, we aimed to fill this gap in the energy economy literature in Türkiye.

3. Data & Methodology

Since using oil, gas, and coal consumption variables as independent variables in the same model causes a multicollinearity problem, we established three models to explore the potential relationship between FEC and economic growth in Türkiye. To rule out the multicollinearity problem, we added the oil, gas, and coal consumption variables separately to the models as independent variables. These models represent neo-classical aggregate production functions and are based on previous work by Stern (1993), Lee and Chang (2008), and Ajlouni (2015).

$$Model\ 1: lnGNI_t = \beta_0 + \beta_1 lnOIL_t + \beta_2 K_t + \beta_3 lnL_t + \mu_t \quad (1)$$

$$Model\ 2: lnGNI_t = \alpha_0 + \alpha_1 lnCOAL_t + \alpha_2 K_t + \alpha_3 lnL_t + \mu_t \quad (2)$$

$$Model\ 3: lnGNI_t = \theta_0 + \theta_1 lnGAS_t + \theta_2 \mathrm{K}_t + \theta_3 lnL_t + \mu_t \tag{3}$$

where *lnGNI* is the dependent variable and the gross national income per capita, *lnOIL* stands for the total final oil consumption, *lnGAS* is the total final natural gas consumption, *lnCOAL* is the total final coal consumption, *lnL* is labor, *K* is the gross fixed capital formation, and μ_t is the error term. The annual data in the models cover the years 1972-2020. These data were collected by open access from the IEA, the World Bank, and the University of Groningen database. All variables are represented in logarithmic form except for the capital variable because this variable is the percentage. The variables used in the models and their explanations are presented in Table 1.

Table: 1
Summary Explanations About the Variables

Variable Symbol	Description	Unit	Expected impact	Source
GNI	GNI per capita	Atlas method (Current US$)	Dependent variable	WB
OIL	Total final oil consumption	Petajoule (PJ)	+	IEA
COAL	Total final coal consumption	Petajoule (PJ)	+	IEA
GAS	Total final natural gas consumption	Petajoule (PJ)	+	IEA
K	Gross fixed capital formation	(% of GDP)	+	WB
L	Number of persons engaged	in millions	+	PWT 10.01

Source: URL1, WB: World Bank; and URL2, IEA: International Energy Agency, URL3, University of Groningen, Penn World Table version 10.01.

Analyses made without considering the differences in the reactions of economic variables to shocks may be insufficient to reveal hidden relationships and undermine confidence in the analyses (Aydın, 2017). Therefore, before conducting the cointegration test, we apply the BDS (Brock-Dechert-Scheinkman) test to ascertain the presence of non-linear dependencies (Broock et al., 1996). Table 2 displays the BDS findings and verifies the data’s non-linearity at the 1% significance level. The findings of the BDS test encourage us even more to continue the NARDL analysis (Syed et al., 2021). In addition, the absence of statistically significant results from the ARDL method is another critical reason for choosing the NARDL method (Göksu & Balkı, 2023).

Table: 2
BDS Test Results

BDS statistic	Embedding dimensions = m				
	m=2	m=3	m=4	m=5	m=6
lnGNI	0,191895***	0,321295***	0,408817***	0,469044***	0,508722***
lnOIL	0,188716***	0,31667***	0,411716***	0,477125***	0,526493***
lnCOAL	0,178116***	0,310125***	0,401221***	0,461977***	0,499866***
lnGAS	0,203796***	0,345828***	0,445732***	0,513084***	0,560681***
K	0,133839***	0,228778***	0,280769***	0,302971***	0,306408***
lnL	0,191909***	0,32488***	0,414718***	0,48055***	0,527644***

The implementation of the NARDL analysis practised the following steps. First, like the ARDL procedure, none of the variables are I(2); Lee and Strazicich (2003) (LS) unit-root tests are performed to decide whether the variables are I(0)/I(1). Second, equation 2 is estimated using the standard OLS method. Third, co-integration between variables is assessed using bound tests (F_{PSS} and t_{BDM}). The fourth detects long-term and short-term asymmetry using the Wald test. Fifth, the normality test (Jarque-Bera), serial correlation test

(LM test), and heteroscedasticity test (BPG and ARCH test) apply to the reliability of the results obtained from the established model. Finally, CUSUM tests were applied to scan the structural solidity.

To specify asymmetric effects between the variables in Model 1, we can write follow Pesaran et al. (2001) and Shin et al. (2014) Equation 4:

$$\Delta lnGNI_t = \beta_0 + \sum_{i=1}^{k=2} \beta_{1i}\, \Delta lnGNI_{t-i} + \sum_{a=1}^{l=1} \beta_{2a}\, \Delta OIL^{+}_{t-i} + \sum_{b=1}^{m=1} \beta_{3b}\, \Delta OIL^{-}_{t-i} + \sum_{c=1}^{n=0} \beta_{4c}\, \Delta K^{+}_{t-i} + \sum_{d=1}^{o=2} \beta_{5d}\, \Delta K^{-}_{t-i} + \sum_{e=1}^{p=2} \beta_{6e}\, \Delta lnL^{+}_{t-i} + \sum_{f=1}^{q=1} \beta_{7f}\, \Delta lnL^{-}_{t-i} + \phi lnGNI_{t-1} + \psi_1^{+} lnOIL^{+}_{t-1} + \psi_1^{-} lnOIL^{-}_{t-1} + \psi_2^{+} lnK^{+}_{t-1} + \psi_2^{-} lnK^{-}_{t-1} + \psi_3^{+} lnL^{+}_{t-1} + \psi_3^{-} lnL^{-}_{t-1} + \mu_t \quad (4)$$

where "Δ" is the primary difference; "μ_t" is error term; "k, l, m, n, o, p, q" are the lag orders; "β_0" is the constant; "β_1", "β_2", "β_3", "β_4","β_5", "β_6" "β_7" are coefficients of the short-run impacts; "ϕ", "ψ_1", "ψ_2", "ψ_3" are coefficients of the long-run impacts. We will adapt all the equations and hypotheses created for Model 1 to Models 2 and 3. Firstly, we decompose oil consumption, capital, and labour variables as following Equation 5:

$$"lnOIL^{+}_t \sum_{i=1}^{t} \Delta lnOIL^{+}_i = \sum_{i=1}^{t} max(\Delta lnOIL_i, 0)\,;\ lnOIL^{-}_t \sum_{i=1}^{t} \Delta lnOIL^{-}_i = \sum_{i=1}^{t} min(\Delta lnOIL_i, 0)\,"$$

$$"lnCOAL^{+}_t \sum_{i=1}^{t} \Delta lnCOAL^{+}_i = \sum_{i=1}^{t} max(\Delta lnCOAL_i 0); lnCOAL^{-}_t \sum_{i=1}^{t} \Delta lnCOAL^{-}_i = \sum_{i=1}^{t} min(\Delta lnCOAL_i 0)"$$

$$"lnGAS^{+}_t \sum_{i=1}^{t} \Delta lnGAS^{+}_i = \sum_{i=1}^{t} max(\Delta lnGAS_i, 0)\,;\ lnGAS^{-}_t \sum_{i=1}^{t} \Delta lnGAS^{-}_i = \sum_{i=1}^{t} mi\,n(\Delta lnGAS_i, 0)\," \quad (5)$$

F-Bounds and t-Bounds tests co-integration between variables in the model. The hypotheses of this test:

$$"H_0: \phi = \psi_1^{+} = \psi_1^{-} = \psi_2^{+} = \psi_2^{-} = \psi_3^{+} = \psi_3^{-} = 0" \Rightarrow "There\ is\ no\ cointegration"$$

$$"H_A: \phi \neq \psi_1^{+} \neq \psi_1^{-} \neq \psi_2^{+} \neq \psi_2^{-} \neq \psi_3^{+} \neq \psi_3^{-} \neq 0" \Rightarrow "There\ is\ cointegration"$$

The calculated F statistic is compared with the lower and upper critical values derived by Narayan (2005) for the small sample and derived by Pesaran et al. (2001) for large samples. If H_0 rejects and H_A accepts, it decides that there is cointegration between the variables in the model. If the estimated F statistic value is smaller than the critical values, there is no cointegration between variables in the model.

Long-term asymmetric relationships are evaluated using the following hypotheses with the help of the Wald test.

$$"H_0: \frac{\psi_1^{+}}{-\phi} = \frac{\psi_1^{-}}{-\phi};\ H_0 = \frac{\psi_2^{+}}{-\phi} = \frac{\psi_2^{-}}{-\phi};\ H_0 = \frac{\psi_3^{+}}{-\phi} = \frac{\psi_3^{-}}{-\phi}\,"$$

"$H_A: \frac{\psi_1^+}{-\phi} \neq \frac{\psi_1^-}{-\phi};\ H_A = \frac{\psi_2^+}{-\phi} \neq \frac{\psi_2^-}{-\phi};\ H_A = \frac{\psi_3^+}{-\phi} \neq \frac{\psi_3^-}{-\phi}$"

According to the Wald test applied, the model has long-term asymmetric relationships if H_0 is rejected, and H_A is accepted. Short-run asymmetric relationships are assessed using the following hypotheses with the help of the Wald test, like the long-run.

"H_0: $\sum_{i=0}^{b} \varphi_{1i}^{+} = \sum_{i=0}^{c} \varphi_{1i}^{-}$; $\sum_{i=0}^{d} \varphi_{2i}^{+} = \sum_{i=0}^{e} \varphi_{2i}^{-}$; $\sum_{i=0}^{f} \varphi_{3i}^{+} = \sum_{i=0}^{g} \varphi_{3i}^{-}$"

"H_A: $\sum_{i=0}^{b} \varphi_{1i}^{+} \neq \sum_{i=0}^{c} \varphi_{1i}^{-}$; $\sum_{i=0}^{d} \varphi_{2i}^{+} \neq \sum_{i=0}^{e} \varphi_{2i}^{-}$; $\sum_{i=0}^{f} \varphi_{3i}^{+} \neq \sum_{i=0}^{g} \varphi_{3i}^{-}$"

According to the Wald test applied, if H_0 is rejected and H_A is accepted, there are short-term asymmetric relationships between variables in the model.

Finally, we applied the Toda and Yamamoto (1995) Granger causality test to determine the causal relationships between the variables. In this analysis procedure, first, the appropriate lag length is determined. The maximum degree of integration is added to this lag length. Then, the VAR model is estimated. The VAR model for Model 1 oil consumption and growth is below Equations 6 and 7.

$$lnGNI_t = \delta_0 + \sum_{i=1}^{k+d_{max}} \delta_{1i}\, lnGNI_{t-i} + \sum_{i=1}^{k+d_{max}} \varphi_{1i}\, lnOIL_{t-i} + \mu_{1t} \quad (6)$$

In Equation 6, where the dependent variable is economic growth, the null hypothesis is that there is no causality from oil consumption to economic growth.

$$lnOIL_t = \theta_0 + \sum_{i=1}^{k+d_{max}} \delta_{2i}\, lnOIL_{t-i} + \sum_{i=1}^{k+d_{max}} \varphi_{2i}\, lnGNI_{t-i} + \mu_{2t} \quad (7)$$

On the other hand, in Equation 7, where the dependent variable is oil consumption, the null hypothesis is that there is no causality from economic growth to oil consumption. These equations will be adapted to other models.

4. Results and Discussions

According to the descriptive statistics values in Table 3, all variables’ close average and median values give the impression that they are normally distributed. Except for the lnGAS variable, all variables exist normally distributed since the probability values of the Jarque-Bera test statistic are more remarkable than 0,05.

Table: 3
Descriptive Statistics

	lnGNI	lnOIL	lnCOAL	lnGAS	K	lnL
Mean	8,139225	6,787692	5,764395	4,793703	22,52347	16,74754
Median	8,051978	6,952512	5,820112	5,393851	23,57077	16,79202
Maximum	9,443830	7,421371	6,430642	7,017787	29,85714	17,17384
Minimum	6,327937	5,860294	4,822378	0,321214	14,39553	16,30722
Std. Dev.	0,891971	0,415133	0,494873	2,191022	5,006016	0,247175
Skewness	0,007404	-0,432130	-0,531938	-1,010563	-0,266968	-0,096703
Kurtosis	1,879850	2,219630	2,043833	2,704977	1,693271	2,115902
Jarque-Bera	2,562201	2,768341	4,177430	6,779482	3,985258	1,638069
Probability	[0,2777]	[0,2505]	[0,1238]	[0,0337]	[0,1363]	[0,4409]
Observations	49	49	49	39	48	48

First, we evaluate the stationarity to verify that none of the variables is I(2), which is a critical rule for NARDL approaches (Akçay, 2021: 3). Table 4 proves that none of these variables is I(2). According to the LS test in Table 4, all variables except gas consumption are I(1). The gas consumption and capital variables are I(0).

Table: 4
Lee and Strazicich (LS) Unit-Root Test Results

Variables	Level			First Difference			Decision
	Lag	Break Years	t-statistic	Lag	Break Years	t-statistic	
lnGNI	1	1999-2009	-3,618525*	2	1988-1998	-4,958640***	I (1)
lnOIL	3	1999-2013	-4,729090	4	1985-1992	-8,114618***	I (1)
lnCOAL	1	1991-2006	-3,992974	1	1978-2017	-5,335692***	I (1)
lnGAS	3	1981-1998	-10,34347***	-	-	-	I (0)
K	2	1985-2009	-3,766012**	-	-	-	I (0)
lnL	3	1994-2007	-3,280069	0	1978-1980	-3,778664**	I (1)

*Notes: *, **, and *** denote 10, 5, and 1% significance levels, respectively.*

Following the stationarity tests, a possible non-linear co-integration relationship is detected by F-bounds and t-bounds tests. For these tests, the proper lag length is first figured out. Since the data is annual, the maximum lag length is 2. Also, lags are determined based on (AIC) the Akaike Information Criterion. F-bounds and t-bound test outcomes are exhibited in Table 5. According to Model 1, the F_{PSS} statistic is higher than the upper-critic value at a 1% significance level; the t_{BDM} value is much less than the lower critical limit value at a 10% significance level. On the other hand, these bounds test results are significant at the 1% significance level according to Model 2 and at the 5% significance level according to Model 3. In addition, the fact that the short-term error correction term coefficient in all models is negative and statistically significant provides additional evidence that the models are cointegrated. According to these test results, all models have a non-linear co-integration relationship. Similar findings were found in the studies of Hammoudeh et al. (2015), Bayramoglu & Yildirim (2017), Luqman et al. (2019), Jiang & Chen (2020), Awodumi & Adewuyi (2020), Wu (2020); Ha & Ngoc (2021).

Table: 5
F-Bounds and t-Bounds Test Results

Model 1: NARDL (2, 1, 1, 0, 2, 2, 1) k:6 m:2			F critical values		F critical values		t-critical values	
$f\,(lnGNI \mid lnOIL_t^{+}, lnOIL_t^{-}, K_t^{+}, K_t^{-}, lnL_t^{+}, lnL_t^{-})$			n=1.000		n=45			
F and t-statistic	Result		I (0)	I (1)	I (0)	I (1)	I (0)	I (1)
F **PSS: 5,55*****	Co-integration	10%	2,12	3,23	2,327	3,541	-2,57	-4,04
t **BDM: -3,57***	Co-integration	5%	2,45	3,61	2,764	4,123	-2,86	-4,38
		1%	3,15	4,43	3,79	5,411	-3,43	-4,99
Model 2: NARDL (2, 2, 1, 0, 2, 1, 0) k:6 m:2			F critical values		F critical values		t-critical values	
$f\,(lnGNI \mid lnCOAL_t^{+}, lnCOAL_t^{-}, K_t^{+}, K_t^{-}, lnL_t^{+}, lnL_t^{-})$			n=1.000		n=45			
F and t-statistic	Result		I (0)	I (1)	I (0)	I (1)	I (0)	I (1)
F **PSS: 9,56*****	Co-integration	10%	2,12	3,23	2,327	3,541	-2,57	-4,04
t **BDM: -5,96*****	Co-integration	5%	2,45	3,61	2,764	4,123	-2,86	-4,38
		1%	3,15	4,43	3,79	5,411	-3,43	-4,99
Model 3: NARDL (2, 2, 0, 1, 2, 2, 2) k:6 m:2			F critical values		F critical values		t-critical values	
$f\,(lnGNI \mid lnGAS_t^{+}, lnGAS_t^{-}, K_t^{+}, K_t^{-}, lnL_t^{+}, lnL_t^{-})$			n=1.000		n=35			
F and t-statistic	Result		I (0)	I (1)	I (0)	I (1)	I (0)	I (1)
F **PSS: 5,10****	Co-integration	10%	2,12	3,23	2,387	3,671	-2,57	-4,04
t **BDM: -4,80****	Co-integration	5%	2,45	3,61	2,864	4,324	-2,86	-4,38
		1%	3,15	4,43	4,016	5,797	-3,43	-4,99

*Note: k: number of independent variables; m: lag length; n: number of observations. *, **, and *** denote 10, 5, and 1% significance levels, respectively.*

Table 6 refers to both short and long-term asymmetry tests. For Model 1, Wald test results reveal that only the capital variable has a symmetric effect on economic growth, while oil consumption and labour variables have asymmetric impacts in the short run. On the other hand, only the labour variable has a symmetric effect on economic growth, while oil consumption and capital variables have asymmetric impacts in the long run. Model 2, in which coal consumption is an independent variable, is remarkable because all variables have asymmetric effects both in the short and long run. Parallel results are also valid for the long term of Model 3. Because in Model 3, all variables have asymmetric effects in the long run. However, in the short run, only the labour variable has asymmetric effects, while the natural gas consumption and capital variables have symmetric effects.

Table: 6
Long and Short-run Asymmetry Test Results

Model 1					
	Long run asymmetry			**Short run asymmetry**	
	Coefficient	**p-value**		**Coefficient**	**p-value**
$W_{LR,\ lnOIL}$	4,005936**	[0,0453]	$W_{SR,\ lnOIL}$	16,50221***	[0,0001]
$W_{LR,\ lnK}$	19,18069***	[0,0000]	$W_{SR,\ lnK}$	0,229597	[0,6318]
$W_{LR,\ lnL}$	0,230705	[0,6310]	$W_{SR,\ lnL}$	23,62052***	[0,0000]
Model 2					
	Coefficient	**p-value**		**Coefficient**	**p-value**
$W_{LR,\ lnCOAL}$	12,88953***	[0,0003]	$W_{SR,\ lnCOAL}$	20,12940***	[0,0000]
$W_{LR,\ lnK}$	32,25771***	[0,0000]	$W_{SR,\ lnK}$	12,86543***	[0,0003]
$W_{LR,\ lnL}$	5,837989**	[0,0157]	$W_{SR,\ lnL}$	37,10628***	[0,0000]
Model 3					
	Coefficient	**p-value**		**Coefficient**	**p-value**
$W_{LR,\ lnGAS}$	5,180483**	[0,0228]	$W_{SR,\ lnGAS}$	1,570986	[0,2101]
$W_{LR,\ lnK}$	33,05549***	[0,0000]	$W_{SR,\ lnK}$	0,066093	[0,7971]
$W_{LR,\ lnL}$	4,379709**	[0,0364]	$W_{SR,\ lnL}$	55,78171***	[0,0000]

*Notes: *, **, and *** denote 10, 5, and 1% significance levels, respectively. "WLR" is the long-run Wald test, and "WsR" is the short-run Wald test.*

Table 7 shows NARDL estimation results and forms the basis for calculating long-term coefficients. For example, the long-term positive coefficient (L_{lnOIL}^{+}) value (1,862858) of the oil variable in Table 8 for Model 1 is calculated as follows: the coefficient of the

L_{LNOIL}^{+} variable, which expresses the one-period lag value of the increases in the oil variable (0,450126), and the coefficient of the $\ln GNI_{t-1}$ dependent variable (-0,241632), found by dividing by its negative sign value. $[-\,lnOIL\,^{+}_{t-1}/\,lnGNI_{t-1} = -(0{,}450126/-0{,}241632 = 1{,}862858]$. Similarly, the long-term coefficient estimation of other independent variables was calculated separately in the light of the explanations made, and the estimation results are presented in Table 8 below.

Table: 7
Estimation of NARDL Results

	Model 1		Model 2		Model 3	
	Coefficient	**p-value**	**Coefficient**	**p-value**	**Coefficient**	**p-value**
Constant	1,737091***	[0,0020]	2,660569***	[0,0000]	3,943329***	[0,0001]
$lnGNI_{t-1}$	-0,241632***	[0,0013]	-0,362567***	[0,0000]	-0,568530***	[0,0001]
$K\,^{+}_{t-1}$	0,021018**	[0,0117]	0,036511***	[0,0000]	0,043386***	[0,0007]
$K\,^{-}_{t-1}$	-0,006434	[0,4777]	-0,026823***	[0,0056]	-0,004525	[0,4948]
L^{+}	-0,909097**	[0,0242]	-0,767084***	[0,0007]		
$L\,^{+}_{t-1}$					-1,434303***	[0,0005]
$L\,^{-}_{t-1}$	-0,524413	[0,5630]	-2,386289***	[0,0006]	1,713874	[0,1510]
$lnOIL\,^{+}_{t-1}$	0,450126*	[0,0986]				
$lnOIL\,^{-}_{t-1}$	1,324579**	[0,0141]				
$lnCOAL\,^{+}_{t-1}$			-0,185501**	[0,0466]		
$lnCOAL^{-}$			0,380613***	[0,0001]		
$lnGAS\,^{+}_{t-1}$					0,082055***	[0,0029]
$lnGAS^{-}$					-0,312784	[0,3455]
$\Delta lnGNI_{t-1}$	0,276170**	[0,0313]	0,328661***	[0,0055]	0,375796**	[0,0125]
ΔK^{+}	0,031941***	[0,0017]	0,033358***	[0,0003]	0,022140**	[0,0142]
$\Delta K\,^{+}_{t-1}$			-0,018964**	[0,0128]		
ΔK^{-}	0,023994	[0,0069]	0,004418	[0,5743]	0,015920*	[0,0820]
$\Delta K\,^{-}_{t-1}$					-0,012812	[0,1337]
ΔL^{+}					-0,197494	[0,7970]
$\Delta L\,^{+}_{t-1}$					0,688039	[0,2643]
ΔL^{-}	2,005337	[0,1008]	1,184739	[0,1585]	0,788598	[0,4207]
$\Delta L\,^{-}_{t-1}$	3,419241**	[0,0104]	4,757093***	[0,0000]	4,642178***	[0,0010]
$\Delta lnOIL^{+}$	-0,125908	[0,6724]				
$\Delta lnOIL\,^{+}_{t-1}$	-0,977374***	[0,0007]				
ΔOIL^{-}	0,433220	[0,4655]				
$\Delta lnCOAL^{+}$			-0,384582***	[0,0052]		
$\Delta lnGAS^{+}$					-0,157400***	[0,0093]
$\Delta lnGAS\,^{+}_{t-1}$					-0,068635	[0,2324]

*Notes: "+" and "-" denote negative and positive partial sums, and *, **, and *** denote 10, 5, and 1% significance levels, respectively.*

The coefficients in Table 8 are calculated based on Table 7 and show the long-term coefficients. For Model 1, the long-term positive coefficient of oil consumption does not significantly impact long-term economic growth, while the negative coefficient is significant. This result means that in the long run, in case of a negative shock of 1% in total oil consumption, per capita income will decrease by about 5,5%. The response of per capita income to a decrease in oil consumption predominates more than the increase in oil consumption out and away.

Like the asymmetric test results, all the long-term coefficients of Model 2 are statistically significant. In the long run, both positive and negative shocks in coal consumption affect economic growth negatively. In case of a 1% increase in coal consumption, the economy will contract by 0,5%, while in a 1% decrease in coal consumption, the economy will contract by 1,05%. Parallel to Model 1, the effect of adverse shocks is more evident in Model 2. In other words, the response of economic growth to a decrease in coal consumption is nearly twice as remarkable as its response to an increase in coal consumption.

In Model 3, the long-term positive coefficient of the gas consumption variable is significant and positive at the 1% significance level. This result means that if there is a 1% positive shock in total gas consumption in the long term, economic growth increases by approximately 0,14%. However, the long-run negative coefficient of this variable is statistically insignificant and positive. To summarise, in this study, we focused on fossil energy consumption. The adverse effects of decreases in fossil energy consumption on economic growth are more dominant than the positive effects of increases in fossil energy consumption on economic growth in general.

Table: 8
Long-Run Coefficients Estimation

Model 1					
	Coefficient	**p-value**		**Coefficient**	**p-value**
L_{lnOIL}^{+}	1,862858	[0,1800]	L_{lnOIL}^{-}	5,481803*	[0,0589]
L_{K}^{+}	0,086983***	[0,0043]	L_{K}^{-}	-0,026627	[0,4825]
L_{lnL}^{+}	-3,762320*	[0,0690]	L_{lnL}^{-}	-2,170297	[0,5557]
Model 2					
	Coefficient	**p-value**		**Coefficient**	**p-value**
L_{lnCOAL}^{+}	-0,511633**	[0,0449]	L_{lnCOAL}^{-}	1,049774***	[0,0008]
L_{K}^{+}	0,100703***	[0,0000]	L_{K}^{-}	-0,073980***	[0,0047]
L_{lnL}^{+}	-2,115704***	[0,0006]	L_{lnL}^{-}	-6,581655***	[0,0030]
Model 3					
	Coefficient	**p-value**		**Coefficient**	**p-value**
L_{lnGAS}^{+}	0,144328***	[0,0005]	L_{lnGAS}^{-}	-0,550163	[0,3144]
L_{K}^{+}	0,076313***	[0,0000]	L_{K}^{-}	-0,007959	[0,4883]
L_{lnL}^{+}	-2,522827***	[0,0000]	L_{lnL}^{-}	3,014570	[0,1273]

*Notes *, **, and *** denote 10, 5, and 1% significance levels, respectively.*

Table 9 denotes diagnostic tests. Diagnostic tests reveal no heteroscedasticity, serial correlation, or functional form problems for Models 1 and 2. However, these explanations for Model 3 cannot be verified.

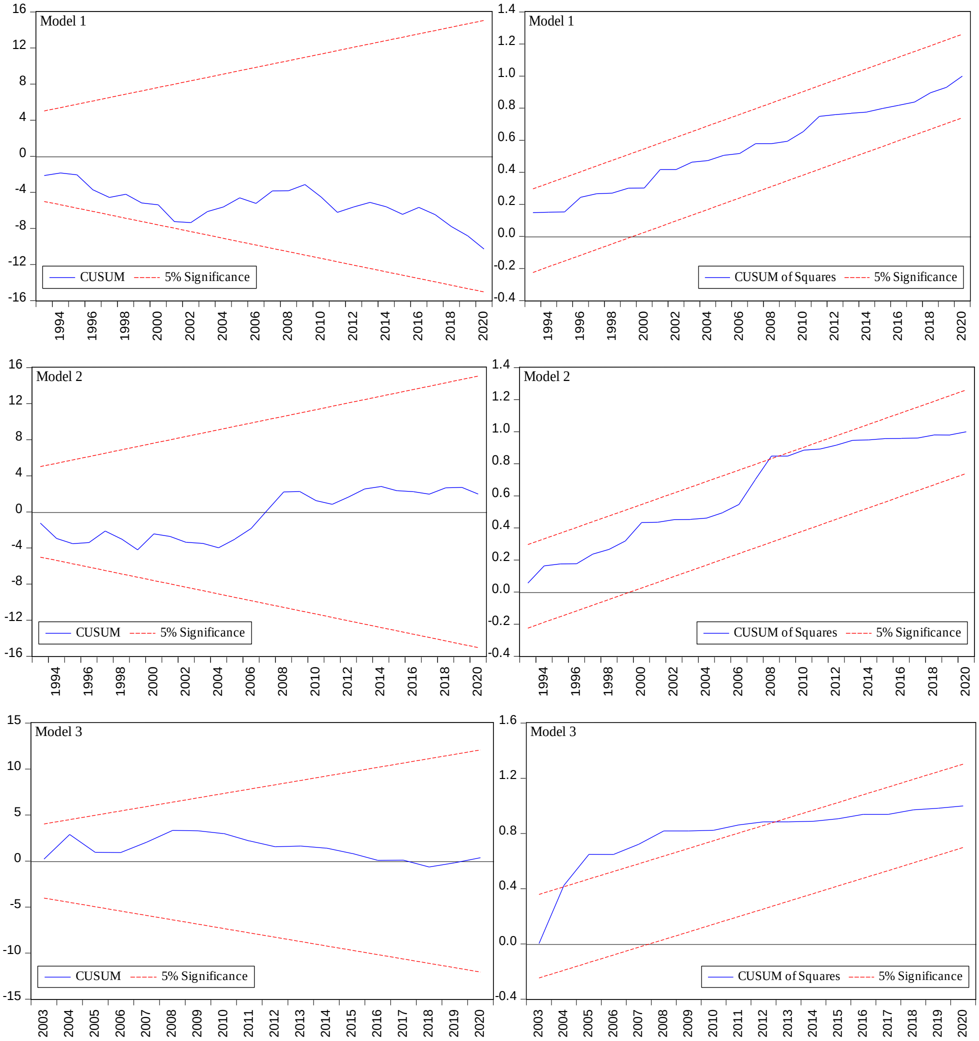
Table 9
Diagnostic Tests Results

	Model 1		**Model 2**		**Model 3**	
	Test value	**p-value**	**Test value**	**p-value**	**Test value**	**p-value**
X^2_{SC}	3,904411	[0,1420]	2,739156	[0,2542]	17,82379	[0,0001]
X^2_{FF}	0,303611	[0,5860]	0,093431	[0,7620]	1,956635	[0,1799]
X^2_{NORM}	2,139000	[0,3432]	2,286966	[0,3188]	4,870085	[0,0876]
$X^2_{HET(ARCH)}$	0,461455	[0,4969]	0,100682	[0,7510]	0,228555	[0,6326]
$X^2_{HET(BPG)}$	7,577173	[0,9396]	10,37994	[0,7339]	19,86021	[0,2814]
CUSUM	Stable		Stable		Stable	
$CUSUM^2$	Stable		Stable		Unstable	

"X^2_{SC}": Serial correlation; "X^2_{NORM}": Normality: Jarque-Bera; "X^2_{FF}": Functional form; "$X^2_{HET(BPG)}$ and $X^2_{HET(ARCH)}$": Heteroscedasticity.

For Models 1 and 2, the CUSUM and CUSUMSQ graphs also show stability because the plot is inside critical bounds at 5%. However, some problems exist in Model 3. Model 3 has a serial correlation problem and an unstable CUSUMSQ graph, so its coefficients are suspicious.

Figure: 1
NARDL CUSUM and CUSUM of Squares Graphs



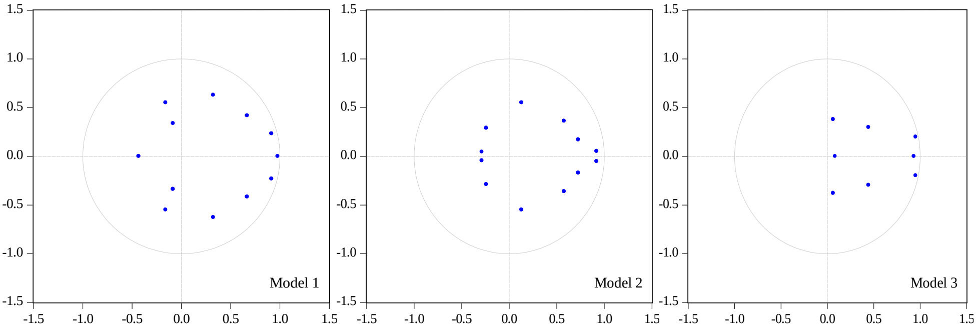
According to the NARDL test results, long-term asymmetrical cointegration is clear. Because of the cointegration, causality relationships can be predicted. The Toda-Yamamoto causality test is preferred because the variables are not stationary at the same level. For this test, the first step is to decide the most appropriate lag length. For this purpose, the information criteria obtained from the standard VAR model are in Table 10. According to this table, the optimal lag lengths for Models 1 and 2 are 2. On the other hand, the optimal lag length for Model 3 is 1.

Table: 10
VAR Latency Length Criteria

	Lag	LogL	LR	FPE	AIC	SC	HQ
Model 1	0	-63,19833	NA	0,000249	3,054470	3,216669	3,114621
	1	134,9855	351,3260	6,34e-08	-5,226616	-4,415620*	-4,925860
	2	159,7715	39,43223*	4,33e-08*	-5,625978*	-4,166187	-5,084617*
	3	170,8015	15,54229	5,71e-08	-5,400070	-3,291482	-4,618104
	4	184,8519	17,24369	6,87e-08	-5,311452	-2,554068	-4,288881
Model 2	0	-100,9102	NA	0,001384	4,768648	4,930847	4,828799
	1	94,73697	346,8292	3,95e-07	-3,397135	-2,586140*	-3,096379*
	2	113,1113	29,23192*	3,61e-07*	-3,505060*	-2,045269	-2,963699
	3	119,6356	9,193260	5,84e-07	-3,074344	-0,965757	-2,292378
	4	134,4119	18,13459	6,80e-07	-3,018723	-0,261339	-1,996152
Model 3	0	-122,8634	NA	0,013521	7,047969	7,223916	7,109379
	1	60,29140	315,4333*	1,26e-06*	-2,238411*	-1,358678*	-1,931361*
	2	75,14766	22,28439	1,39e-06	-2,174870	-0,591351	-1,622180
	3	82,65487	9,592547	2,45e-06	-1,703048	0,584257	-0,904718

Figure 2 shows the models' inverse roots of AR characteristic polynomials inside the unit circle (Hendry & Juselius, 2001). Therefore, we interpret the established VAR model as stationary (Karakuş & Atabey, 2021).

Figure: 2
Inverse Roots of AR Characteristic Polynomial in Models



The LS unit root tests in the Table above show that the variables are stationary at the maximum I(1) level. Therefore, we decide that the highest degree of integration of the series is d_{max}=1. In Table 10 above, we detect that for Models 1 and 2, optimal lag length values (k) were two, while Model 3 was one. For the Toda-Yamamoto causality analysis, we decide that the optimal total lag lengths for the first two models are 3 (k+d_{max}=2+1=3), while Model 3 is 2 (k+d_{max}=2+1=3). The results obtained for this situation are in Table 11.

Tablo: 11
Toda-Yamamoto Causality Test Results

H_0	Model 1		Model 2		Model 3		H_0 Decision		
	Wald Stat.	Prob.	Wald Stat.	Prob.	Wald Stat.	Prob.	Model 1	Model 2	Model 3
lnOIL⇏lnGNI	7,3438**	[0,0254]	-	-	-	-	Reject	-	-
lnGNI⇏lnOIL	3,0875	[0,2136]	-	-	-	-	Accept	-	-
lnCOAL⇏lnGNI	-	-	3,6229	[0,1634]	-	-	-	Accept	-
lnGNI⇏lnCOAL	-	-	0,1922	[0,9084]	-	-	-	Accept	-
lnGAS⇏lnGNI	-	-	-	-	5,4005**	[0,0201]	-	-	Reject
lnGNI⇏lnGAS	-	-	-	-	5,3366**	[0,0209]	-	-	Reject
lnGNI⇏K	10,8865***	[0,0043]	4,0776	[0,1302]	2,2245	[0,1358]	Reject	Accept	Accept
K⇏lnGNI	13,7199***	[0,0010]	9,2478***	[0,0098]	12,8883***	[0,0003]	Reject	Reject	Reject
lnGNI⇏lnL	11,3168***	[0,0035]	11,135***	[0,0038]	12,3031***	[0,0005]	Reject	Reject	Reject
lnL⇏lnGNI	14,2901***	[0,0008]	8,4033**	[0,0150]	13,5905***	[0,0002]	Reject	Reject	Reject

*Notes: *, **, and *** denote 10, 5, and 1% significance levels, respectively. Model 1 and 2: $k+d_{max}=2+1=3$. Model 3: $k+d_{max}=1+1=3$*

According to the Toda-Yamamoto Granger causality test results for Model 1, a one-way (unidirectional) causality relationship exists, going from oil consumption to economic growth. This result shows that oil consumption is an influential factor in economic growth. There is a two-way (bidirectional) causality between economic growth and other variables. In other words, bidirectional causality relationships exist between economic growth and capital variables and between economic growth and labour variables. These results show a feedback relationship between economic growth, labour, and capital variables and that these variables can shape each other.

In Model 2, there is no causal relationship between coal consumption and economic growth. However, a unidirectional causality relationship exists, going from the capital variable to economic growth. In addition, bidirectional causality relationships exist between economic growth and labour variables.

In Model 3, bidirectional causality relationships exist between economic growth and natural gas consumption variables and between economic growth and labour variables. On the other hand, like Model 2, a unidirectional causality relationship exists, going from capital variable to economic growth.

5. Conclusion

In realising sustainable economic growth and development efforts, energy is undoubtedly one of the most fundamental factors countries should have. After steam power in machines, energy is essential for economic development and growth. Especially in recent years, technological advances have increased the need for energy. For these reasons, production and EC are among the most significant issues on policymakers' agendas. Due to this essential function, both the production and consumption of energy are considered indicators of development for countries today.

Despite this increasing EC, sustainable economic development targets (Selçuk et al., 2019) nearly every country's principal goals. In order to achieve this goal, there is no doubt that energy resources should not be wasted, waste of energy resources should be prevented, and renewable energy resources should be used rather than fossil fuels. The understanding of “sustainable development,” which envisages the realisation of development without consuming the resources of future generations today, is a complex process involving many actors and factors (Göçoğlu, 2022: 2). While this understanding provides that future generations live in a better environment, it also brings along a complex policy process that must manage effectively to ensure the optimum use of resources against the ever-increasing world population and human needs (Campagna, 2005: 3). It can be said that more effective energy policies are necessary, especially in countries like Türkiye, where energy production does not meet EC. Foreign dependency on energy causes high prices of energy resources in the country and creates pressure, especially on producer costs. Rising energy costs weaken competitiveness, exclude domestically produced goods and lower national income.

According to earlier empirical studies on FEC, linear methods are predominant. In other words, these studies conducted with linear methods show that the effects of increases and decreases in the coefficients of the independent variables on the dependent variable are the same. This paper explores the impacts of FEC usage on growth in Türkiye by employing the NARDL method. Results reveal that there is an asymmetric co-integration relationship between the variables. This means that the effect of the increase and decrease in the independent variable on the dependent variable is different. When examining the models comprehensively, it becomes evident that the impact of declining energy consumption on gross national income per capita across all models is significantly more pronounced than the effect of increased energy consumption. This discrepancy primarily stems from Türkiye’s reliance on imported energy resources, particularly in fossil fuels like oil and natural gas, due to the limited availability of domestic resources. Using fossil fuels as a critical input within Türkiye’s industrial production means reducing energy consumption, which decreases gross national income per capita. In this context, policymakers should primarily turn to alternative and renewable energy sources instead of fossil fuels to reduce foreign dependency and diversify energy supply. Exploration activities for discovering domestic energy resources should be accelerated, and more investments should be made in research and development studies for renewable energy technologies. On the other hand, while increases in the capital variable, a common independent variable in the models, positively affect economic growth in the long term, the negative effect of the labour variable, which expresses the number of persons engaged, is striking. Causality tests reveal a bidirectional relationship between economic growth and natural gas consumption and confirm the feedback hypothesis. No causality between economic growth and coal consumption has been found, and the neutrality hypothesis is confirmed. A one-way causality relationship between oil consumption and economic growth confirms the growth hypothesis. Finally, an essential limitation of the study is that it does not include renewable energy sources. Therefore, modifying the created models to renewable energy sources can be recommended for future studies.

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