

## The Dynamic Effect of Biomass Energy Consumption on Economic Growth and Environmental Quality in Turkey

*Mohammed ALNOUR* (<https://orcid.org/0000-0003-3276-7380>), Erciyes University, Turkey;  
[mohamedmershing88@gmail.com](mailto:mohamedmershing88@gmail.com)

*Hayriye ATİK* (<https://orcid.org/0000-0001-7480-080X>), Erciyes University, Turkey; [atik@erciyes.edu.tr](mailto:atik@erciyes.edu.tr)

### Türkiye’de Biokütle Enerji Tüketiminin Ekonomik Büyüme ve Çevre Kalitesi Üzerindeki Dinamik Etkisi

#### Abstract

This study investigates the impact of biomass energy consumption on Turkey's economic growth and environmental quality. The research used annual time series data from 2004 to 2019. The ADF and Phillips-Perron unit root tests were utilised to test the stationarity of the series. In this study, the ARDL model is employed as an estimation technique. The results indicate that biomass energy consumption helps to reduce pollution and improve environmental quality in the long-run and short-run in Turkey, while economic growth and technological innovation increase the environmental deterioration. Therefore, this paper recommends that economic policymakers, specifically in Turkey, consider strategies that support sustainable economic growth using reusable energy sources.

**Keywords** : Economic Growth, EKC, Technological Innovation, Environmental Pollution, Time Series, Ecological Footprint.

**JEL Classification Codes** : Q53, Q56, Q57, R11.

#### Öz

Bu çalışma, Türkiye’de biokütle enerjisi tüketiminin ekonomik büyüme ve çevre kalitesi üzerindeki etkisini araştırmaktadır. Araştırmada 2004-2019 yılları arasındaki yıllık zaman serisi verileri kullanılmıştır. Serilerin durağanlığını test etmek için ADF ve Phillips-Perron birim kök testleri kullanılmıştır. Bu çalışmada bir tahmin tekniği olarak ARDL modeli kullanılmıştır. Sonuçlar, biokütle enerji tüketiminin Türkiye’de uzun ve kısa vadede kirliliği azaltmada ve çevre kalitesini iyileştirmede yardımcı olduğunu, ekonomik büyüme ve teknolojik yeniliklerin ise çevresel bozulmayı artırdığını göstermektedir. Bu nedenle, bu makale, özellikle Türkiye’deki ekonomi politikası yapıcılarının, temiz ve yeniden kullanılabilir enerji kaynakları kullanarak sürdürülebilir ekonomik büyümeyi destekleyen stratejileri dikkate almalarını tavsiye etmektedir.

**Anahtar Sözcükler** : Ekonomik Büyüme, EKC, Teknolojik Yenilik, Çevre Kirliliği, Zaman Serisi, Ekolojik Ayak İzi.

## 1. Introduction

The primary goal of economic activities is to increase human welfare, and rapid economic growth is seen as a way to reach this goal. However, when production increases the use of resources while the relative cost of production factors diminishes, wastes generated by the production and consumption process increase the environmental cost. As long as economic growth occurs, the use of natural resources will exceed production capacity, leading to an increase in the amount of waste and greenhouse gas emissions (Pata, 2018).

Therefore, human beings are presently confronted by two significant challenges; economic growth and preserving the environment (Uddin et al., 2017). When the economy starts moving along the development trajectory, then at the earliest stage of the economic growth environment deteriorates due to air pollution, deforestation, and many other pollutants. With an increase in per capita income economy starts to develop, and environmental deterioration declines (Sinha & Shahbaz, 2018). As environmental degradation has become more severe, the relationship between environmental degradation and economic growth has become an increasingly important issue (Tutulmaz, 2015).

One may claim that researchers in the 21<sup>st</sup> century are aware of air pollution's growing severe threat to human health and welfare. Therefore, the source of environmental deterioration has become today's most serious concern in the scientific literature on the environment, climate change, and global warming. The interest in the possible relationships between energy consumption, environmental quality, and economic growth dates back to the early 1970s, when policymakers and researchers started to be aware of the potential connection between energy consumption, environmental quality, and economic growth. Discussion concerning the relationship between economic growth, energy consumption, and environmental quality has received considerable attention over the last few years, but researchers have no consensus.

The unprecedented level of carbon dioxide in the earth's atmosphere poses challenges to humans' and other life forms' health. CO<sub>2</sub> emissions have reached their highest level in recorded history; they increased from 19,809 million tons to 33,431 million tons. It is considered the leading cause of global warming and climate change since it contributes to more than 60% of greenhouse gas (GHG) emissions (Danish & Ulucak, 2020).

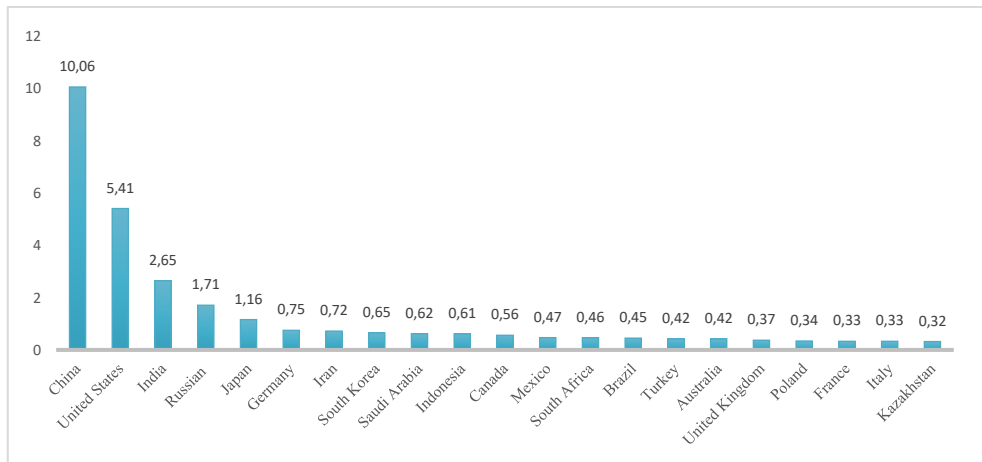
As a result of increasing environmental degradation, demand for clean and reusable energy has increased. The generation and consumption of clean energy sources like biomass and other reusables are the most effective tools for addressing rising environmental concerns (Owusu & Asumadu-Sarkodie, 2016). Biomass energy consumption and development may be the foundation of a sustainable energy system by changing the pattern of energy production and consumption, which can efficiently contribute to economic growth and strengthen environmental protections (Mao et al., 2018).

Biomass is expected to contribute half the 20% renewable target. Kaygusuz (2012) foresees that fossil fuels meet 80% of global energy demand in 2008 and will be corresponding to 78% of global demand in 2030. Do renewable energy sources reduce environmental damage? Or, more specifically, can biomass energy use improve environmental quality? And what is its impact on economic growth? Or in other words, how is economic growth affected by an increase in renewable energy consumption?

Turkey has experienced a significant increase in energy consumption and carbon emissions alongside economic growth. According to the International Energy Agency (IEA), Turkey is among the 20 countries that emitted the most carbon dioxide in 2018; as in figure 1, Turkey's share in carbon emissions is 1% of the entire world's emissions.

In its eleventh development plan (2019-2023), Turkey aims to protect the environment and natural resources, improve quality, ensure effective, integrated, and sustainable management, implement environment and climate-friendly practices in all areas, and increase environmental awareness and sensitivity of all segments of the society. In addition, and within the scope of national conditions, climate change will be tackled in sectors causing greenhouse gas emissions, and the resilience of the economy and society to climate risks will be increased by capacity building for adaptation to climate change (see, Eleventh Development Plan, 2019-2023).

**Figure: 1**  
**The 20 Countries That Emitted the Most Carbon Dioxide in 2018**



Source: International Energy Agency (IEA).

For these reasons, investigating the impact of renewable energy consumption on economic growth and environmental degradation in Turkey is very important. It will significantly contribute to designing environmental management policies and their implementation. In this regard and within the framework of the Kuznets Curve Hypothesis,

many studies have investigated the link between economic growth and environmental quality in Turkey (see, for instance, Altınay et al., 2004; Erdal et al., 2008; Halicioğlu, 2009; Jobert & Karanfil, 2007; Lise & Van Montfort, 2007; Lise, 2006; Canbay, 2019; Say & Yücel, 2006; Soytas, 2001; Soytas & Sari, 2009; Soytas & Sari, 2003). However, none of these studies has examined the influence of renewable energy consumption, specifically biomass energy consumption, on Turkey's economic growth and environmental quality. Therefore, unlike the previous studies, this research aims to investigate the impact of renewable energy use on Turkey's economic growth and environmental quality.

The rest of the paper is organised as follows: Section two reviews important literature on the subject. Section three presents the methodology. Section four shows the results and discussion, while section five provides the conclusion.

## **2. Literature Review**

This study investigates the impact of biomass energy consumption on Turkey's economic growth and environmental quality. We classified the literature review into two parts: biomass energy consumption-economic growth nexus and biomass energy consumption-environmental quality nexus.

### **2.1. Biomass Energy Consumption-Economic Growth Nexus**

Over the last few decades, many studies have investigated the association between economic growth and energy consumption in the context of causality. However, the empirical outcomes of the studies that examined the relationship between these variables are mixed and inconclusive. In his survey of the recent progress in the literature on energy consumption-economic growth, Ozturk (2010) concluded that using different data sets, alternative econometric methodologies, and other countries' characteristics are the main reasons for this conflicting result. In addition, the survey highlights that most empirical studies focus on either testing the role of energy (electricity) in stimulating economic growth or examining the direction of causality between these two variables. (Apergis & Payne, 2009a; Squalli, 2007; Chen et al., 2007; Mozumder & Marathe, 2007) argued that the directions that the causal relationship between energy consumption and economic growth could be categorised into four types of hypotheses:

First, the neutrality hypothesis; means no causal relationship between energy consumption and economic growth. In other words, neither conservative nor expansive policies about energy consumption affect economic growth. Second, the conservation hypothesis; means a uni-directional causality running from economic growth to energy consumption. The validity of this hypothesis is confirmed if an increase in economic growth increases energy consumption. Third, the growth hypothesis; means that energy consumption plays a substantial role in economic growth directly and indirectly in the production process as a complement to labour and capital. Fourth, the feedback hypothesis;

implies that energy consumption and economic growth are jointly determined and affected simultaneously.

Recently, many studies have examined the relationship between renewable energy consumption and economic growth. These studies are as follows: Shahbaz et al. (2016) examined the relationship between biomass energy consumption and economic growth by incorporating capital and trade openness in production function for the case of BRICS countries. The results showed that the feedback effect exists between biomass energy consumption and economic growth. Aydin (2019) found different results when he investigated the impact of biomass energy consumption on economic growth in BRICS countries using a country-specific panel data analysis. He concluded that the growth hypothesis is valid in Brazil and India; however, the conservation hypothesis is valid in China and South Africa. The feedback hypothesis is supported in the case of Russia. Ajmi and Inglesi-Lotz, (2020) found a feedback hypothesis when studying the short-run and long-run causality analyses between biomass energy consumption and economic growth nexus in OECD countries using panel cointegration analyses, dynamic OLS analyses, fully modified OLS analyses, and panel VECM Granger causality tests.

Bildirici and Özaksoy (2016) also tested the causal relationship between woody biomass energy consumption and economic growth in Sub-Saharan Africa using the ARDL model. They found a uni-directional causality from woody biomass energy consumption to economic growth for Angola, Guinea-Bissau, and Niger, from economic growth to woody biomass energy consumption for Seychelles. The bidirectional relationship is confirmed for Benin, Mauritania, Nigeria, and South Africa. Bhattacharya et al. (2016) used Renewable Energy Country Attractiveness Index to investigate the effects of renewable energy consumption on the economic growth in major renewable energy-consuming countries worldwide. They confirmed the evidence of long-run dynamics between economic growth and traditional and energy-related inputs. Ali et al. (2017) investigated the dynamic implication of biomass energy consumption on economic growth in Sub-Saharan African countries using panel data analysis. They concluded a causal relationship between biomass energy consumption and economic growth. Their findings reveal that biomass energy consumption, capital stock, and human capital positively influence economic growth at a 1% level.

Destek (2017) studied the relationship between biomass energy consumption and economic growth in the top ten biomass consumer countries. The obtained results indicate that the growth hypothesis is valid for Brazil, Germany, India, and Italy; the conservation hypothesis is proved in Sweden; the feedback hypothesis is supported in China and the United States, and the neutrality hypothesis is confirmed in Finland, Japan, and the United Kingdom. Bilgili and Ozturk (2015) tested the long-run dynamics of biomass energy consumption and GDP growth through homogeneous and heterogeneous variance structures for G7 countries. The study's findings indicate that the growth hypothesis is valid, which means that biomass energy consumption positively affects the economic growth of G7 countries. Aslan (2016) confirmed the growth hypothesis when studying the causal

relationship between energy consumption and economic growth in the U.S. using the ARDL model.

## **2.2. Biomass Energy Consumption-Environmental Quality Nexus**

Many studies have examined the use of biomass energy to improve environmental quality using different econometric methods. However, researchers have no consensus on whether biomass energy use improves or worsens the environmental quality. Zafar et al. (2021) investigated the impact of biomass energy consumption on environmental quality in Asia-Pacific Economic Cooperation countries using the panel quantile regression. The results indicate that biomass energy consumption and technological innovation reduce environmental quality.

Umar et al. (2021) studied the imperativeness of environmental quality in the United States transportation sector amidst biomass-fossil energy consumption and growth by employing FMOLS, DOLS, and CCR cointegration regression. They concluded that biomass energy consumption has a negative impact on carbon dioxide emissions in the transportation sector. Unlike the previous studies, Shahbaz et al. (2019) found that biomass energy consumption contributes to CO<sub>2</sub> emissions when investigating the factors influencing CO<sub>2</sub> using the generalised method of moments.

By employing the generalised method of the moments, Wang (2019) checked the effect of biomass energy consumption on environmental pollution in BRICS countries. The empirical study findings show that biomass energy consumption behaves as a clean energy source in reducing environmental pollution. But Solarin et al. (2018) concluded that biomass energy consumption increases carbon emissions in developed and developing countries. Within the Environmental Kuznets Curve hypothesis, Bilgili et al. (2016) found a negative causality from renewables to CO<sub>2</sub> emissions.

However, Sarkodie et al. (2019) reported a negative relationship between biomass energy and carbon emissions when investigating the link between biomass energy consumption and carbon emissions and other control variables in Australia. The study results suggest that Australia can improve environmental quality by increasing the share of biomass energy in the total power. Ahmed et al. (2016) studied the link between biomass energy, technological progress, and the environmental Kuznets curve in selected European countries. In particular, the results indicate that biomass energy is insignificantly linked to CO<sub>2</sub> emission. However, technological innovation significantly facilitates the reduction of CO<sub>2</sub> emissions.

Adewuyi and Awodumi (2017) also examined the relationship between biomass energy use, economic growth, and carbon emissions in the simultaneous education model for West African countries. The panel methodology results suggested a positive link between biomass energy use and carbon emissions; however, they found mixed results for the time series analysis. Gao and Zhang (2021) used conventional methodology to study the link

between biomass energy use and emissions in developing Asian countries. Their study results show a positive relationship between biomass energy and carbon emissions. Sulaiman and Abdul-Rahim (2020) also tested the impact of clean biomass energy on carbon emission in selected African countries. The empirical findings reveal that clean biomass energy use decreases CO<sub>2</sub> emission in the long run. But the effect of biomass energy consumption on CO<sub>2</sub> emission is insignificant in the short run. The results imply that CO<sub>2</sub> emission can be decreased by increasing clean biomass energy in the energy mix of these selected African countries.

In the light of the importance of addressing the effect of renewable energy use on economic growth and environmental quality, many studies have investigated the association between biomass energy consumption, environmental quality, and economic growth under neutrality, conservation, growth, and feedback hypotheses. However, a significant limitation of previous studies is that carbon dioxide (CO<sub>2</sub>) was used to proxy environmental quality. This measure, however, relates only to air pollution and excludes other pollutants impacting soil, forests, and other environmental aspects. Therefore, carbon dioxide as an indicator of environmental quality seems to be an inadequate measure. Therefore, to better understand the association between biomass energy use, economic growth, and environmental quality in Turkey, this study utilises the ecological footprint (EFP) to measure environmental quality.

The ecological footprint is widely used as an index of sustainability. The ecological footprint is an aggregate measure of the environment. It consists of six components of productive surface areas: carbon footprint, fishing ground, build-up, forest land, cropland, and grazing land (Solarin & Bello, 2018).

### 3. Research Methodology

#### 3.1. Model Specification and Data

This article studies the impact of biomass energy use on per capita income and ecological footprint (EFP) in both the long-run and short-run following the empirical testing procedures suggested by Narayan and Narayan (2010). According to the idea of Narayan and Narayan (2010), our two models can be specified as follows:

$$\ln EFP_t = \alpha_0 + \alpha_1 \ln BEC_t + \alpha_2 \ln GDP_t + \alpha_3 \ln TCI_t + e_t \quad (1)$$

$$\ln GDP_t = \varphi_0 + \varphi_1 \ln BEC_t + \varphi_2 \ln EFP_t + \varphi_3 \ln TCI_t + e_t \quad (2)$$

Where the EFP is the ecological footprint, BEC is the biomass energy consumption, GDP is the per capita real income, and TCI is the technological innovation and  $\alpha_1, \alpha_2, \alpha_3, \varphi_1, \varphi_2, \varphi_3$  are their long-run elasticities and  $e_t$  is the error term.

To investigate the relationship between biomass energy consumption, economic growth, and environmental quality in Turkey, this study uses the ecological footprint (EFP) and per capita real income proxy for environmental quality and economic growth. The time-

series data about EFP is obtained from the (Global Footprint Network). The per capita real income series is obtained from the World Bank (world development indicators). Data on biomass energy consumption is collected from U.S. Energy Information Administration (EIA). The data on technological innovation is obtained from European Innovation Scoreboard. All variables are transformed to the natural logarithmic form in empirical analysis.

### 3.2. Method of Estimation

Generally, most of the time-series data are non-stationary, resulting in misleading regression analysis outcomes. To test for the stationarity properties of the variables, this research applies the augmented Dickey-Fuller (1979) (ADF) and Phillips and Perron (1988) (PP) unit root tests. The null hypothesis of the ADF and PP tests indicates a unit root. To investigate the impact of biomass energy consumption on economic growth and environmental quality in Turkey, this research employs the Autoregressive Distributed Lag model due to many reasons. First, this model does not require that all variables be integrated of order zero or I(0). Second, both short-run and long-run models are estimated simultaneously. Furthermore, the ARDL method performs better in small sample sizes than other multivariate techniques. To test the existence of cointegration relationships among the variables in Models (1) and (2), the unrestricted error correction model (ECM) proposed by Pesaran et al. (2001) can be specified as follows:

$$\begin{aligned} \Delta \ln EFP_t = & \gamma_0 + \gamma_1 \ln EFP_{t-1} + \gamma_2 \ln BEC_{t-1} + \gamma_3 \ln GDP_{t-1} + \gamma_4 \ln TCI_{t-1} + \\ & \sum_{i=1}^q \gamma_5 \Delta \ln EFP_{t-i} + \sum_{i=0}^p \gamma_6 \Delta \ln BEC_{t-i} + \sum_{i=0}^m \gamma_7 \Delta \ln GDP_{t-i} + \sum_{i=0}^n \gamma_8 \Delta \ln TCI_{t-i} + \\ & \theta ECT_{t-1} + v_t \end{aligned} \quad (3)$$

$$\begin{aligned} \Delta \ln GDP_t = & \lambda_0 + \lambda_1 \ln GDP_{t-1} + \lambda_2 \ln BEC_{t-1} + \lambda_3 \ln EFP_{t-1} + \lambda_4 \ln TCI_{t-1} + \\ & \sum_{i=1}^q \lambda_5 \Delta \ln GDP_{t-i} + \sum_{i=0}^p \lambda_6 \Delta \ln BEC_{t-i} + \sum_{i=0}^m \lambda_7 \Delta \ln EFP_{t-i} + \sum_{i=0}^n \lambda_8 \Delta \ln TCI_{t-i} + \\ & \theta ECT_{t-1} + v_t \end{aligned} \quad (4)$$

Where equations (3) and (4) are ARDL models and the lag lengths (q, p, m, n) are chosen according to Akaike Information Criterion (AIC). The bound test for cointegration is conducted based on the joint null hypothesis of no cointegration  $H_0: \gamma_1 = \gamma_2 = \gamma_3 = \gamma_4 = 0$  against the alternative of cointegration  $H_1: \gamma_1 \neq \gamma_2 \neq \gamma_3 \neq \gamma_4 \neq 0$ , for equations (3) and  $H_0: \lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = 0$  of no cointegration against the alternative of cointegration  $H_1: \lambda_1 \neq \lambda_2 \neq \lambda_3 \neq \lambda_4 \neq 0$  for equations (4) The Wald F-statistic is employed to examine the existence of cointegration relationship among the selected variables. The F-statistic is compared with the lower and upper bounds critical values. If the F-statistic is greater than the upper critical bound, then the null hypothesis of no cointegration is rejected and thus cointegration does exist. If the F-statistic, however, is less than the lower critical bound the null hypothesis cannot be rejected and, therefore, cointegration does not exist. If the cointegration relationship exists, then the error correction model (ECM) can be estimated. The error correction model shows the short-run dynamics and the speed of adjustment.



#### 4. Results and Discussion

In this segment of the study, we present the discussion of the results in the following manner: initially, we set off with analysis by the investigation into the summary descriptive statistic properties. The descriptive statistic reports the measure of central tendencies and dispersion. Table 1 indicates that economic growth has the highest average, followed by technological innovation, biomass energy consumption, and ecological footprint. All series show negative Skewness except for economic growth. Furthermore, only economic growth and biomass energy use mirror the normal distribution reported by Kurtosis, less than 3.

**Table: 1**  
**Descriptive Statistic Test**

	LnEFP	LnBEC	LnGDP	LnTCI
Mean	0.656616	0.378916	9.394553	-1.991918
Median	0.675282	0.669900	9.388016	-1.937942
Maximum	0.799834	2.140066	9.628399	-1.599488
Minimum	0.437188	-2.302585	9.116223	-2.995732
Std. Dev.	0.101784	1.138985	0.170204	0.392062
Skewness	-0.474152	-0.745369	0.007729	-1.556997
Kurtosis	2.552414	3.034004	1.632686	4.640842
Jarque-Bera	0.733077	1.482306	1.246524	8.259547
Probability	0.693129	0.476564	0.536192	0.016087
Sum	10.50586	6.062651	150.3128	-31.87069
Sum Sq. Dev.	0.155398	19.45932	0.434541	2.305689
Observations	16	16	16	16

This section of the study examined the possible existence of stationarity of the variables. The Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests were used to test the stationarity. The findings of the unit root test in Table 2 show that the variables are tested at the level and first difference. The Augmented Dickey-Fuller and Phillips-Perron test results are almost similar since none of the variables is integrated into the second-order or I(2). Specifically, the ADF and PP tests show that the EFP and TCI series are stationary at the level %5 and %1 level of significance, respectively. Like BEC and GDP, the other series is stationary at the first-difference level. Mainly, the series of GDP and BEC are stationary at %10 and %5 levels of significance, respectively, in the ADF test, while the same is true in the PP test.

**Table: 2**  
**Unit Root Tests**

Variables	ADF		PP	
	C	C&T	C	C&T
LnEFP <sub>it</sub>	-0.068889	-4.751255 <sup>b</sup>	-2.185505	-6.232310 <sup>a</sup>
LnBEC <sub>it</sub>	-1.741074	-3.059223	-1.807294	-2.311215
LnGDP <sub>it</sub>	-0.995893	-2.691298	-0.992581	-2.164045
LnTCI <sub>it</sub>	-3.38205 <sup>a</sup>	-3.000889	-3.49879 <sup>b</sup>	-6.64549 <sup>a</sup>
DLnEFP <sub>it</sub>	-6.256881 <sup>a</sup>	-5.597538 <sup>a</sup>	-5.347906 <sup>a</sup>	-4.652382 <sup>c</sup>
DLnBEC <sub>it</sub>	-3.45915 <sup>b</sup>	-3.31557 <sup>c</sup>	-3.771194 <sup>b</sup>	-3.525015 <sup>c</sup>
DLnGDP <sub>it</sub>	-3.034537 <sup>c</sup>	-2.910841	-3.051839 <sup>c</sup>	-2.811967
DLnTCI <sub>it</sub>	-3.01075 <sup>b</sup>	-2.897759	-3.010753 <sup>b</sup>	-3.646600 <sup>c</sup>

Note: a,b,c denotes significant at %1, %5 and %10 respectively. C refers to intercept, and C&T refers to intercept and trend.

Although the Autoregressive Distributed Lag model or bound test to cointegration is preferable due to many advantages, it has low power since it does not consider the possibility of structural or regime shifts in the cointegrating vector (Gregory & Hansen, 1996; Hatemi-j, 2008). Table 3 illustrates the unit root test results with one structural break. The results indicate that all the variables are non-stationary at I(1). From the analysis of various unit root tests, the variables are compatible with the Autoregressive Distributed Lag model. After identifying the series order of stationarity and stationarity with a structural break, the next step is to apply the cointegration test to verify the long-run relationships among the variables.

**Table: 3**  
**ADF Unit Root Test with Structural Break**

Variables	ADF			
	C	Break date	C&T	Break date
<b>LnEFP<sub>it</sub></b>	-1.421846	2016	-6.937272 <sup>a</sup>	2014
<b>LnBEC<sub>it</sub></b>	-4.110109 <sup>c</sup>	2012	-4.767953 <sup>c</sup>	2012
<b>LnGDP<sub>it</sub></b>	-3.155443	2010	-3.742357	2012
<b>LnTCI<sub>it</sub></b>	-18.01126 <sup>a</sup>	2011	-5.480869 <sup>a</sup>	2010
<b>DLnEFP<sub>it</sub></b>	-6.842827 <sup>a</sup>	2017	-6.121959 <sup>a</sup>	2016
<b>DLnBEC<sub>it</sub></b>	-4.153096 <sup>c</sup>	2013	-3.638243	2016
<b>DLnGDP<sub>it</sub></b>	-3.413075	2011	-11.00444 <sup>a</sup>	2012
<b>DLnTCI<sub>it</sub></b>	-6.518767 <sup>a</sup>	2014	-8.344287 <sup>a</sup>	2014

Note: a,b denotes significance at %1 and %5 respectively. C refers to intercept, and C&T refers to intercept and trend.

The most important test is the long-run cointegration test among the variables. We can conclude a long-run relationship among the variables if cointegration exists. Table (4) reveals that the cointegration exists among Model (1) variables. The F-statistic value (5.706345) is greater than the upper critical value (4.89). However, Table (4) indicates that Model 2 has failed to pass the cointegration test since the F-statistic value (1.315077) is less than the lower critical value (3.79). Therefore, only the short-run model can be estimated for Model 2. It is possible to conclude that the cointegration test shows long-run relationships among the variables in Model 1. Still, there is no evidence of a long-run relationship in Model 2, so Model 1 will focus on the subsequent analysis.

**Table: 4**  
**Bound Test for Cointegration**

The Model	F-statistic	Critical Values	
		I(0)	I(1)
$\text{LnEFP}_{it} = F(\text{LnBEC}_{it}, \text{LnGDP}_{it}, \text{LnTCI}_{it})$	5.706345 <sup>a</sup>	3.69	4.89
$\text{LnGDP}_{it} = F(\text{LnBEC}_{it}, \text{LnEFP}_{it}, \text{LnTCI}_{it})$	1.315077	3.79	4.85

Note: a denotes significant at level 1%. According to Pesaran et al. (2001), the critical values are at a 1% level.

After verifying the existence of the long-run relationship in our model, we now can estimate the long-run and short-run coefficients for Model 1 and the only short-run coefficient for Model 2. Table (5) presents the long-run and short-run estimates for Model 1; it reveals that the biomass energy consumption (BEC) and per capita real income (GDP) are significant in explaining the change the environmental pollution. The results indicate that biomass energy consumption improves environmental quality since a 1% increase in biomass energy use leads to a -0.03487% and -0.00065% decrease in environmental pollution in the long-run and short-run, respectively. Meanwhile, more economic growth

and technological innovation are harmful to the environment since a 1% increase in GDP and TCI increases environmental damage by 0.68087% and 0.02163% in the long run and by 0.48329% 0.01535% in the short run, respectively.

**Table: 5**  
**ARDL Results - Model 1**

Long-Run Coefficients				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
Constant	-5.675365	0.923499	-6.145500	0.0002
LnBEC <sub>it</sub>	-0.034873	0.017960	-1.941696	0.0841
LnGDP <sub>it</sub>	0.680876	0.097800	6.961911	0.0001
LnTCI <sub>it</sub>	0.021636	0.032576	0.664176	0.5232
Short-Run Coefficients				
DLnBEC <sub>it</sub>	-0.000653	0.008435	-0.077469	0.9399
DLnGDP <sub>it</sub>	0.483299	0.119554	4.042518	0.0029
DLnTCI <sub>it</sub>	0.015358	0.025379	0.605120	0.5600
ECT	-0.709820	0.184482	-3.847630	0.0039
R-squared	0.912480	Mean dependent var		0.671245
Adjusted R-squared	0.877471	S.D. dependent var		0.086206
S.E. of regression	0.030176	Akaike info criterion		-3.902369
Sum squared resid	0.009106	Schwarz criterion		-3.666352
Log likelihood	34.26777	Hannan-Quinn criteria.		-3.904883
F-statistic	26.06474	Durbin-Watson stat		1.427906
Prob(F-statistic)	0.000029			

Table (6) illustrates the findings of the short-run estimates for Model 2. The table shows that biomass energy consumption and ecological footprint are significant in explaining real per capita income changes. Moreover, the results also reveal that BEC and EFP contribute positively to economic growth. A one-unit increase in biomass energy use and ecological footprint result in 0.024473% and 0.672482% increase in per capita real income, respectively. Nonetheless, technological innovation plays a negative role in determining economic growth in the short run. The result reveals that a 1% increase in technological innovation reduces economic growth by -0.0217%.

**Table: 6**  
**Short-Run Coefficients - Model 2**

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
DLNBEC	0.024473	0.007174	3.411219	0.0077
DLNEFP	0.672482	0.163308	4.117862	0.0026
DLNEFP (-1)	-0.354694	0.209530	-1.692805	0.1247
LNTCI	-0.021785	0.022417	-0.971846	0.3565
C	2.599619	0.895536	2.902866	0.0175
R-squared	0.990062	Mean dependent var		9.413108
Adjusted R-squared	0.984540	S.D. dependent var		0.158544
S.E. of regression	0.019713	Akaike info criterion		-4.725908
Sum squared resid	0.003497	Schwarz criterion		-4.442688
Log likelihood	41.44431	Hannan-Quinn criteria.		-4.728925
F-statistic	179.3161	Durbin-Watson stat		1.820204
Prob(F-statistic)	0.000000			

\* Note: p-values and subsequent tests do not account for model selection.

The speed of adjustment facilitates long-run convergence among the parameters with a significant and negative error correction term (ECT) coefficient. The result of ECT is -0.709, which presents evidence of cointegration among the parameters. This signifies the

capability of the model to witness a 70% speed of adjustment to verify the tendency to equilibrium in the long-term on economic growth because of dependent variables.

A diagnostic test further evaluates our Autoregressive Distributed Lag models. Table (7) presents the findings of the Breusch-Godfrey Serial Correlation LM Test for Model (1). It indicates that the model does not suffer from serial correlation since the null hypothesis of no serial correlation cannot be rejected due to a probability value that is less than a 5% level of significance. Furthermore, Table (8) summarises the Breusch-Pagan-Godfrey test of heteroskedasticity. The results show no evidence of heteroskedasticity is detected since the null hypothesis of no heteroskedasticity cannot be rejected because the p-value is 0.7391. In addition, our model is also further tested by the Histogram Normality. Figure 2 indicates that the model follows the normality since the probability value of the Jarque-Bera is 0.5557.

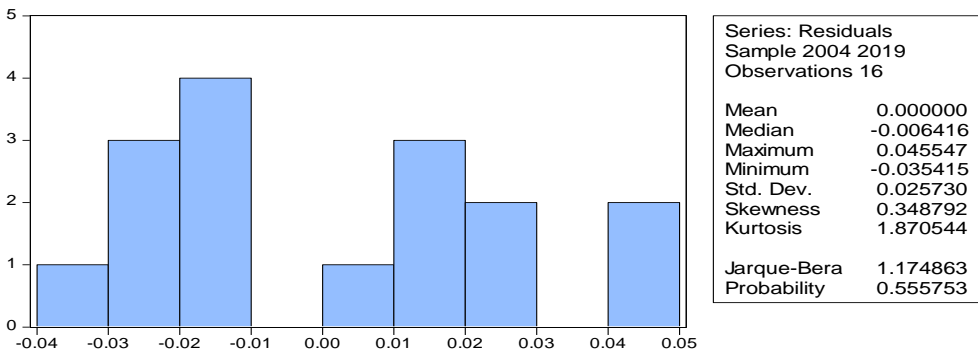
**Table: 7**  
**Breusch-Godfrey Serial Correlation lm Test: Model (1)**

F-statistic	1.126597	Prob. F(2,10)	0.3620
Obs*R-squared	2.942179	Prob. Chi-Square(2)	0.2297

**Table: 8**  
**Heteroskedasticity Test: Breusch-Pagan-Godfrey: Model (1)**

F-statistic	0.341404	Prob. F(3,12)	0.7959
Obs*R-squared	1.258224	Prob. Chi-Square(3)	0.7391
Scaled explained SS	0.308064	Prob. Chi-Square(3)	0.9585

**Figure: 2**  
**Histogram Normality Test: Model (1)**



In recent years, the dilemma of increasing environmental deterioration has raised the demand for clean energy sources. Therefore, biomass energy use has received considerable attention because previous studies have found mixed results regarding the impact of biomass energy on environmental quality; the findings of the study provide evidence that renewable energy consumption improves environmental quality in the case of Turkey, indicating that biomass energy use plays an essential role in the environmental improvement in short-run and long-run. This result agrees with studies (see, for example, Wang, 2019; Ahmed, 2016;

Bilgili et al., 2016; Shahbaz et al., 2017; Kim et al., 2020; Ulucak, 2020). The main contribution of this study is the inclusion of ecological footprint as a measure of environmental quality instead of CO<sub>2</sub>. Although this study differs from the earlier studies regarding the environmental quality indicator, it has a similar relationship -for biomass energy usage and environmental quality- with most of the earlier literature. Our results are similar to that of the BRICS countries examined by Wang (2019) and Shahbaz et al. (2017). This study differs from some studies by using only biomass (Bilgili et al., 2016; Sarkodie et al., 2019) instead of other renewable energy sources. The relationship between biomass energy consumption and environmental quality has the same direction.

But unsurprisingly, more economic growth causes further damage to the environment; this relationship between economic growth and environmental degradation has been much debated in literature within the framework of the environmental Kuznets Curve Hypothesis (EKC). This finding agrees with many studies (see, for instance, Al-Mulali et al., 2015; Lacheheb et al., 2015; Sirag et al., 2018). As discussed in the literature section, different hypotheses were tested to determine the relationship between energy consumption and economic growth. Generally, the literature has found that biomass energy consumption increases economic growth (Bilgili & Ozturk, 2015; Aslan, 2016; Destek, 2017). But the role of both economic growth and technological innovations on environmental quality was not tested too much. So, this study made an important contribution to the literature by testing this relationship. The results indicated that economic growth and technological innovations increase environmental pollution.

In addition to that, the stability of models is assessed using the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) tests, as suggested by Pesaran. Figures (3) and (4) present the findings of CUSUM and CUSUMSQ for Model 1 and Model 2, respectively. The models have passed the stability tests indicating the stability of the estimated parameters, except the CUSUM test for Model 2, since there is a slight deviation from 5% boundaries which means that the model is suffering from a bit of structural break.

## **5. Conclusion and Policy Recommendations**

Over the last few decades, many countries have been experiencing continued economic growth and prosperity. Therefore, the demand for fossil fuels has increased over the past few years. Moreover, the instability of the price of fossil fuels and rising greenhouse gases motivated many countries around the globe to find renewable energy. Furthermore, the demand for clean energy sources has increased due to environmental damage. Therefore, biomass energy use on environmental quality and economic growth has received considerable attention from researchers and policymakers.

This study investigates the impact of renewable energy consumption on economic growth and environmental quality in Turkey to determine whether renewable energy use can mitigate the deterioration of the environment. Among other renewable sources, biomass is given priority in the study. It has been a subject of ongoing discussions throughout the

literature to explore if biomass is efficient to promote environmental quality. The ecological footprint (EFP) and per capita real income (GDP) measured environmental quality and economic growth. In addition to the technological innovation index. The study relied on time series data spanning 2004-2019 based on the data availability. The ADF and PP unit root tests were employed to test the stationarity of the variables and to determine the series order of integration. After the stationarity of the variables is confirmed, the cointegration test of Pesaran et al. (2001) was performed to verify the existence of long-run relations among the variables. The Autoregressive Distributed Lag Model approach for cointegration was employed to estimate the long-run and short-run models.

The results indicate that biomass energy consumption improves environmental quality in the long-run and short-run in Turkey, while economic growth and technological innovation increase environmental pollution. Furthermore, economic growth is positively affected by reusable energy consumption. These findings can help build a comprehensive policy framework for attaining the objectives of SDGs concerning environmental targets. Since renewable energy consumption can improve the quality of the environment, there will be a need to concentrate more on clean and renewable energy sources such as biomass energy. Turkey's government should seek more environmentally friendly energy sources to accomplish the environmental targets in its 2019-2023 development plan.

This research will contribute significantly to establishing the literature on the intersection of ecological footprint, renewable energy, and economic growth. These indicators are profoundly interconnected and affect one another. So economic policymakers, specifically in Turkey, should consider strategies that support sustainable economic growth using reusable energy sources.

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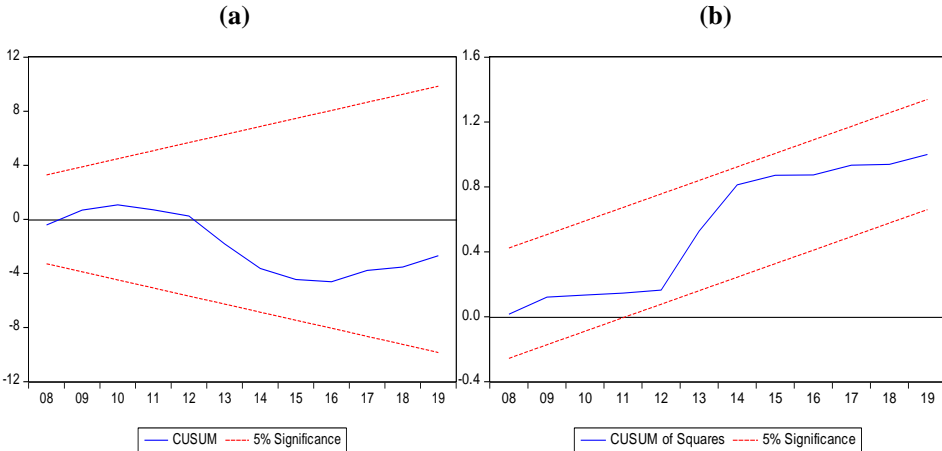


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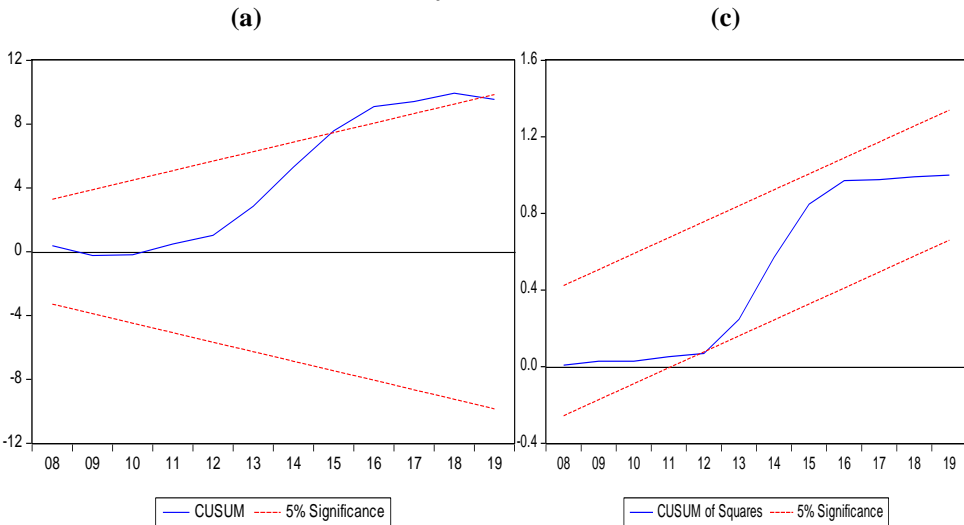
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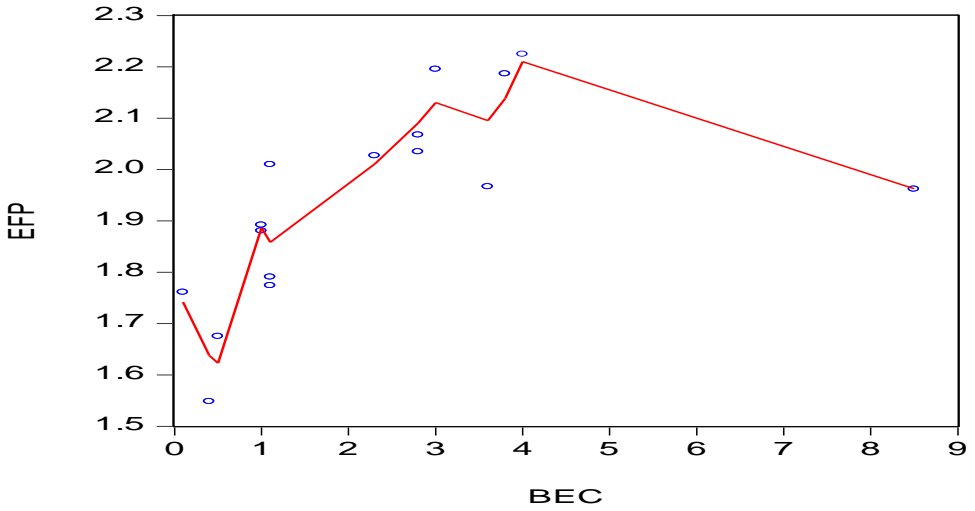
**Appendix**  
**Figure: 3**  
**Stability Test - Model 1**



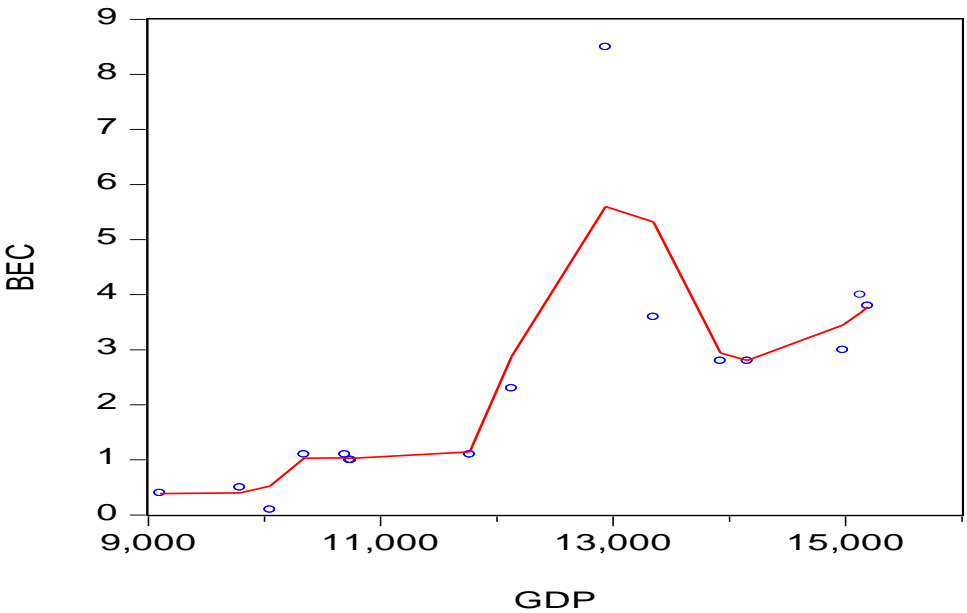
**Figure: 4**  
**Stability Test - Model 2**



**Figure: 5**  
**Biomass Energy Consumption and Ecological Footprint**



**Figure: 6**  
**Biomass Energy Consumption and Economic Growth**



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