Does Renewable Energy Determine the Environmental Impacts of Economic Growth? New Evidence from PSTR Analysis

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Abstract

This study investigates the relationship between environmental pollution and economic growth in the context of renewable energy in OECD countries using the panel smooth transition regression (PSTR) model for the 1995-2018 period. The study finds the value of the threshold variable, determined as the share of renewable energy use in total energy consumption, as 7.825%. In this context, economic growth affects the environment negatively and increases environmental pollution when the share of renewable energy use in energy consumption is below the threshold level. On the other hand, when it is above the threshold level, it reduces environmental pollution by affecting the environment positively. Therefore, the widespread use of renewable energy is a solution to reduce environmental pollution. Accordingly, it is very important for policy makers to both highlight and encourage renewable energy use. Furthermore, countries need to both invest in this area and focus on R&D to increase renewable energy production.

1. Introduction

Economic growth, which is very important for the welfare and development levels of countries, showed a rapidly increasing trend after the industrial revolution. Fast-growing economies cause some effects on nature. Especially in industrializing countries, increased growth is accompanied by rising damage to the environment. The relationship between environment and growth draws attention as environmental changes are experienced in the growth process. While maximizing growth is one of the important goals for countries, clean environment and use of natural sources have also gained importance. The basis of the problems caused by growth on the environment and natural sources is related to excessive industrialization, intensive production, and intensive consumption. The size of the pollution resulting from industrialization is quite large. While the greenhouse gas generated by use of fossil-based fuels causes air pollution, the wastes formed as a result of not using the right treatment facilities cause water and soil pollution as they mix with rivers, seas, and soil. On the other hand, the population increase caused by migration from agriculture to industry disrupts the balance of nature and leads to excessive use of natural sources, and thus to their depletion. In countries that have not completed their development yet, factors such as inability to industrialize, irregularity and lack of control in the existing industrial structure, and the unplanned use of natural sources cause environmental pollution (Lin and Xu, 2020). For this reason, a report called *The Limits to Growth* was published by the Club of Rome in 1972. This report highlights that growth cannot be unlimited due to scarcity of sources and establishes a relationship between economy and environment. Following this report, the Stockholm Environment Conference was held in the same year, and sustainable development was targeted with the purpose of raising awareness of the damage to the environment (Peccei, 1978).

Sustainable growth is one of the main goals of countries. It is considered in two dimensions: economic and environmental. These two are complementary to each other. At this point, both the efficient use of sources and the protection of the environment are important. However, countries may ignore environmental problems as they focus on growth targets. Especially the use of fossil-based energy in the production phase increases CO_2 emissions in parallel with growth and development. While CO_2 gas causes environmental problems at the local level in many countries, it leads to extremely important problems affecting the world such as global warming and climate change at the global level. On the other hand, energy is needed to carry out production activities and meet the requirements. For this reason, minimizing the damage to the environment while meeting the energy demand has become a necessity for the goal of sustainable growth.

Environmental quality is improved through practices conducted for preventing environmental degradation according to the development of countries. Prevention of environmental degradation is directly or indirectly related to factors such as education, environmental policies, and per capita income. In this regard, the literature involves the study of the extent of the relationship between economic growth and environmental pollution for revealing the relationship between the factors causing environmental pollution and economic growth through use of the Environmental Kuznets Curve (EKC) hypothesis. According to the EKC hypothesis, environmental degradation increases in the initial phase of growth due to industrialization. Technologies that cause environmental degradation are used in the industrialization phase, and more importance is attached to increasing the amount of production than environmental awareness. For this reason, more pollutants causing deterioration in environmental quality are released (Dinda, 2004). Technological progress takes place as economic growth occurs. Hence, dirty and old technological activities are replaced by clean and environmentally friendly ones. Therefore, in the advancing phases of economic growth, environmental policies are implemented better, environmental awareness increases, and environmental pollution decreases with the investment made in knowledge-intensive sources as a result of technological developments (Panayotou, 1993).

The primary study on the EKC hypothesis is the one by Grossman & Krueger (1991). Examining the relationship between environmental quality and per capita income, they found an inverted U-shaped relationship between the two variables, which first increases and then decreases after a certain threshold level. They likened this relationship to Kuznets' study exploring the relationship between income distribution and per capita income and named it as the Kuznets curve.

Panayotou (1993), in a similar study, named this curve as the Environmental Kuznets Curve hypothesis, which is how it was introduced to the literature. The studies based on this hypothesis have concluded that as economic growth increases, environmental pollution also increases in the initial phase; and then, after the countries reach a certain growth level, environmental pollution decreases in the second phase. There has been an increase in the number of studies examining the relationship between economic growth and environment using the EKC hypothesis (Orubu & Omotor, 2011; Sarisoy & Yildiz, 2013; Al-Mulali et al., 2014; Ergun & Polat, 2015; Gulmez, 2015; Isik et al., 2015; Eratas & Uysal, 2015; Topalli, 2015; Erturk, 2016; Li et al., 2016; Aydin & Esen, 2017; Lu, 2017; Sterpu et al., 2018; Ornek & Turkmen, 2019; Unal & Polat, 2019).

Among these studies, Ergun & Polat (2015) examined the 1980–2010 period for 30 OECD countries and investigated whether the EKC hypothesis is valid for these countries. They detected a cointegration relationship between CO_2 emissions and GDP. In the long run, a one-way causal relationship was detected from GDP to CO_2 emissions. In addition, the EKC hypothesis, suggesting a non-linear relationship between CO_2 emissions and economic growth, was confirmed.

Lu (2017) analyzed the data between 1990 and 2012 for 16 Asian countries with the Granger Causality Test. He determined a bidirectional causality relationship between the variables and concluded that there is no linear relationship between greenhouse gases and economic growth. As a result of the analysis, it was concluded that the EKC Hypothesis is valid for the country group that is the subject of the analysis and that renewable energy is supported.

Isik et al. (2015) analyzed 157 countries by income level for the validity of the EKC hypothesis. They examined 31 low-income countries, 79 middle-income countries, and 47 high-income countries. They used not only CO_2 but also air pollutants such as NO_2 and CH_4 as an indicator of environmental pollution. As a result of the analysis, they determined an inverted U-shaped relationship between the two variables in the high- and low-income groups, thus confirming the EKC hypothesis, while the hypothesis was not found valid in the middle-income group. These findings support the view that as economic growth increases, the demand for technology to prevent environmental pollution rises, and people have higher environmental awareness, especially in countries with high income levels. Addressing the issue in the context of Africa, Orubu & Omotor (2011) investigated whether the EKC hypothesis is valid for air and water pollutants. In terms of water pollutants, they found that pollution rises as income increases. In addition, they determined that the threshold income level for the two pollution indicators is lower than the threshold income levels of other studies. Based on all these, they concluded that the EKC is valid for African countries, that income level is very important to reduce the pollution caused by these pollutants in African countries, and that stricter policies should be applied, especially in the industrial terms.

The number of studies suggesting that growth alone cannot account for environmental pollution, in other words that the EKC hypothesis is not supported in various countries is increasing in the literature (Sarisoy & Yildiz, 2013; Al-Mulali et al., 2015; Aydın & Esen, 2017; Sterpu et al., 2018).

In their study investigating the EKC hypothesis within the scope of the BRICT countries (Brazil, Russia, India, China, Turkey), Eratas & Uysal (2015) examined the 1992–2010 period through panel data analysis. While performing the analysis, they first determined a threshold value and then proved the existence of the relationship between the two variables by the Westerlund ECM panel cointegration test. They found an inverted U-shaped relationship between the two variables and proved the validity of the EKC hypothesis for the country group subject to the analysis.

Sarisoy & Yildiz (2013) analyzed the relationship between GDP and CO_2 emissions for 15 developed and 15 developing countries, totaling in 30 countries. They found a causal relationship from GDP to CO_2 emissions, not supporting the EKC hypothesis, and proved the existence of an N-shaped relationship for both country groups. In the country groups, the pollution level increased until the income reached a certain level in the initial phase of economic growth, and the linear relationship between income and CO_2

level continued after a certain level of income as well. Addressing the subject from the perspective of Turkey, Aydin & Esen (2017) found that the EKC hypothesis is not supported for Turkey.

Sterpu et al. (2018) examined the relationship between greenhouse gas emissions and GDP per capita using the Panel Data Method, taking 28 EU countries as a criterion for the period 1990–2016. The purpose of doing the study is to find out whether the EKC Hypothesis is valid in the country group they have determined. They used cointegration tests to predict the course of the curve. As a result of these applications, a bell-shaped relationship between the variables could not be determined, on the contrary, an inverted N-shaped relationship was determined. As a result, in the first stage of economic growth in the base countries, CO2 emissions decrease as income increases, and CO2 emissions increase depending on income as income increases after a certain growth level. In the study, it was concluded that electricity consumption creates greenhouse gases, while renewable energy consumption plays a reducing factor in greenhouse gases.

Considering the protection of the environment while economic growth is taking place, it is very important to provide sustainable energy. Environmentally friendly renewable energy sources are the key to sustainable growth and energy. Sustainable energy is a concept that aims to achieve economic growth by applying the energy production from alternative energy sources with up-to-date and clean technologies that do not harm the environment and thus obtaining maximum efficiency. This concept is of great importance for countries to achieve development and welfare. However, attaining the necessary innovations and accessing these sources is not easy for every country. Some environmental degradation occurs in countries that fail to achieve these stages. Wastes or damages arising from climatic changes, agricultural activities, and industrial production are some of these deteriorations (Song, 2006).

Traditional energy production and consumption harm living beings, environment, and natural sources globally or regionally. Greenhouse gases resulting from fossil-based energy production cause climate change and global warming. Energy, which is used as an input in production, is widely used especially in industrial production. The use of fossil fuels in this process affects both the environment and the life of living things. Accordingly, in line with the purpose of sustainable growth and energy, it is essential that energy production and consumption be done without harming the environment. The fact that renewable energy sources are unlimited in nature, reliable, and economical increases the interest in them. Given these factors, countries need to switch from fossil-based energy production to renewable energy production.

Renewable energy remains on the agenda for two reasons. The first is the limited amount of fossil sources and their inability to meet the energy demand of the increasing population, that is, the lack of sources. However, renewable energy sources are unlimited in nature, and there is no lack of these sources. The second is environmental pollution caused by transformation technologies used in energy production (Dincer, 2000). However, wind turbines, solar panels, etc. used in the production of renewable energy sources are highly environmentally friendly transformation technologies. No greenhouse gas such as carbon dioxide and environmental waste causing air pollution are formed when renewable sources are used. Renewable energy sources, which remain the same in nature with the days passing, are renewed in perpetual motion, and there is usually no need for any stage in their production (Herjanne & Korhonen, 2019). In the past centuries, countries had difficulties in producing renewable energy sources. However, today, with the advancing technology, policies, and incentives, countries can produce their own energy. Especially energy importing countries are turning to renewable sources that they incorporate. This is because the energy sources they import from other countries negatively affect their economic growth and welfare, also causing debts. In fact, renewable sources are not an alternative to fossil fuels but a necessity for these countries.

Countries that are foreign-dependent in energy use carry out some activities to reduce their energy imports by using their own sources. These activities aim to improve the balance of payments deficits by decreasing energy imports, reduce energy input costs, and use environmentally friendly production techniques. The use of renewable sources is also important for increasing the energy supply (Acaravci & Erdogan, 2018). The success of the environmentally friendly growth process, which started with the Stockholm Conference, is of great importance for all countries. Renewable energy is the key to both combating environmental pollution and sustainable growth. Many countries have realized this and have developed incentives and policies on this matter.

The literature contains many studies on renewable energy. Studies have mostly investigated the relationship between economic growth and renewable energy (Hung-Pin, 2014; Bozkurt & Destek, 2015; Ntanos et al., 2018; Marinas et al., 2018; Onder & Polat, 2018; Usupbeyli & Ucak, 2018; Alam & Murad, 2019; Bao & Xu, 2019; Smionescu et al., 2020).

Among these studies, Hung-Pin (2014), examining the relationship between renewable energy and economic growth, handled the 1982–2011 data of 9 OECD countries (USA, Japan, Germany, Italy, UK, France, Denmark, Portugal, and Spain) and analyzed such data through the ARDL bounds test and the Granger causality approach. Based on the analysis results, it was concluded that renewable energy has no effect on France, Denmark, Portugal, and Spain. The analysis results indicated a one-way relationship from renewable energy to economic growth in the short run for the UK and Italy and a one-way relationship from renewable energy to economic growth in the long run for Germany, the USA, and Italy. In addition, the study found a one-way relationship from economic growth to renewable energy in the long run for the USA and Japan, a strong one-way relationship from renewable energy to economic growth in the long run for Germany and the UK, and a very strong one-way relationship from economic growth to renewable energy in the long run for the US.

The literature also includes studies, though not many, examining the role of renewable energy in the relationship between economic growth and environmental pollution. However, these studies have tried to identify the causal relationship between the variables. Therefore, there is no study that determines a threshold level for renewable energy (Thombs, 2017; Acaravci & Erdogan, 2017; Cetin & Sezen, 2018; Jebli et al., 2019; Sasano & Aminato, 2019).

Among these studies, Thombs (2017), exploring the relationship between renewable energy, economic growth, and environment, took 129 countries from different income groups and investigated the relationship between the variables through time series and Prais-Winsten regression model. Annual data from the 1990–2013 period were used in that study. The analysis results led to two findings, and the existence of the renewable energy paradox was accepted. While the first finding was that renewable energy has a positive effect on CO_2 emissions at high renewable energy levels, the second finding was that CO_2 emissions decrease at high income levels. In this context, the analysis results indicated a one-way, negative relationship from renewable energy consumption to economic growth and CO_2 emissions in low-income countries and a one-way, positive relationship from renewable energy consumption to economic growth and CO_2 emissions in high-income countries. For this reason, it can be said that underdeveloped countries have dirtier energy use than developed countries.

The present study contributes to the literature in three ways. First, although previous studies investigated the relationship between the two variables using non-linear EKC hypothesis, linear models were used for testing in the analyses. However, this study investigates the relationship between the two variables through a non-linear model. Second, the study examines the relationship between economic growth and environment in the context of renewable energy. A threshold is determined for the share of renewable energy consumption in total energy consumption. This makes a new contribution to the literature. Third, the study employs panel smooth transition regression (PSTR) model, which is a panel data analysis technique developed by Gonzalez, Teravista, & Van Dijk (2005). The symmetric and monotonous increase or decrease in the effect of economic growth on environmental pollution in relation to growth level requires the use of a regression model based on the threshold effect. Unlike the panel threshold regression model, the aforementioned analysis method allows the parameters to change gradually, not suddenly and sharply, while passing from one regime to another, which shows that the analysis method is more advantageous in terms of the robustness of the results.

The purpose of this study is to investigate the role of renewable energy in the relationship between economic growth and environmental pollution through the EKC hypothesis for OECD countries. To this end, the first section of this study addresses the possible effects of renewable energy on the relationship between economic growth and environmental pollution. In the following sections, a threshold level is set by determining the share of renewable energy in total energy consumption using the PSTR model, and the relationship between economic growth and environmental pollution is examined on conditions that the share of renewable energy in total energy consumption is above and below that threshold level. Lastly, the consistence of the analysis results with the existing literature is evaluated.

2. Model

To examine the effect of renewable energy on the relationship between economic growth and environmental pollution, a model based on the framework developed by Kuznets was created in line with the model used by Gonzalez et al. (2005), Fouquau et al. (2008), Chiu (2017), and Aydin & Esen (2017). The created model is shown in Eq. 1.

$$CO_{2_{it}} = a_0 + a_1 Growth_{it} + \epsilon_{it}$$

1

In Eq. 1, for country i in period t, CO_2 refers to CO_2 emission representing environmental pollution, *Growth* represents economic growth, and ε to the white noise error term.

In OECD countries, energy use stands out as the main input in production. In these countries, the use of fossil fuels is common in general. The use of these fuels contributes to production and positively affects economic growth. However, the increase in the use of these energy sources leads to cost inflation by causing production costs to rise, especially in countries that are foreign-dependent in terms of energy. Therefore, the competitiveness of the countries decreases, and the items of economy are negatively affected. On the other hand, the unconscious and intensive use of fossil fuels causes various environmental problems such as air, soil, and water pollution. This has negative consequences in terms of sustainable growth. Given that consumption and production cannot be abandoned, the problems caused by the use of fossil fuel can be avoided through the use of renewable energy, which is a good alternative to fossil fuel sources.

3. Methodology

The intensive use of fossil energy sources in production in OECD countries contributes to economic growth on the one hand but increases CO_2 emissions on the other, causing environmental pollution. This affects not only OECD countries but also the whole world, causing extremely important environmental problems such as global warming and climate change. Hence, the use of renewable energy sources, which are a good alternative to fossil energy sources, is a solution. From this point of view, this study departs from the question of whether there is a break, that is an asymmetrical relationship between the variables of economic growth and environmental pollution and the thought that renewable energy consumption level may have an effect on such break. On the other hand, the aforementioned breaks can lead to the emergence of a non-linear structure in econometric models. This leads to the development of non-linear models that can represent regime changes and estimation methods for these models.

In this study, the role of renewable energy in the non-linear relationship between economic growth and environment in OECD countries is examined by panel data analysis. In panel data analyses, the lack of a linear relationship between the variables and the application of methods related to linear models cause problems in terms of the results. For this reason, in a non-linear model, the relationship between variables should be examined through non-linear panel data analysis methods. Hansen (1999) first developed the panel threshold regression (PTR) method to examine the non-linear relationship in panel data. The main feature of the PTR method is that the effect of the threshold variable on the dependent variable may differ depending on the regimes below and above the threshold. This causes the coefficient determining how the threshold variable affects the dependent variable to differ depending on regimes (Aydin & Esen, 2017). In the PTR method, it is assumed that the coefficients vary sharply and suddenly between regimes. In this method, regimes are separated based on the calculated threshold level. However, from an economic point of view, parameters do not always show such sharp and sudden changes between regimes (Güloglu & Nazlıoglu, 2013). In the relationship between CO_2 emissions and GDP growth rate, this approach divides the countries included in the panel into groups based on the determined CO_2 emission and estimates different parameters for each group. Thus, it assumes clear differences between developed countries with low CO_2 emissions and developing countries with high CO_2 emissions. This assumption posits that a developing country becomes a developed country over time, which means that the estimated parameters do not change suddenly, but smoothly. This is why this study uses the PSTR model developed by Gonzalez, Terasvirta, & Van Dijk (2005), which allows the movement of the parameters in the regression between the regimes to occur more slowly, not sharply and suddenly.

To examine the non-linear relationship between CO_2 emissions and GDP growth rate, a two-regime fixed PSTR model was created based on Eq. 1. The model is expressed in Eq. 2:

$$LnCO2_{it} = \mu_i + \beta_0 Growth_{it} + \beta_1 Growth_{it} * g\left(q_{it}; \gamma, \theta\right) + \epsilon_{it}$$

2

$LnCO2_{it}$ and $Growth_{it}$ refer to CO_2 emission in the logarithmic form and GDP growth rate increase, respectively; ε to error term; t = 1, 2, …, T to time; and i = 1, 2, 3…, N to countries. μ_i and q_{it} represent, respectively, unit fixed effects and the threshold variable (*Renewable*) indicating the share of renewable energy consumption in total energy consumption, used as threshold (transition) variable in the model. In Eq. 2, $g\left(q_{it}; \gamma, \theta\right)$ is used as a transition function and is shown in the logistic function form as in Eq. 3:

$$g\left(q_{it}; \gamma, \theta\right) = \left[1 + exp(-\gamma\left(q_{it} - \theta\right))\right]^{-1}$$

3

In Eq. 3 parameter $\theta$is the threshold coefficient between the two variables corresponding to $g\left(q_{it}; \gamma, \theta\right) = 0andg\left(q_{it}; \gamma, \theta\right) = 1$, while γ (smoothing parameter) determines the smoothness of the increase or decrease in the value of the transition function, that is, the transition from one regime to another. The change occurs from 0 to 1 in the transition function ($\gamma \to \infty$), while the smoothing parameter goes to infinity. At the point where the threshold variable is equal to θ, transition from one regime to another takes place suddenly and sharply, as observed in the PTR model. Therefore, the model is estimated using the PTR approach. On the other hand, while the smoothing parameter goes towards zero, transition function ($\gamma \to 0$) is equal to a constant. When the smoothing parameter is equal to zero, model ($\gamma = 0$)is in linear form. Thus, the model is tested using the panel cross-section estimator (Fouquau, Hurlin, & Rabaud, 2008).

The transition function is both a continuous function of the transition variable and takes values between 0 and 1. When the transition function takes the value 0 in Eq. 3($g\left(q_{it}; \gamma, \theta\right) = 0$), the regression coefficient shows the value β_0, and when the transition function takes the value 1 ($g\left(q_{it}; \gamma, \theta\right) = 1$), the regression coefficient shows the value $\beta_0 + \beta_1$. On the other hand, when the transition function takes a value between 0 and 1 ($0 < g\left(q_{it}; \gamma, \theta\right) < 1$), the regression coefficient is calculated as the weighted average of β_0 and β_1. Therefore, the interpretation of the signs of parameters may be better than interpreting the parameters for the PSTR model (Fouquau, Hurlin, & Rabaud, 2008: 287–288). In other words, how the independent variable affects the dependent variable (positive/negative) and the elasticity that changes over time are explained (Güloglu & Nazlıoglu, 2013).

PSTR analysis is carried out in three stages, namely testing the linearity, determining the number of regimes (*r*), and estimation, respectively (Fouquau, Hurlin, & Rabaud, 2008). In testing the linearity, the PSTR model is the alternative hypothesis, and the linear model is the null hypothesis. The next step following the rejection of the linear model hypothesis is to determine the number of regimes. The estimation stage is the final stage in the PSTR analysis. At this stage, first, the fixed effects of the cross-sections that make up the panel are subtracted from the time averages of the variables, and then the transformed model is estimated with non-linear least squares (Gonzalez, Terasvirta, & Van Dijk, 2005).

4. Dataset And Empirical Results

4.1. Dataset

This study, covering 36 OECD countries, examined the role of renewable energy in the non-linear relationship between economic growth and environment for the 1995–2018 period using the PSTR model. There are 38 member countries in the OECD country group. However, Colombia (2020) and Costa Rica (2021) were not included in the analysis as they could not provide data for the period taken as basis in the analysis. The study used yearly CO_2 emissions (million tons of CO_2) for representing environmental pollution and GDP growth rate (%) for representing economic growth. The variable of renewable energy was calculated proportionally by dividing total renewable energy consumption by total energy consumption (ktoe). The GDP growth rate data were obtained from the World Bank, while the data on renewable energy consumption, total energy consumption, and CO_2 emissions were obtained from the International Energy Agency (IEA). Table 1 presents descriptive statistics for the variables.

[Table 1]

As indicated in Table 1, the averages for the variables of GDP growth rate and CO_2 emissions on country basis are 2.83% and 65.249 million tons, respectively. The average share of renewable energy use in total energy consumption is 9.885%. The country with the highest growth rate in the OECD country group is Ireland with 25.163% recorded in 2015, while the country with the lowest growth rate is Lithuania with −14.839% recorded in 2009. Furthermore, the country with the highest CO_2 emissions is the United States (USA) with 5729.875 million tons in 2000, while the country with the lowest CO_2 emissions is Iceland with 1.860 million tons.

4.2 Empirical Results

The study investigated the role of renewable energy in the non-linear relationship between CO_2 emissions and GDP growth rate. Firstly, the interdependence of countries, that is, of cross-sections, was analyzed. In addition, the LMadj (adjusted Lagrange multiplier) test, which was found by Breusch-Pagan (1980) and bias corrected by Pesaran, Ullah, & Yamagata (2008), was applied to detect the presence of cross-sectional dependence. The obtained results are indicated in Table 2.

[Table 2**]**

The null hypothesis created based on the test statistics for the GDP growth rate and CO_2 emissions series in Table 2 (there is no cross-sectional dependence) was strongly rejected. The model and the series were found to have cross-sectional dependence. Thus, it was observed that a shock to one of the countries also affected other countries. The presence of cross-sectional dependence is very important in choosing the tests to be applied at some stages of the analysis. The importance is so much so that in case of cross-sectional dependence, second generation unit root tests taking this into account should be applied. Moon & Perron's (2004) test, which is one of the second-generation unit root tests, was preferred to test the stationarity of the series in order to check the presence of cross-sectional dependence in the series used in the study, and the results are presented in Table 3.

[Table 3**]**

Based on the obtained findings, the null hypothesis that the series contains a unit root was rejected for the series of GDP growth rate, CO_2 emissions, and the share of renewable energy use in total energy consumption. The obtained results indicate that the series are stationary at the level values (I(0)).

After the variables to be used in the analysis were found to be stationary at the level values, the first stage of the PSTR analysis, the testing of the linear model against the non-linear model, was started. For this purpose, Wald (*LM)*, Fisher (LM_F), and LRT (*LRT*) tests were performed to test the linearity of the model and to determine the number of transition functions. The results are given in Table 4.

[Table 4**]**

The *LM*, LM_F, and *LRT* test results in Table 4 have significance at the 10% level. Based on the obtained findings, the null hypothesis was rejected, and the alternative hypothesis that the model contains at least one non-linear threshold variable was accepted. Therefore, it was concluded that it would not be appropriate to use linear models through the model created on the role of renewable energy in the relationship between CO_2 emissions and GDP growth rate. After that, the next stage involving the determination of the number of regimes was initiated. To determine the right number of regimes, the *LM*, LM_F, and *LRT* tests were re-applied. The results are shown in Table 5.

[Table 5]

Based on the results in Table 5, the null hypothesis of the model could not be rejected. For this reason, it was decided that the model contains a threshold value and should be estimated with the two-regime PSTR model. In the next stage of the analysis, the role of renewable energy in the relationship between CO_2 emissions and GDP growth rate was estimated through the two-regime PSTR model. The estimation results are provided in Table 6.

[Table 6]

As shown in Table 6, the low value of the transition coefficient (slope parameter, γ=11.394) indicates smooth transition between the regimes. This suggests that the PSTR model cannot be reduced to the PTR model. It also shows that transition between the regimes is not sudden in the relationship between CO_2 emissions and GDP growth rate; instead, it is slow and requires a process. This is indicated in Fig. 1. On the other hand, the coefficient for the share of renewable energy use in energy consumption (*Renew/TPES*), which is used as a threshold variable in the model, was found to be 7.825.

[Figure 1**]**

In Table 6, the estimated coefficient for the GDP growth rate in the first regime where the share of renewable energy use in total energy consumption is below 7.825% (β_0) takes a statistically significant and positive value (0.009) at the 1% significance level. In the second regime where the threshold variable is above 7.825%, the estimated coefficient for the GDP growth rate, expressed as the sum of β_0 andβ_1, takes a statistically significant and negative value (-0.002) at the 1% significance level. However, these parameters cannot be directly interpreted as elasticity, as in the logit and probit models. Only their signs can be interpreted. The fact that the sign of these coefficients takes a positive value in the first regime (β_0) and a negative value in the second regime ($\beta_0 + \beta_1$) shows that the relationship between CO_2 emissions and economic growth in OECD countries is positive below a certain threshold level and negative above the threshold level. Therefore, in parallel with the related literature, this study confirms the EKC hypothesis that there is a non-linear, inverted U-shaped relationship between CO_2 emissions and GDP growth rate depending on the share of renewable energy consumption in total energy consumption.

The results of the analysis covering 36 countries showed Norway and Iceland to have extreme values. In this regard, Iceland and Norway were excluded from the analysis, and the PSTR analysis was repeated both to determine the robustness of the model and to check the threshold value by re-testing the model.

[Table 7]

The *LM*, LM_F, and *LRT* test results in Table 7 have significance at the 1% level, and therefore, the null hypothesis was rejected. Accordingly, the alternative hypothesis that the model contains at least one non-linear threshold effect was accepted. To determine the right number of regimes, in the next stage, the *LM*, LM_F, and *LRT* tests were re-applied. The results are shown in Table 8.

[Table 8]

Based on the results in Table 8, the null hypothesis of the model could not be rejected. For this reason, it was decided that the model contains a threshold effect and should be estimated with the two-regime PSTR model. In the next stage of the analysis, the role of renewable energy in the relationship between CO_2 emissions and GDP growth rate was estimated through the two-regime PSTR model. The estimation results are provided in Table 9.

[Table 9]

As shown in Table 9, the low value of the transition coefficient (slope parameter, γ=11.302) indicates smooth transition between the regimes. This suggests that the PSTR model cannot be reduced to the PTR model. It also shows that transition between the regimes is not sudden in the relationship between CO_2 emissions and GDP growth rate; instead, it is slow and requires a process. This is indicated in Fig. 2. On the other hand, the coefficient for the share of renewable energy consumption in total energy consumption (*Renew/TPES*), which is used as a threshold variable in the model, was found to be 7.842.

[Figure 2**]**

In Table 9, the estimated coefficient for the GDP growth rate in the first regime where the share of renewable energy consumption in total energy consumption is below 7.842% (β_0) takes a statistically significant and positive value (0.009) at the 1% significance level. In the second regime where the threshold variable is above 7.842%, the estimated coefficient for the GDP growth rate, expressed as the sum of $\beta_0$andβ_1, takes a statistically significant and negative value (-0.002) at the 1% significance level.

The analysis covering 36 countries showed the share of renewable energy consumption in total energy consumption, which is the threshold level, to be 7.825%. When the PSTR analysis was performed again for 34 countries, the threshold level was found to be 7.842%. In the two analyses, the threshold value did not differ much. These findings show that when growth occurs below the threshold level, the greenhouse effect arises as a result of the use of fossil-based energy, that is, traditional energy consumption, and this causes an increase in CO_2 emissions and consequently environmental pollution (Krataş & Uysal: 2014). Therefore, factors such as global warming and climate change cannot be avoided. When growth is above the threshold level, on the other hand, countries allocate the necessary share of their budgets to the use of clean energy sources and turn to using renewable energy. As a result, fossil sources are used at the lowest level possible, thus reducing CO_2 emissions and environmental pollution. All these show that the use of renewable energy is an important factor in explaining the environmental pollution and its effect on economic growth and that there is a non-linear, inverted U-shaped relationship between the two variables.

5. Conclusion

Recently, environmental pollution has been increasing day by day due to factors that cause environmental degradation such as industrialization, fuel use, population growth, and urbanization. Population growth, which is one of the causes of environmental pollution, has changed and increased social needs, thus necessitating increased production. The increase in production brings growth, which is one of the ultimate goals of countries. However, prioritizing only growth leads to environmental problems brought about by growth. Especially the industrial revolution made the use of fossil-based energy widespread in production and raw material supply. The use of fossil sources causes air, soil, and water pollution, and adverse effects emerge in terms of the environment. These negative effects lead to consequences such as global warming, climate change, and scarcity of sources. For this reason, sensitivity about the environment increases in the context of sustainable growth, and various policies need to be developed on this matter. This makes it compulsory for countries to turn to clean energy sources. Therefore, the use of renewable energy draws attention as an important factor in overcoming these problems to both reduce environmental pollution and use the existing sources efficiently.

Renewable energy sources, which are readily available in nature, are sources that can constantly renew themselves. These sources, which are a very good alternative to fossil fuels, do not generate CO_2 gas when used during production. Therefore, they do not cause air, soil, and water pollution. They also play an important role both for the zero-carbon target and for the fight against global warming. Moreover, since renewable sources are the sources owned by the countries, there is no shortage of sources and importation in terms of meeting the ever-increasing needs. For this reason, renewable energy sources are the key point for a stable growth target.

This study, examining the relationship between environmental pollution and economic growth in the context of renewable energy, found that the use of renewable energy plays a major role in the relationship between the two variables. In parallel with the literature, the study found, as Thombs (2017) mentioned, that renewable energy use at a high level reduces CO_2 emissions, and also CO_2 emissions decrease in countries with high income levels. In addition, the finding that the use of renewable energy has a negative effect on CO_2 emissions supports the result of Acaravci & Erdogan (2017). In this context, increasing the use of renewable energy is of vital importance in terms of protecting the environment, and it is understood that there is a need to consider the threshold level for the share of renewable energy consumption in total energy consumption regarding the effect of economic growth on environmental pollution. Countries with a threshold level below the threshold level determined in the present study are Israel and Korea, which have shares of 2.480% and 3.116%, respectively. Hence, these countries need to increase the share of renewable energy consumption in their total energy consumption. In addition, the Kyoto Protocol, signed by many countries to reduce carbon gases and greenhouse effect within the scope of combating the problem of global warming and climate change, is important at this point. However, considering that the USA, which has the highest energy consumption per capita, is responsible for one-third of the world’s carbon emissions but does not have its sign under this protocol constitutes a major obstacle to solving the problem of global warming and climate change. In this context, the widespread use of renewable energy is a solution. It is very important for policy makers to both highlight and encourage renewable energy use. It is necessary to develop R&D infrastructure in countries and organize informative seminars and trainings in terms of renewable energy. In line with all these, a successful result can be obtained through a stable and effective implementation.

Declarations

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Author's contributions Celil Aydin and Yagmur Cetintas contributed to the conception of the study. Yagmur Cetintas performed the experiment and wrote the manuscript. Celil Aydin and Yagmur Cetintas performed the analysis with constructive discussions. All authors read and approved the final manuscript.

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Tables

Table 1. Descriptive statistics of variables in levels over the period 1995–2018

	Mean	Std. Dev.	Max.	Min.	Obs.
GDP Growth Rate	2.804	3.155	25.163	-14.838	862
CO_2 Emissions	339.773	881.316	5729.875	1,859.894	862
Renew/TPES	15.420	15.825	89.746	0.682	862

Note: Std. Dev. is the abbreviation of standard deviation. Max. is the maximum value. Min. is the minimum value. Obs. means the number of observation.

Table 2
Cross Section Dependence

	CD_{BP}	CD_{LM}	CD	LM_{adj}
$LnCO_2$	5189.564*	128.451*	22.115*	127.668*
$Growth$	4555.325*	110.583*	62.735*	109.800*
$Model$	3982.206*	94.437*	46.100*	-

Note: *, **, *** indicate significance at 1%, 5% and 10% levels, respectively. CD_{BP} :Breusch and Pagan 1980 test, CD_{LM} :Pesaran 2004 CDlm test, CD :Pesaran 2004 CD test and LM_{adj} :Bias-adjusted CD test.

Table 3
Results of Moon and Perron's (2004) panel unit root tests

	$\hat{r}$	t_a^*	t_b^*	$\hat{\rho}_{pool}^*$
$LnCO_2$	5	-17.570*	-9.789***	0.780
$Growt$	1	-41.628*	-12.987*	0.306
$Rene/TPES$	1	-5.084*	-2.335*	0.852

Note: $\hat{r}$ is the estimated number of common factors. t_a^* and t_b^* are the unit root test statistics based on de-factored panel data. Corresponding *p-values* are in parentheses. $\hat{\rho}_{pool}^*$ is the corrected pooled estimates of the autoregressive parameter. *, **, *** indicate significance at 1%, 5% and 10% levels, respectively.

Table 4. Tests for the linearity

Threshold variables (*Renew/TPES*)	
$H_0: r = 0 vs H_1: r = 1$	
LM	3.365***
	(0.067)
LM_F	3.233***
	(0.073)
LRT	3.371***
	(0.067)

Note: Under H_0, the *LM* and *LRT* statistics have an asymptotic $\chi^2(mK)$ distribution, whereas LM_F has an asymptotic $F(mK, TN - N - m(K+1))$ distribution. Moreover, *r* is the number of transition functions. *P-values* are in parentheses. *, **, *** indicate significance at 1%, 5% and 10% levels, respectively.

Table 5. Tests for the remaining non-linearity of the PSTR model

Threshold variables (*Renew/TPES*)	
$H_0: r = 1 vs H_1: r = 2$	
LM	0.003
	(0.953)
LM_F	0.003
	(0.954)
LRT	0.003
	(0.953)

Note: Under H_0, the *LM* and *LRT* statistics have an asymptotic $\chi^2(mK)$ distribution, whereas LM_F has an asymptotic $F(mK, TN - N - m(K+1))$ distribution. Moreover, *r* is the number of transition functions. *P-values* are in parentheses.

Table 6. Estimated results of the PSTR model

Threshold variables (*Renew/TPES*)	
$Growth_1$	**0.009***
	(0.002)
$Growth_2$	**-0.011***
	(0.002)
Location parameters, θ	7.825
Slope parameters, γ	11.394
Note: Standard errors are corrected for heteroskedasticity in parentheses. *, **, *** indicate significance at 1%, 5% and 10% levels, respectively.	

Table 7. Tests for the linearity (34 OECD Countries)

Threshold variables (*Renew/TPES*)	
$H_0: r = 0 vs H_1: r = 1$	
LM	14.779*
	(0.000)
LM_F	14.405*
	(0.000)
LRT	14.915*
	(0.000)
Note: Under H_0, the *LM* and *LRT* statistics have an asymptotic $\chi^2(mK)$ distribution, whereas LM_F has an asymptotic $F(mK, TN - N - m(K+1))$ distribution. Moreover, *r* is the number of transition functions. *P-values* are in parentheses. *, **, *** indicate significance at 1%, 5% and 10% levels, respectively.	

Table 8. Tests for the remaining non-linearity of the PSTR model for 34 OECD Countries

Threshold variables (*Renew/TPES*)	
$H_0: r = 1 vs H_1: r = 2$	
LM	2.768
	(0.106)
LM_F	2.651
	(0.104)
LR	2.773
	(0.106)
Note: Under H_0, the LM and LR statistics have an asymptotic $\chi^2(mK)$ distribution, whereas LM_F has an asymptotic $F(mK, TN - N - m(K+1))$ distribution. Moreover, r is the number of transition functions. *P-values* are in parentheses.	

Table 9. Estimated results of the PSTR model for 34 OECD Countries

Threshold variables (*Renew/TPES*)	
$Growth_1$	**0.009***
	(0.002)
$Growth_2$	**-0.011***
	(0.002)
Location parameters, θ	7.842
Slope parameters, γ	11.302
Note: Standard errors are corrected for heteroskedasticity in parentheses. *, **, *** indicate significance at 1%, 5% and 10% levels, respectively.	

Figures

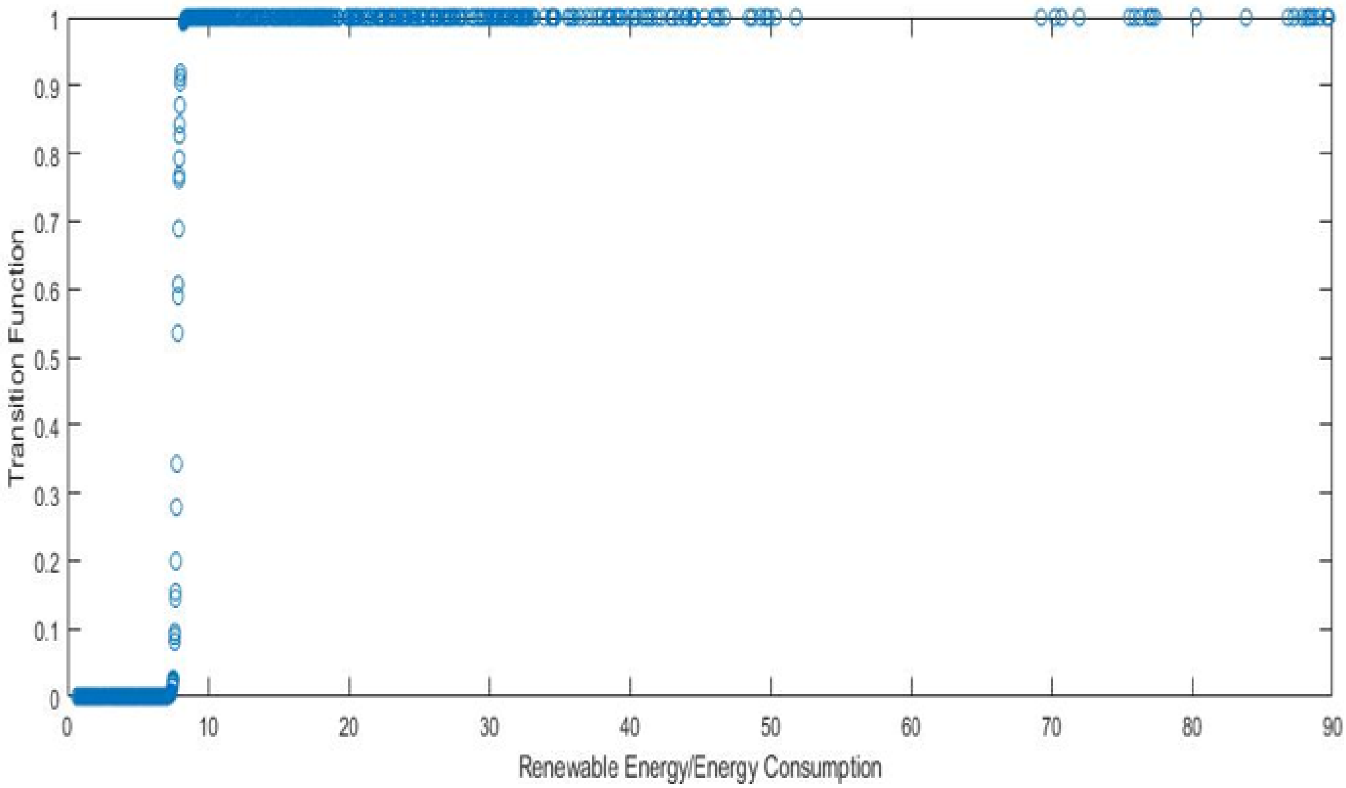

Figure 1

Estimated transition function of the PSTR model against the share of renewable energy in energy consumption (36 OECD Countries)

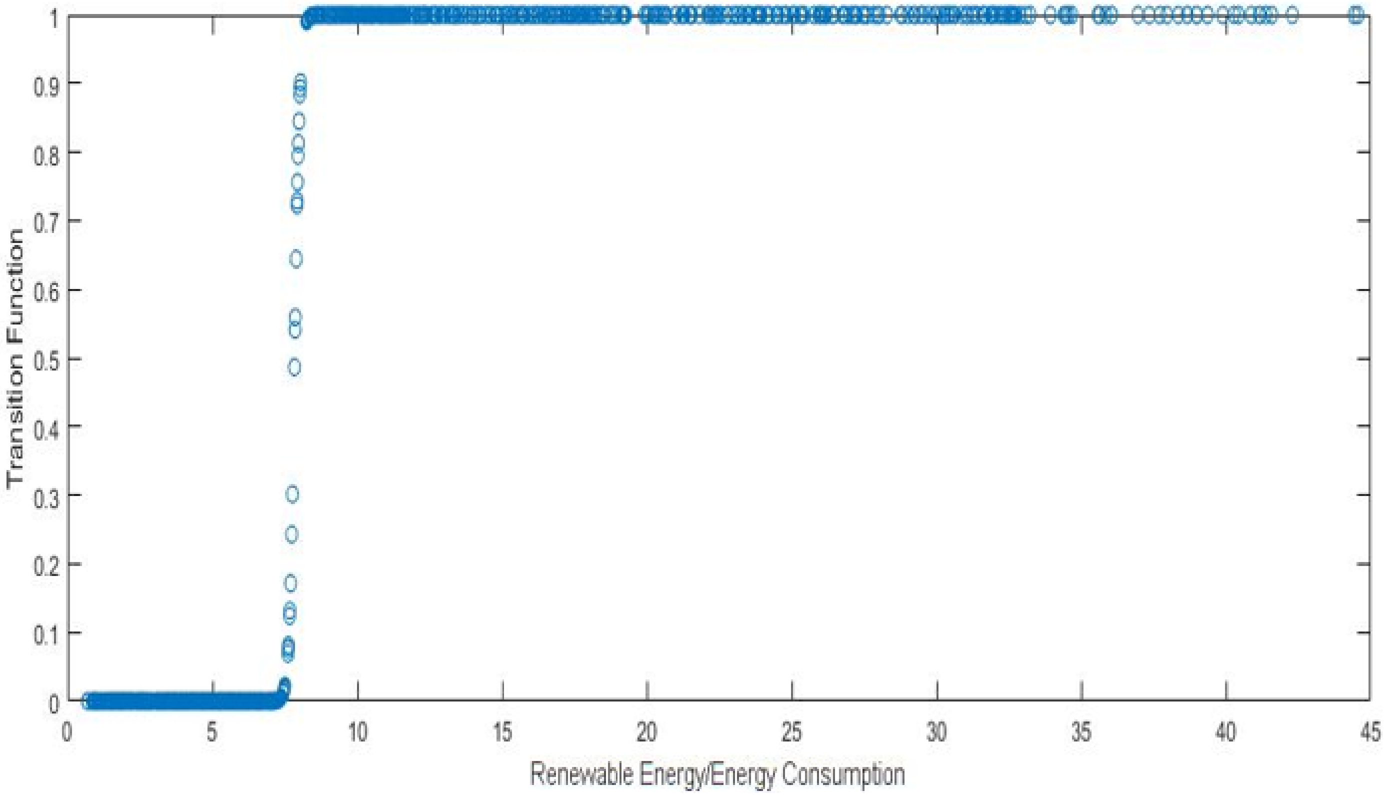

Figure 2

Estimated transition function of the PSTR model against the share of renewable energy in energy consumption (34 OECD Countries)