Available online at www.alphanumericjournal.com

alphanumeric journal
The Journal of Operations Research, Statistics, Econometrics and Management Information Systems

Volume 11, Issue 1, 2023

Received: August 02, 2021
Accepted: May 21, 2023
Published Online: July 12, 2023

AJ ID: 2023.11.01.ECON.01
DOI: 10.17093/alphanumeric.977654
Research Article

A Comparative Analysis of the Relationship between Renewable Energy Production and Economic Growth

Mehmet Uçaravcı *

Adnan Menderes University, Aydın, Turkiye, mucaravci@gmail.com

Tuğba Akın, Ph.D.

Assoc. Prof., Department of Econometrics, Aydın Faculty of Economics, Adnan Menderes University, Aydın, Turkiye, tugba.akin@adu.edu.tr

* Aydın Adnan Menderes Üniversitesi, Aydın İktisat Fakültesi, Merkez Kampüs Kepez Mevki 09100 Efeler, Aydın,Türkiye

ABSTRACT

The world has relied heavily on non-renewable sources in energy production for a long time. Although renewable energy investment is costly, especially for developing countries, the energy continuity provided by these sustainable sources can lower investment costs dramatically in the long run. Improvement of factors like economic growth and social welfare are believed to increase awareness of sustainable energy production. In this context, this paper examines the relationship between renewable energy production and the economic growth of Germany, and France, which are low energy-dependent countries, and Turkey, which is heavily dependent on external sources in terms of energy. The paper uses annual data between 1970-2018. The stationarity of variables was tested with methods developed by Zivot and Andrews (1992), and Enders and Lee (2012). Cointegration analysis with structural breaks developed by Gregory and Hansen (1996) was used to evaluate the relationship between variables. The results from the regime shift model indicate that structural reforms caused a significant regime shift in the relationship between energy production and economic growth in Germany and Turkey whereas the reforms did not lead to such a shift in France. The results of the causality analysis indicate a unidirectional causality from GDP to RN for Turkey and Germany.

Keywords: Renewable Energy, Growth, Co-integration, Fourier Approach

This article is an expanded/revised version of a presentation given at the Seventh International Conference on Economics (IceTea2021).

1. Introduction

Inventions such as steam motors, turbines, and other electricity-related apparatus let us prosper by bolstering the Industrial Revolutions and the subsequent boom in our collective production abilities; however, these inventions were not enough to commercialize and improve energy production on their own. Advancements like Faraday's scientific groundwork on alternators and other energy production/storage materials, the abundance of copper, and developments in wiring and energy distribution techniques enabled humans to push the frontiers of energy production (Patton, n.d.). Paralleling advancements in hydroelectricity and hydroelectric production caused a boom in energy production efforts. The emergence of hydroelectric power plants (HPPs) pushed our production capabilities so far that even the smallest companies began building their own HPP facilities at the turn of the 20th century. Countries like France, Germany, and the US aimed to display their industrial might by showcasing their latest energy production technologies (Sørensen, 1991).

The advent of the internal combustion engine and the emergence of non-renewable energy sources such as kerosene, oil, and diesel opened another page in global energy production history. Thanks to oil discoveries in the US and the Persian Gulf, the world began to adopt oil and diesel for industrial use and energy production. The first studies on energy production emerged during this era. Hubbert King analyzed the use of petrol and nuclear fuels in his 1956 article "Nuclear Energy and Fossil Fuels" and proposed the "peak oil" hypothesis, which stated that the world would reach the highest level of oil production in 1965 and begin a downward trend. With the effects of the OPEC crisis in the 1970s, the invention of newer technologies, and the increasing popularity of nuclear sources, the world began to shift its focus from non-renewable fuels to more renewable and/or economically viable sources. The crisis also expedited studies on the relationship between economic and energy indicators. The first paper examining the relationship between energy and economic growth was conducted by Kraft and Kraft in 1978, who analyzed the causality relationship between energy consumption and the GNP of the US. Following their seminal paper, more and more scientists began studying the energy-economy intersection. Works such as Akarca and Long (1980), Yu and Hwang (1984), Cheng et al. (1995, 1997, 1998, 1999), and Soytaş et al. (2001) all examined the energy-economy nexus from different perspectives.

Recent studies focusing on the relationship between energy consumption (or production) and economic growth established four categories to define the energy-economic growth nexus. These are (Squalli, 2007; Chen et. al., 2007; Apergis and Payne, 2009; Ozturk, 2010):

- **Neutrality hypothesis:** This suggests that there is no relationship between energy and economic growth. As a result, the literature argues that countries that display the neutrality hypothesis should not adopt expansive nor contractive policies concerning their energy or economy.
- **Conservation hypothesis:** This indicates a unidirectional causality from GDP to energy. In case of a one-way causality from economy to energy, the country is assumed to be energy independent and their energy policies have no negative or positive effect

on the economy. The hypothesis also correlates economic growth with energy consumption.

- **Growth hypothesis**: A unidirectional causality from energy to GDP. In this situation, any adverse or positive effect coming from energy causes economic output to increase or decline. In other words, energy serves as a limiting factor in a country's economic performance. As shocks to energy translate to fluctuations in GDP, countries, where the growth hypothesis exists, should adopt calculated approaches to their energy policies.

- **Feedback hypothesis:** A bidirectional relationship between economic growth and GDP. The existence of this hypothesis indicates that economic growth and energy move at the same time, and perhaps, are jointly affected by other factors.

Numerous papers have been published that aim to test these hypotheses; some notable examples are summarized in the Literature Review. The majority of the literature on the energy-economy intersection has focused on the consumption aspect of energy. According to the neoclassical production function, one of the important factors of production is energy consumption. By employing an energy production standpoint, we intend to better reflect economic output with energy capabilities. For this purpose, we analyzed the relationship between energy production and economic growth for the period 1970-2018 in Germany, France, and Turkey.

Germany has made significant progress in terms of renewable energy production within the European Union countries while also taking major steps to protect the environment and use more renewable energy sources with the Renewable Energy law, which entered into force on January 1, 2021. Compared to other European countries, France cannot use its renewable energy production potential very efficiently compared to other European countries. There are only a small number of photovoltaic and wind production facilities which output a minute amount of energy. Despite this, the country is ahead of others in terms of renewable energy production through the application of economic policies that encourage renewable energy production (Kulözü, 2005). Turkey shows similarities with France in terms of energy potential, physical and demographic structure and has taken important steps towards improving its renewable energy production over the last decade. Renewable energy production in Turkey has shown a 20 percent growth in 2020 compared to the previous year. However, considering that the country imports approximately 74 percent of its energy consumption, Turkey needs additional policies to allocate resources to renewable energy production. The European Union aims to increase the share of renewable energy production in the energy supply. In accordance, Turkey has taken remarkable steps for efficient use of renewable energy sources (T.C. Avrupa Birliği Bakanlığı, 2014). In this context, we conducted a comparative analysis of the relationship between economic growth and renewable energy production for Germany, France, and Turkey by employing methods that assume and examine the existence of smooth breaks. In doing so, we aim to reflect the transitional nature of energy production and economic growth.

Following the introduction, we will provide a brief overview of the countries in our sample which will be followed by a summary of recent literature. Then, we will focus on our data and methodology. We will provide results of our analysis results and the article will conclude with a brief discussion of these results.

2. Country Information

The study utilizes annual data between 1978 and 2018 from Germany, France and Turkey. The following chapter lays out the historical framework of the countries in this study. The combined GDP and renewable energy production graphs for Germany, France and Turkey are provided in Figure 1-3, respectively.

Germany's introduction to renewable energy sources was in 1974 after the OPEC crisis. The country focused its resources almost solely on research and development for 15 years. Following a brief period of decline, Germany expeditiously shifted its focus from nuclear energy to alternative sources after the Chernobyl accident in 1986. Ensuing public discontent pushed the government at the time to direct the country's energy production to greener resources. The German government began subsidizing photovoltaic and wind technologies in the 90s. In 2001, the country decided to phase out its nuclear energy production facilities (Lauber, 2004). Germany, pledging to reduce its GHG emissions under the Kyoto Protocol and the EU regulations, enacted a green tax reform in 2003. The bill raised taxes on mineral oils like petrol, diesel, natural gas, and other fuels from mineral sources except for coal and nuclear energy-producing facilities that meet a certain level of efficiency. Energy production and awareness have been at the heart of Germany's political arena since 2004, and in 2010 the German government introduced its "Energiekonzept," which featured very ambitious goals for Germany's future such as cutting the country's GHG emissions by 40 percent by 2020, and by at least 80 percent until 2050 (Hake, 2015).

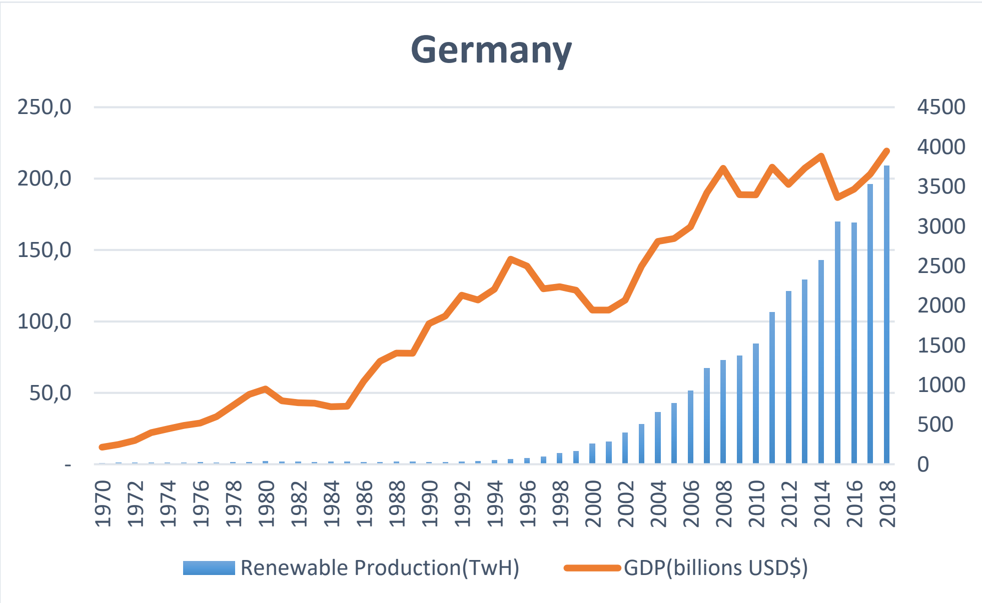

Figure 1. Germany's Renewable Energy Production and GDP between 1970-2018

France's debut in renewable energy production dates back to the 1950s. After WWII, the country constructed numerous hydropower plants. They were followed by solar power projects such as Themis Solar Plant in the 1970s. Despite their rapid development in renewable energy, France relied heavily on nuclear power. After the OPEC crisis, they began prioritizing nuclear energy. Aiming to gain its independence in energy after a series of oil shocks, France built around 60 nuclear power plants between 1970 and 1990. Similar to Germany, France also began phasing out its nuclear efforts in recent years. Since the early 2000s, France has expedited its efforts in renewable energy production. The energy production from wind and solar power increased by up to 25 percent. The country also uses biomass-generated power, which accounts for almost half of the total energy output (Rohwer, 2017). In 2014, the French government passed a law to promote the use of sustainable and eco-friendly energy sources (Patel, 2014). The bill aims to decrease taxes and offer low-interest loans. Former French president François Holland stated that the country aims to decrease the share of nuclear energy in total production down to 50 percent from the current value of approximately 75 percent (Irfan, 2015).

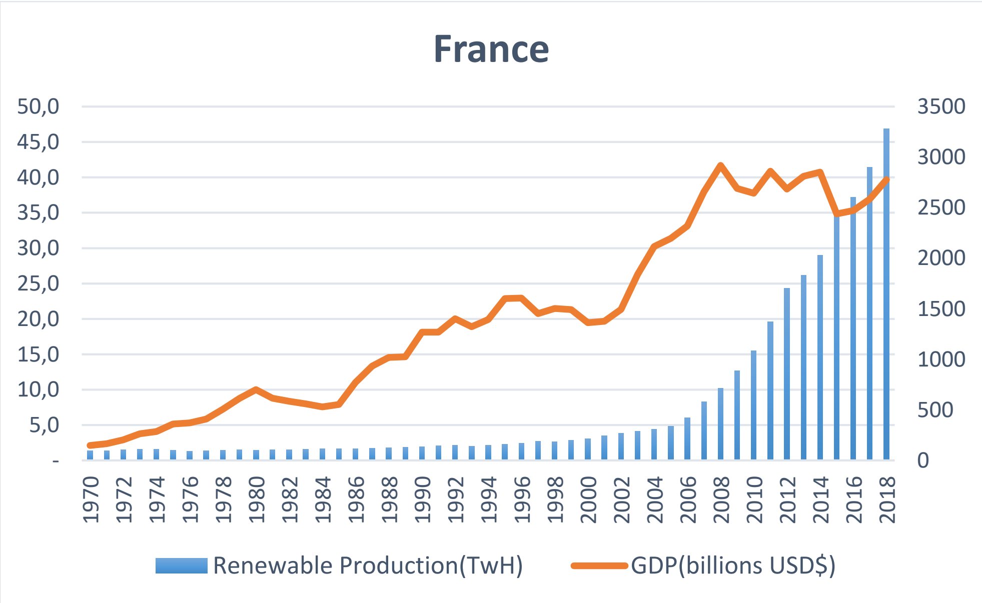

Figure 2. France's Renewable Energy Production and GDP between 1970-2018

Turkey's renewable history begins with experimental hydroelectric plants built at the turn of the 20th century. After a brief pause during WWI, the newly established republic amped up the efforts to bolster its energy production. The country had approximately 50 plants generating up to 110 GWh of electricity at the beginning of the 1930s. Turkey continued its efforts to increase its energy production and bring electricity to more households. The country established numerous institutions to promote and regulate the energy sector. Around the 1970s, Turkey began consolidating its production capabilities under one roof. It launched the Southeastern Anatolia Project (GAP) which foresaw the construction of 13 HPPs in its rich water sources in the southeastern region. The energy in Turkey encountered an impactful transition in 1982 when all local and regional facilities not covered by the prior decision were transferred to the Turkish Electricity Authority (tr. Türkiye Elektrik Kurumu, TEK). The TEK's monopoly over energy ended in 1984 when the government introduced a law privatizing the energy sector (OECD). The same decision also pushed the use of thermal resources in electricity generation into the spotlight. Turkey began investing in geothermal facilities and until 1997, remained dependent on renewable resources for energy. The agreement with Iran in 1996 secured approximately three million cubic meters of natural gas (Hepbasli, 2004). This shifted the country's focus from hydroelectric and geothermal production but as part of its EU negotiations, the country began prioritizing solar and wind energy in 2003 (Özkaya, 2004). The following decade saw numerous investments in solar and wind power facilities. Although the majority of this is still generated by hydroelectric facilities, the country aims to generate close to 60,000 MWh from renewable sources by 2023 (Karagöl, 2017).

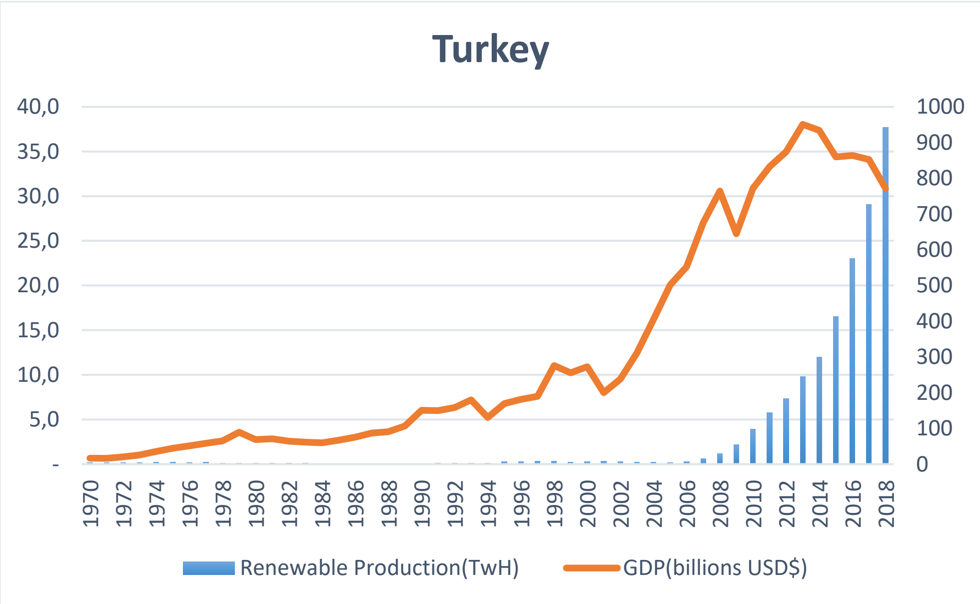

Figure 3. Turkey's Renewable Energy Production and GDP between 1970-2018

3. Literature Review

The relationship between energy and economic growth has been studied extensively for the past 40 years. A selection of recent studies carried out in the field is summarized below.

Apergis and Payne (2010) analyzed the connection between renewable energy and the economic growth of OECD countries using data between 1985 and 2005. The panel data integration and error correction models showed a long-run relationship between GDP, renewable energy consumption, real gross fixed capital formation and labor force. The Granger causality test indicated a bidirectional relationship between renewable energy and economic growth.

Tiwari et al. (2014) analyzed the relationship between renewable and non-renewable energy production in 12 Sub-Saharan countries and found mixed unidirectional causalities with hidden cointegration test. The results point to the growth hypothesis in some countries while indicating a conservation hypothesis for both renewable and non-renewable energy production.

Kazar and Kazar (2014) examined the relationship between renewable electricity generation and economic growth for 154 countries using data between 2005 and 2010 using Granger causality. Their analyses showed that economic development will lead to higher renewable energy production, confirming the conservation hypothesis. After separating the sample according to their human development index score, analyses of subsamples show that there are no causality relationships for countries with very high development values while pointing to a bidirectional relationship for countries with mid-level development scores.

Bhattacharya et. al. (2015) investigates the renewable energy-economic growth nexus for 38 counties using panel cointegration and causality tests. Their results show no relationship between renewable energy consumption and economic growth.

Destek and Aslan (2017) studied the relationship between renewable and non-renewable energy consumption and economic growth in 17 emerging economies between 1980 and 2012 using bootstrap panel causality analysis. In terms of renewable energy, the results confirmed the growth hypothesis for Peru; the conservation hypothesis for Thailand and Columbia; the feedback hypothesis for Greece and South Korea; and the neutrality hypothesis for the other 12.

Dinç et. al. (2017) examined the relationship between renewable energy production and economic growth for Turkey by using Johansen cointegration, vector error-correction model (VECM), Granger causality analyses. Their findings indicate that there is a short and long-run unidirectional causality from GDP growth to renewable energy production in the case of Turkey, which confirms the existence of conservation hypothesis.

Zafar et. al. (2018) analyzed the relationship between non-renewable and renewable energy consumption and economic growth for Asia-Pacific Economic Cooperation (APEC) countries. The paper used the Westerlund cointegration test and Continuously-updated Fully Modified OLS(CUPFM) tests to investigate the relationship between 1990 and 2015. The results indicate that there are bidirectional causalities between renewable and non-renewable energy consumption, and economic growth.

Danish et. al. (2018) studied the relationship between energy production, economic growth and CO2 emissions of Pakistan using the Johansen cointegration test, ARDL approach and Granger causality. Their results indicate the existence of a cointegration relationship between the variables however, the causality analysis showed no evidence of a relationship between energy production and economic growth.

Ntanos et. al. (2018) examined the relationship between renewable energy consumption and economic growth of 25 European countries applying cluster analysis and ARDL approach to data between 2007 and 2016. The results indicate a high correlation between renewable energy production and economic growth.

Singh, Nyuur and Richmond (2019) used data between 1995 and 2016 from 20 developed and developing countries to investigate the relationship between renewable energy production and economic growth. The study employed the Pedroni panel cointegration test and the FMOLS method, which revealed that renewable energy production is associated with economic growth, and its impact varied between developed and developing countries.

Since there are very few studies focusing on the relationship between renewable energy production and economic growth, it is thought that this study will expand the literature on the subject with a new perspective.

4. Analysis

4.1. Data and Model

In this study, the relationship between renewable energy production (RN) and economic growth (G) data of Germany, France, and Turkey was analyzed for the period between 1970 and 2018. The studied data were obtained from the World Bank's Database and BP's Statistical Review of World Energy dataset. Logarithms of renewable energy production (LNRN) and economic growth (LNG) were included in the analysis to obtain measurable results with certain elasticity and to ensure homogeneity between variables. The effect of LNG on LNRN was investigated by using the following model for each country:

$$LNRN_t = \beta_0 + \beta_1 LNG_t + \varepsilon_t \quad (1)$$

The missing observations of Turkey between 1980 and 1982, which are most likely due to the transient environment resulting from the military coup in 1980, were calculated through the extrapolation method (Durlauf, et al., 2005).

4.2. Methodology

The stationarity of variables was tested with methods developed by Zivot and Andrews (1992), and Enders and Lee (2012). Zivot and Andrews ADF test with single breaks (ZA) (1992) was used to determine the susceptibility of the series to structural breaks. Fourier ADF method (EL), developed by Enders and Lee (2012), was used in conjunction with the Zivot and Andrews' ADF test to validate the results of the ZA test. Unlike ZA, the Fourier ADF makes no assumptions about the structural breaks in a series i.e., whether they are sharp or not, so it performs very well if structural breaks occur with smooth transitions. The EL Fourier ADF test allows a structural unit root analysis for up to three frequencies. For this reason, the EL Fourier ADF test was included in the structural break unit root analysis of our variables. Thus, an analysis can be made without the need for prior knowledge and assumptions about the structural break dates. As the variables contain trends, constant and trend models were preferred as deterministic variables. The equations of the ZA ADF and EL Fourier ADF tests with constant and trend are expressed as (Zivot and Andrews, 1992; Enders and Lee, 2012):

ZA ADF Test

$$\Delta Y_t = \alpha Y_{t-1} + \mu_0 + \beta_0 t + \mu_1 DU_t + \beta_1 DT_t + \sum_{i=1}^{q} p_q \Delta Y_{t-q} + \delta_t \quad (2)$$

where $DU_t = 1, \quad DT_t = (t - T_b), \ t > Tb$

t and T_b denote time and break date, respectively,

EL Fourier ADF test

$$Y_t = \alpha Y_{t-1} + \mu_0 + \beta_0 t + \sum_{k=1}^{n} a_k \sin(2\pi kt/T) + \sum_{k=1}^{n} b_k \vartheta \cos(2\pi kt/T) + \sum_{i=1}^{q} p_q \Delta Y_{t-q} + \delta_t \quad (3)$$

n denotes the number of frequencies and k is a specific frequency. In the study, the maximum number of frequencies was taken as 3 and the results obtained with the optimum frequency were reported in Table 1.

After testing the series for unit root, the cointegration relationship between the variables was analyzed with the Gregory-Hansen (1996a, 1996b) cointegration test with a structural break. This test is a single structural break cointegration method that can examine the cointegration relationship between variables in the presence of a structural break with four different models. Our study uses two of them, level and trend shift, and regime and trend shift models. The equations for the tests are provided below (Gregory and Hansen, 1996a: 103; Gregory and Hansen 1996b:556):

Model 1: Level and trend shift model;

$$y_t = \beta_0 + \beta_1\varphi_t + \alpha_1 t + \acute{\gamma}_1 x_t + \epsilon_t \tag{4}$$

Model 2: Regime and trend shift model;

$$y_t = \beta_0 + \beta_1\varphi_t + \alpha_1 t + \acute{\gamma}_1 x_t + \acute{\gamma}_2(x_t\varphi_t) + \alpha_2(t\varphi_t) + \epsilon_t \tag{5}$$

φ_t is dummy variable of the models and is defined as

$$\varphi_t = \begin{cases} 0, & t \leq T_b \\ 1, & t > T_b \end{cases}$$

T_b denotes break date. The null hypothesis of the test is "There is no cointegration relationship between series under structural breaks. The critical values required to test this hypothesis were calculated using Monte Carlo simulation by Gregory and Hansen (1996a, 1996b). The long-term relationship between the variables was analyzed using the Fully Modified Ordinary Least Squares (FMOLS) method (Phillips & Hansen, 1990).

The causality relationship between the variables was examined by the Fourier Granger causality analysis (Enders & Jones, 2016). In a situation where there are structural breaks with unknown form, date, and/or number, the Fourier approach assumes the existence of smooth shifts. The Fourier Granger causality equation can be expressed as (Enders and Jones, 2016);

$$Y_t = \alpha_0 + \sum_{k=1}^{n}\gamma_{1k}\sin(\frac{2\pi kt}{T}) + \sum_{k=1}^{n}\gamma_{2k}\cos(\frac{2\pi kt}{T}) + \alpha_1 Y_{t-1} + \cdots + \alpha_p Y_{t-p} + \beta_1 X_{t-1} + \cdots + \beta_p X_{t-p} + \varepsilon_t \tag{6}$$

n is the number of frequencies, k represents frequency, and γ_{1k} and γ_{2k} denote trigonometric frequencies.

5. Findings

5.1. Results of the Unit Root Tests

Unit root results are presented in Table 1.

Upon examining Table 1, we can see that the series contain unit root at level but become stationary when their first differences are taken. This indicates that shocks to the level variables are not temporary.

The break dates in the table represent shocks to the series, so we should take a closer look at the specified dates. The shock to Germany's LNRN is probably due to the latent effects of Germany's new tariff/subsidy on renewable energy and the agreement between the German government (BDI), VIK, and VDEW, which both took place in 1979. The break in LNG is most likely a result of Germany's increased economic reforms and other circumstances that led to the eventual fall of the Berlin Wall, the culmination of economic recovery from the oil crisis, the boom of the West German economy, and decreased state visibility in the market after the changes of the new government, elected in 1982.

The break dates of France's GDP can be explained by the OPEC crisis in the 70s and the economic decisions of Mitterrand's government. The effects of compounding economic crises and the global wave of deregulation pushed the French government to first assume and then abandon dirigisme, characterized by a strong government presence in the market. The most prominent events in this process are the implementation of the ninth and tenth economic plans in 1986 and 1988, which aimed to improve France's economy and devoted plenty of resources to employment and R&D programs (Sachs et. al. 1986) (Advameg NE). The shift in renewable energy can be best explained by the EC Directive on energy production in Europe that took place in 1997, which affected the French energy sector as France's EDF (Éléctricité de France) lost its privileges in the country (Bergman et. al., 1999).

Finally, Turkey's break date in renewable energy is likely a result of the consolidation of energy production facilities in 1981 under the TEK, and the re-privatization of these projects in 1985 (OECD). The break date in GDP can be explained by the recovery from the economic crisis in 2001 and the economic reforms brought on by the new government.

	Sharp Shift			**Smooth Shift**		
Germany	***Zivot and Andrews***	***TB***	***CV (%5)***	***Enders and Lee***	***k***	***CV (%5)***
LNRN	-3.5264	1980	-5.08	-3.5323	2	-4.05
LNG	-4.46	1989	-5.08	-2.2245	3	-3.78
DLNRN	-7.8747***	1991	-5.08	-6.9359***	1	-4.35
DLNG	-5.7641***	1985	-5.08	-5.0512***	3	-3.78
France	***Zivot and Andrews***	***TB***	***CV (%5)***	***Enders and Lee***	***k***	***CV (%5)***
LNRN	-3.7171	1997	-5.08	-3.1514	1	-4.35
LNG	-3.6494	1989	-5.08	-2.379	3	-3.78
DLNRN	-7.1811***	2005	-5.08	-3.9227*	2	-4.05
DLNG	-5.9915***	1984	-5.08	-5.0708***	3	-3.78
Turkey	***Zivot and Andrews***	***TB***	***CV (%5)***	***Enders and Lee***	***k***	***CV (%5)***
LNRN	-3.2638	1981	-5.08	-1.0699	3	-3.78
LNG	-3.6929	2003	-5.08	-3.2701	3	-3.78
DLNRN	-9.6032***	1985	-5.08	-8.5079***	3	-3.78
DLNG	-8.3598***	1985	-5.08	-5.3116***	3	-3.78

Note: *, ** and *** denote stationarity at 10%, 5%, and 1% significance levels, respectively. In unit root analysis (EL), the maximum lag length was chosen as 2 and the optimal lag length is determined according to the significance level of the t-statistic.

Table 1. Unit Root Test Results

5.2. Results of the Cointegration Test

The results of the Gregory-Hansen (1996a; 1996b) cointegration test with a single structural break are provided in Table 2.

When we check the results of the GH cointegration test, it becomes apparent that there are cointegration relationships between the variables. The structural break dates were calculated using ADF and Phillips-Perron (Z_t) tests.

The break dates in Germany's variables are, again, most likely due to the series of reforms that were implemented during the early 1990s by the German government. France's expedited renewable energy production agenda of the 2000s can be attributed to the break in 2004, and Turkey's break can be a result of economic recovery from the transient environment created by the 1980 military coup and economic reforms in the early- to mid-80s, or correction of data irregularities due to the same reason.

Germany	**ADF**	**Break Date**	**Zt**	**Break Date**
Level and Trend Shift	-8.633***	1991	-8.727***	1991
Regime and Trend Shift	-8.836***	1992	-8.931***	1992
France	**ADF**	**Break Date**	**Zt**	**Break Date**
Level and Trend Shift	-5.154***	2004	-5.209***	2004
Regime and Trend Shift	-6.474***	2004	-7.149***	2005
Turkey	**ADF**	**Break Date**	**Zt**	**Break Date**
Level and Trend Shift	-8.845***	1982	-8.922***	1982
Regime and Trend Shift	-9.731***	1982	-11.76***	1985
Critical Values for ADF and Zt tests with one independent variable (m=1)				
	%1	%5	%10	
Level and Trend Shift	-5.13	-4.61	-4.34	
Regime and Trend Shift	-6.02	-5.50	-5.24	

Note: Critical values are taken from Gregory-Hansen (1996a; 1996b) Table 1. *, ** and *** denote the rejection of the null hypothesis at 10%, 5%, and 1% significance level, respectively.

Table 2. The results of the cointegration test with a single structural break

5.3. Results of the long-term cointegration coefficient estimation

The long-term relationship between variables with the existence of cointegration relationship is analyzed by using the Fully Modified Ordinary Least Squares (FMOLS) (Phillips & Hansen, 1990) method and the results are presented in Table 3.

When the figures in Table 3 are examined, it is clear that while the relationship between renewable energy production and growth before the structural break was statistically insignificant in Germany, there was a serious regime shift after the break in which one percent increase in growth caused an increase of 4.94 percent in renewable energy production. This indicates that the renewable energy reforms in the early 1990s had a major impact on the relationship between the two variables. Similarly, France's growth elasticity of renewable energy generation increased as a result of the country's sustainable energy efforts during the 2000s. In Turkey, a negative and statistically insignificant relationship between the two variables became positive and significant after 1985. From this, we can also deduce that the increased awareness on the importance of renewable energy production in Turkey has led to a significant regime change. The results of our analyses concur with our literature as there is a cointegration relationship between variables for each country.

	FMOLS (Level and Trend Shift)		FMOLS (Regime and Trend Shift)	
Variables	**Coefficient**	**t- stat**	**Coefficient**	**t- stat**
$LNG_{Germany}$	1.4735**	2.2453	0.2801	0.834
$Constant_{Germany}$	-40.305**	-2.244	-7.4302	-0.806
$LNG * DT_{Germany}$	----	----	4.9431***	6.186
DT_{1991}	1.153	1.51		
DT_{1992}	----	----	-138.8860***	-6.107
LNG_{France}	0.3863**	2.196	0.384**	2.366
$Constant_{France}$	-9.9516**	-2.063	-9.900**	-2.221
$LNG * DT_{France}$	----	----	4.057*	1.918
DT_{2004}	1.8457***	6.088	----	----
DT_{2004}	----	----	-114.175*	-1.887
LNG_{Turkey}	2.09***	6.443	-0.5312	-0.644
$Constant_{Turkey}$	-53.436***	-6.677	10.2368	0.507
$LNG * DT_{Turkey}$	----	----	2.9213***	3.290
DT_{1982}	-2.6447***	-3.077		
DT_{1985}	----	----	-73.9926***	-3.349
$R^2_{Germany}$	0.70		0.91	
R^2_{France}	0.86		0.87	
R^2_{Turkey}	0.71		0.81	

Note: *, **, *** denote that the coefficient is significant at 10%, 5% and 1%, respectively.

Table 3. The long-term cointegration coefficients

5.4. Short Term Analysis

The short-term coefficients have been estimated by the error correction model. The one-period lagged values (Error Correction Term: ECT_{t-1}) of the error term series were obtained using the long-term analysis with the systematic approach and the results are given in Table 4.

According to the results, we can see that the short-term deviations disappear in the long term and the series converge at their long-term equilibrium values. This also shows that there is a long-term causality relationship between variables. The short-term deviations of approximately 37, 19 and 1 percent for Germany, France and Turkey, respectively and they all recede in the first period.

	$\Delta LNRN$	ΔLNG
$ECT_{t-1,Germany}$	0.371**	-0.056***
$t\ statistic$	1.916	-3.868
$ECT_{t-1,France}$	0.186*	-0.075***
$t\ statistic$	1.613	-4.714
$ECT_{t-1,Turkey}$	-0.014**	0.007***
$t\ statistic$	-1.714	2.899

Note: *, **, *** denote that the coefficient is significant at 10%, 5% and 1%, respectively.

Table 4. Error Correction Models

5.5. Fourier Granger Causality Test

The causality among the variables was tested with the Fourier Granger causality approach which introduces trigonometric functions in the presence of a smooth break. The Fourier Granger causality results (considering only the single frequency) are reported in Table 5.

The results in Table 5 indicate that there is unidirectional causality from growth to renewable energy in Turkey and Germany in the short term but there is no causal relationship in France. These results support the conservation hypothesis for Turkey and Germany, and the neutrality relationship in the case of France. Our results are similar to those of Tiwari et. al. (2014), Kazar and Kazar (2014), Bhattacharya et. al. (2016) and Dinç et.al. (2017), and differ from other studies in the literature review due to mixed results.

	Causality	Wald Test	p-Valuea	p-Valueb	k	p
Germany	GDP to RN	2.964	0.085*	0.092*	1	1
	RN to GDP	0.919	0.338	0.352	1	1
France	GDP to RN	3.314	0.191	0.209	3	2
	RN to GDP	3.772	0.152	0.156	3	2
Turkey	GDP to RN	5.055	0.025**	0.026**	3	1
	RN to GDP	0.065	0.798	0.795	3	1

Note: *, ** and *** denote causality at 10, 5, and 1 percent significance levels, respectively. Maximum *k* and *p* are calculated as 3 and 2, respectively. Optimal *k* and *p* are then determined by the Akaike information criterion. *p-Value*[a] represents the asymptotic chi-square distribution with *p* degrees of freedom. *p-Value*[b] shows the bootstrap distribution with 1000 replications.

Table 5. Fourier Granger Causality Test Results

6. Conclusion

The adverse effects of climate change lead countries to the production of renewable energy. The relationship between economy and energy, namely its renewable aspect, has been studied extensively throughout history. Some researchers categorized the economic growth-energy nexus into four different hypotheses. Using the data of Germany, France and Turkey between 1970 and 2018, we examined the causal relationship between renewable energy production and economic growth. This article aims to expand the literature on the topic from a new perspective, as there are only a small number of studies focusing on the relationship between renewable energy production and economic growth. Our results indicate that there is a cointegration relationship between renewable energy production and economic growth for all countries. The long-term estimates show that the countries were affected positively by the regime changes and the results of causality analysis reveal that there is unidirectional causality from GDP to RN in Germany and Turkey, which proves the existence of conservation hypothesis, and no causality in France, proving the neutrality hypothesis. Specifically, the renewable energy reforms in the early 1990s caused a schism in the relationship between GDP and RN positively in Germany. Likewise, France's growth elasticity of renewable energy generation increased after the country's reforms on sustainable energy production during the 2000s. In Turkey, increased awareness on the importance of renewable production after 1985 has to led to a significant regime change. Consequently, the relationship between GDP and RN became positive and statistically significant. Our analyses show that as a country prioritizes renewable energy production and innovation of renewable technologies, its economic growth begins to have a more positive effect on renewable energy production and governments begin to invest in and develop their renewable energy production capabilities, notably because of the environmental awareness increases and easier financing of start-up cost. This effect becomes more pronounced with further investments in the area. Therefore, governments should not avoid renewable technologies for high implementation costs as their long-term yields outweigh short-term setbacks, and the increase in renewable energy production will reduce external dependency on energy and the energy production and economic growth will begin to mutually affect each other. At the same time, the government revised policies containing restrictions such as taxes, price increases and bureaucratic obstacles that can be applied to renewable energies will stop the loss of welfare in the country.

References

Advameg NE. (n.d.). France - economic development. Retrieved April 01, 2021, from https://www.nationsencyclopedia.com/Europe/France-ECONOMIC-DEVELOPMENT.html

Akarca, A.T., Long, T.V., 1980. On the relationship between energy and GNP: a reexamination. Journal of Energy Development 5, 326–331

Apergis, N., & Payne, J. E. (2009). Energy consumption and economic growth in Central America: Evidence from a panel cointegration and error correction model. Energy Economics, 31(2), 211–216. doi: 10.1016/j.eneco.2008.09.002

Apergis, N., & Payne, J. E. (2010). Renewable energy consumption and economic growth: Evidence from a panel of OECD countries. Energy Policy, 38(1), 656–660. doi: 10.1016/j.enpol.2009.09.002

Bergman, L., Brunekreeft, G., Doyle, C., Von der Fehr, N. M., Newberry, D. M., Pollitt, M., & Regibeau, P. (1999). A European Market for Electricity? - Monitoring European Deregulation 2 (1282954140 946261666 R. Vaitilingham, Ed.). London: Swedish Center for Business and Policy Studies.

Bhattacharya, M., Paramati, S. R., Ozturk, I., & Bhattacharya, S. (2016). The effect of renewable energy consumption on economic growth: Evidence from top 38 countries. Applied Energy, 162, 733–741. doi: 10.1016/j.apenergy.2015.10.104

Chen, S.-T., Kuo, H.-I., & Chen, C.-C. (2007). The relationship between GDP and electricity consumption in 10 Asian countries. Energy Policy, 35(4), 2611–2621. doi: 10.1016/j.enpol.2006.10.001

Cheng, B., 1995. An investigation of cointegration and causality between energy consumption and economic growth. Journal of Energy Development 21, 73–84.

Cheng, B.S., 1997. Energy consumption and economic growth in Brazil, Mexico and Venezuela: a time series analysis. Applied Economics Letters 4 (11), 671–674.

Cheng, B.S., 1998. Energy consumption, employment and causality in Japan: a multivariate approach. Indian Economic Review 33 (1), 19–29.

Cheng, B.S., 1999. Causality between energy consumption and economic growth in India: An application of cointegration and error-correction modeling. Indian Economic Review 34, 39–49.

Cheng, B.S., Lai, T.W., 1997. An investigation of co-integration and causality between energy consumption and economic activity in Taiwan. Energy Economics 19 (4), 435–444.

Danish, Zhang, B., Wang, Z., & Wang, B. (2017). Energy production, economic growth and CO2 emission: evidence from Pakistan. Natural Hazards, 90(1), 27–50. doi:10.1007/s11069-017-3031-z

Destek, M. A., & Aslan, A. (2017). Renewable and non-renewable energy consumption and economic growth in emerging economies: Evidence from bootstrap panel causality. Renewable Energy, 111, 757–763. doi: 10.1016/j.renene.2017.05.008

Dinç, D. T., Gökmen, A., & Kanık, Z. B. (2017). Energy policy issues in Turkey: Renewable Energy Production and Economic Growth Nexus. International Journal of Sustainable Economies Management, 6(3), 50-65. doi:10.4018/ijsem.2017070105

Durlauf, S.N., Johnson, P.A., and Temple, J.R.W. (2005). Growth Econometrics (Chapter 8), Handbook of Economic Growth, Volume 1a, Edited by Philippe Aghion and Steven N. Durlauf, pp.652. DOI: 10.1016/S1574-0684(05)01008-7

EDF. (2021, February 09). EDF Group - History. Retrieved March 31, 2021, from https://www.edf.fr/en/the-edf-group/edf-at-a-glance/history

Enders, W., Jones, P. "Grain prices, oil prices, and multiple smooth breaks in a VAR." Studies in Nonlinear Dynamics & Econometrics 20.4 (2016): 399-419.

Enders, W., Lee, J. “The flexible Fourier form and Dickey–Fuller type unit root tests.", Economics Letters 117.1 (2012): 196-199.

Gregory, Allan W., Hansen, Bruce E. "Residual-based tests for Cointegration in models regime shifts. " Journal of Econometrics 70 (1996a): 99-126.

Gregory, A.W., Hansen, Bruce E. "Practitioner’s corner: tests for cointegration in models with regime and trend shifts." Oxford bulletin of Economics and Statistics 58.3 (1996b): 555-560.

Hake, J.-F., Fischer, W., Venghaus, S., & Weckenbrock, C. (2015). The German Energiewende – History and status quo. Energy, 92, 532–546. doi: 10.1016/j.energy.2015.04.027

Hepbasli A., & Ozgener O. (2004) Turkey's Renewable Energy Sources: Part 1. Historical Development, Energy Sources, 26:10, 961-969, DOI: 10.1080/00908310490473183

Irfan, U. (2015, June 29). France loses enthusiasm for nuclear power. Retrieved March 27, 2021, from https://www.scientificamerican.com/article/france-loses-enthusiasm-for-nuclear-power/

Karagöl, E.T., & Kavaz, İ. (2017). Dünyada ve Türkiye’de Yenilenebilir Enerji. Seta. https://setav.org/assets/uploads/2017/04/yenilenebilirenerji.pdf.

Kazar, G., & Kazar, A. (2014). The renewable energy production-economic development nexus. International Journal of Energy Economics and Policy, 4(2), 312.

Kraft, J., Kraft, A., 1978. On the relationship between energy and GNP. Journal of Energy and Development 3, 401–403.

Kulözü, A. G. N. (2005). Yenilenebilir Enerji Politikalari: Fransa Örneği. III. Yenilenebilir Enerji Kaynakları Sempozyumu ve Sergisi, Kocaeli.

Lauber, V., & Mez, L. (2004). Three Decades of Renewable Electricity Policies in Germany. Energy & Environment, 15(4), 599–623. doi:10.1260/0958305042259792

Ntanos, S., Skordoulis, M., Kyriakopoulos, G., Arabatzis, G., Chalikias, M., Galatsidas, S., Batzios A., Katsarou, A. (2018). Renewable Energy and Economic Growth: Evidence from European Countries. Sustainability, 10(8), 2626. doi:10.3390/su10082626

OECD. (2002). Regulatory Reform in Electricity, Gas and Road Freight Transport. Organisation for Economic Co-operation and Development. https://www.oecd.org/turkey/1840779.pdf.

Özkaya, S. Y. (2004). Yenilenebilir Enerji Kaynakları. Uluslararası Ekonomik Sorunlar Dergisi, T.C. Dışişleri Bakanlığı Yayınları, Sayı XIV. http://www.mfa.gov.tr/yenilenebilir-enerji-kaynaklari.tr.mfa.

Ozturk, I. (2010). A literature survey on energy–growth nexus. Energy Policy, 38(1), 340–349. doi: 10.1016/j.enpol.2009.09.024

Patton, J. (n.d.). Energy sources: History, selection, and transitions. Retrieved March 27, 2021, from https://www.ag.ndsu.edu/archive/streeter/Energy_Report/Chapters/History.htm

Phillips, P.C.B., Hansen, Bruce E. "Statistical inference in instrumental variables regression with I (1) processes." The Review of Economic Studies 57.1 (1990): 99-125.

Rohwer, S. (2017, May 04). Energy in France: Nuclear and Renewable Power. Retrieved March 27,2021, from https://sites.stedwards.edu/pangaea/2017/05/04/1339

Sachs, J., Wyplosz, C., Buiter, W., Fels, G., & de Menil, G. (1986). The Economic Consequences of President Mitterrand. Economic Policy, 1(2), 261. doi: 10.2307/1344559

Singh, N., Nyuur, R., & Richmond, B. (2019). Renewable Energy Development as a Driver of Economic Growth: Evidence from Multivariate Panel Data Analysis. Sustainability, 11(8), 2418. doi:10.3390/su11082418

Sørensen, B. (1991). A history of renewable energy technology. Energy Policy, 19(1), 8–12. doi:10.1016/0301-4215(91)90072-v

Soytas, U., Sarı, R., Özdemir, O., 2001. Energy consumption and GDP relation in Turkey: a cointegration and vector error correction analysis. In: Economies and Business in Transition: Facilitating Competitiveness and Change in the Global EnvironmentProceedings. Global Business and Technology Association, pp. 838–844.

Squalli, J. (2007). Electricity consumption and economic growth: Bounds and causality analyses of OPEC members. Energy Economics, 29(6), 1192–1205. doi: 10.1016/j.eneco.2006.10.001

T.C. Avrupa Birliği Bakanlığı, 2014. Avrupa Birliği Sürecinde Enerj Faslı, ISBN:978-605-5197-24-7, https://www.ab.gov.tr/files/SEPB/yayinlarveraporlar/enerjikitap.pdf

Tara Patel, "France Spurs Efficiency, Renewables with $13.4 Billion Energy Plan," Renewable Energy World, July 30, 2014, http://www.renewableenergyworld.com/news/2014/07/france-spurs-efficiency-renewables-with-13-4-billion-energy-plan.html.

Tiwari, A. K., Apergis, N., & Olayeni, O. R. (2014). Renewable and nonrenewable energy production and economic growth in sub-Saharan Africa: a hidden cointegration analysis. Applied Economics, 47(9), 861–882. doi:10.1080/00036846.2014.982855

Yu, E.S.H., Hwang, B.K., 1984. The relationship between energy and GNP: further results. Energy Economics 6, 186–190

Zafar, M. W., Shahbaz, M., Hou, F., & Sinha, A. (2018). From Nonrenewable to Renewable Energy and Its Impact on Economic Growth: The role of Research & Development Expenditures in Asia-Pacific Economic Cooperation Countries. Journal of Cleaner Production. doi: 10.1016/j.jclepro.2018.12.081

Zivot, E., Andrews, D. (1992). Further Evidence on The Great Crash, The Oil Price Shock, and The Unit Root Hypothesis. Journal of Business & Economic Statistics, vol. 10, no. 3, pp.251-270.