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Research Article

Stationarity Test of Renewable Energy Consumption with Fractional Frequency Fourier Unit Root Test: Evidence from BRICS-T Countries

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ABSTRACT Countries consume large amounts of coal, oil, and natural gas due to the energy structure dominated by fossil fuels worldwide. For this reason, the rate of renewable energies in countries or country groups in general is below the global average level. In this study, I aimed to test the stationarity of renewable energy consumption for Brazil, Russia, India, China, South Africa, and Turkey (the BRICS-T countries), which are in a rapid development. For this purpose, fractional frequency Fourier unit root test, which was introduced to the literature by Bozoklu et al. (2020), was used. Annual data on renewable energy consumption covering the period of 1990–2015 have been accessed from the official database of the World Bank. According to the results obtained, it has been found that the renewable energy consumption of China, one of the BRICS-T countries, is stationary and that other countries contain unit root.

Keywords: Energy, Renewable Energy, BRICS-T, Fractional Frequency, Fourier Unit Root

1. Introduction

Energy has been one of the main reasons for all the struggles between countries from the past to the present and in many wars in history. This is because energy, which became more important with the industrial revolution, has had a key role in the worldwide economy and social life since the oil crisis; It causes countries to be uneasy due to reasons such as being limited, being difficult to obtain, and increasing rapidly day by day. The growth of the global economy, ongoing increase in the population, important developments in technology, and globalization between countries have caused dependence on energy to increase rapidly. In the 21st century, energy resources are the leading factors that determine the foreign policy strategies of nation states in international relations. Categories of energy include (a) primary energies or non-transformed energies, which can be obtained from natural resources and include solar, wind, petroleum, hydraulic, geothermal, nuclear and coal energy and (b) derived or converted energies, consisting of electrical, thermal (heat), mechanical, chemical, electromagnetic, and light energy namely, secondary energies it is divided into two groups. Energy, according to the article, includes solar energy, wind energy, hydraulic energy, geothermal energy, wave energy, biogas energy, and biomass energy. It is obtained from the energy that flows continuously or repetitively from the natural environment, renewable (alternative) energy, nuclear energy, and fossil fuels (coal, petroleum, natural gas, etc.) are divided into two types of energy called non-renewable energies (Duran, 2020, pp. 5–9; Karhan, 2016, pp. 2–7). Governments have preferred to invest more in renewable energy sources because they aim to increase renewable energy consumption and because renewable energy consumption causes less environmental pollution than fossil fuel consumption (Izgi ve Destek, 2017, p. 15).

According to the BP Statistical Review of World Energy 2020, growth in energy markets slowed in 2019, in line with weak economic growth and the partial relaxation of some one-off factors that boosted energy demand in 2018. This slowdown was particularly pronounced in the USA, Russia, and India. China, on the other hand, was an exception, with energy consumption accelerating in 2019. In other words, China has dominated the expansion in global energy markets and has been the country with the greatest increase in demand for each energy source other than natural gas, which is barely exceeded by the US. Despite support from China, all fuels (except nuclear) grew more slowly than their 10-year averages, and coal consumption declined for the fourth time in six years. However, renewable energies still continued to grow at a record rate, with the level of renewable energy generation surpassing nuclear for the first time, providing the largest contributor to growth in primary energy (41%).

Energy need, which was an important problem in the past, has an even greater importance for developing countries such as high-income countries like Brazil, Russia, India, China, South Africa, and Turkey (the BRICS-T countries) as well as others, and it has outpaced production factors such as labor, capital, and land. Therefore, the energy sector has a great importance in terms of economic growth (Karhan, 2017, p. 13). Understanding the stochastic behavior of energy consumption is also central to several aspects for energy economists and policy makers (Hasanov ve Telatar, 2011, p. 7726).

With this context, in this study, annual renewable energy consumption data for the fast-developing BRICS-T countries covering the period 1990-2015 and the fractional frequency Fourier unit root test brought to the literature by Bozoklu et al. (2020) were analyzed and the results were shared according to the findings.

2. Literature Review

There are many studies in the literature examining the stationarity of energy consumption and its effects on the economy. Among these studies, Narayan and Smyth (2007) pioneered studies in the field of the stationarity testing of energy consumption. Narayan and Smyth (2007) examined the stationarity test of energy consumption for 182 countries using the augmented Dickey–Fuller (ADF) unit root test with data from the 1979–2000 period. They found a unit root in energy consumption per capita for only 31% of countries with the ADF univariate test. However, when they applied the panel version of the ADF test, they concluded that there was no unit root in energy consumption per capita for various panels.

Chen and Lee (2007) used the stationarity test of per capita energy consumption for 104 countries to examine the data of the 1971–2002 period with the multiple structural break panel unit root test developed by Carrion-i-Silvestre et al. (2005). With the structural breaks and cross-sectional correlations brought to the model according to the findings they obtained in the study, they concluded that all regionally based per capita energy consumption panels are stationary.

Mishra et al. (2009) tested the stationarity of energy consumption per capita for 13 Pacific Island countries with data for the period of 1980–2005. They used Carrion-i Silvestre et al. (2005) which allows for multiple structural breaks that can differ between countries at unknown dates and can explain all forms of cross-sectional correlations between countries. They analyzed using the panel stationarity test. According to the findings they obtained through their analysis, they concluded that the energy consumption per capita is constant in approximately 60% of the countries and that the energy consumption per capita is constant for the entire panel.

Narayan et al. (2010) analyzed time series data for the 1973-2007 period and energy consumption for Australian states and territory using the unit root null hypothesis. The first finding from their analysis is that the unit root zero hypothesis is rejected for most sectors, except for the consumption of electricity in the Tasmania sample and the energy consumption of the transport sector in the South Australian sample. The second finding is that total energy consumption is not stable in the South Australian sample alone, while total energy consumption is stable for the rest of the states and Australia as a whole.

Aslan ve Kum (2011) investigated the stationarity of energy consumption for Turkey with 1970-2006 data using linear and nonlinear unit root tests. According to the findings they obtained through their analysis, they concluded that linearity was rejected in 4 cases in 7 Turkish sectors.

Hasanov and Telatar (2011) investigated the stochastic behavior of total primary energy consumption per capita for 178 countries using the nonlinear unit root test with data from 1980–2006. They found mixed results in line with their findings from the studies and emphasized that energy policies will not always have the same effect. Therefore, governments should design their energy policies very carefully.

Agnollucci and Venn (2011) wanted to examine whether there is a deterministic or stochastic difference in industrial energy densities in the UK between sectors. Therefore, they analyzed data for the periods 1970–2004 and 1978–2004 for a number of British industrial subsectors using the panel unit root test. After allowing for structural breaks in the series as a result of their findings from this study, the authors concluded that the long-term differences in the energy intensities of British industrial subsectors are determinative.

Lean and Smyth (2013) examined whether policies promoting renewable electricity generation would be effective by applying panel unit root and stationarity tests to time series data on renewable electricity. They used data from 1980–2008 for 115 countries. According to their findings, they reached the conclusion that there will be more policies that will encourage renewable electricity generation like renewable portfolio standards, causing annual increases in renewable energy and therefore representing permanent positive shocks on the long-term growth path of renewable electricity generation.

Meng et al. (2013) analyzed the convergence of energy use per capita among 25 OECD countries using the data for the period of 1960–2010 and the newly developed Lagrange multiplier and RALS-Lagrange multiplier unit root tests with two structural breaks determined as endogenous. In line with the findings they obtained from their analysis, they concluded that there is a convergence in energy use per capita among OECD countries.

Yilanci and Tunali (2014) used a Fourier Lagrange Multiplier unit root test, which can capture the unknown nature of structural breaks, with data from 1960–2011, to re-examine the stationarity characteristics of the per capita energy consumption of 109 countries. In line with the findings obtained from the study, energy consumption per capita in 25 countries (Algeria, Australia, Benin, Bolivia, Canada, Costa Rica, Denmark, Egypt, Greece, Guatemala, Hong Kong, Ireland, Jordan, Democratic Republic of Korea, Mexico, Myanmar, Netherlands, New Zealand, Oman, Paraguay, Qatar, Singapore, Tanzania, United States, and Vietnam) is stationary, and energy demand management policies will not have an impact on energy consumption in the long run.

Mishra and Smyth (2014) investigated the convergence in per capita energy consumption among ASEAN countries using data for the period of 1971–2011, the panel Kwiatkowski–Phillips–Schmidt–Shin (KPSS) stationarity test, and the panel Lagrange multiplier unit root test. In line with the findings that they obtained from the analysis, they concluded that energy convergence, i.e., energy integration targets, can be achieved in ASEAN countries. The results showed that countries with low energy consumption catch the countries with higher energy consumption.

Karhan (2016) analyzed the relationship between the energy intensity and economic development levels for BRICS-T countries with cointegration tests and soft transition panel regression data for the period of 1990–2012. According to the findings, the author determined that there is an inverse U-shaped relationship between energy density and per capita income.

Bozkurt and Okumus (2016) examined the stationarity of total oil consumption for the BRICS-T countries by using linear and nonlinear unit root tests with data from 1965–2014. In line with the findings obtained from both unit root tests, the authors indicated that oil consumption is stationary in Brazil, China, and Turkey and that the impact of shocks in oil consumption is temporary. In the countries of South Africa, India and Russia, they concluded that the series contain unit root and that the shocks in oil consumption are permanent.

Ozcan and Ozturk (2016) examined the time-series properties of the series using the data of the 1971–2013 period of energy consumption per capita for 32 OECD countries. They extended CBL univariate and panel constant tests with a Fourier function as proposed by Bahmani-Oskooee et al. (2014). According to their findings, per capita energy consumption is stationary for 16 OECD countries (Belgium, Canada, Chile, Czech Republic, Denmark, Finland, Germany, Hungary, Japan, Mexico, Netherlands, Norway, Spain, Sweden, the United States, and the United Kingdom). They concluded that for these countries, the mean is stationary, whereas for the remaining 16 OECD countries (Austria, Australia, France, Greece, Iceland, Ireland, Israel, Italy, South Korea, Luxembourg, New Zealand, Poland, Portugal, Slovakia, Switzerland, and Turkey), the mean is not stationary. They also found that per capita energy consumption did not exhibit sharp and smooth structural changes (breaks) in average and/or trend levels and corresponded to certain macroeconomic events, such as internally determined break times, oil crises, the Gulf War, and Asian and global financial crises.

Can (2017) examined the relationship between renewable energy production in Turkey and domestic output using data from 1960–2013 and VAR analysis. According to the findings of the author's econometric analysis, he concluded that an increase in energy consumption causes an increase in renewable energy demand, but the increase in renewable energy production does not have a statistically significant effect on the GDP.

Izgi and Destek (2017) investigated the effects of both renewable and nonrenewable energy consumption on economic growth for the BRICS countries as well as Mexico, Indonesia, South Korea, and Turkey (the MIST countries). They analyzed the data for the period of 1992-2014 using panel cointegration and panel causality methods. According to the findings they obtained as a result of this analysis, they concluded that both renewable and nonrenewable energy consumptions affect economic activities positively. They also concluded that nonrenewable energy consumption is more effective on economic growth than renewable energy consumption.

Baki (2018) studied the relationship between energy consumption (per capita energy consumption, general energy consumption, and final energy consumption) and economic growth, urbanization, trade volume, and industrialization in Turkey. He used annual data for the period of 1980–2015; Engle–Granger, Johansen, and autoregressive distributed lag model (ARDL) methods; dynamic least squares, canonical regression, and fully corrected least squares cointegration methods; and Granger and Toda–Yamamoto causality tests. According to the findings obtained from the study, it has been concluded that there are long-term significant relationships in all of the used ones, namely, economic growth, industrialization, urbanization and trade volume have significant and energy-increasing effects on energy consumption.

Bozma et al. (2018) examined the relationship between energy consumption and economic growth for the BRICS and MINT countries with the data for the period 1190-2014 using the Westerlund (2008) cointegration test. According to the empirical findings they obtained as a result of their analysis, they concluded that there is a cointegrated relationship between economic growth and energy consumption.

Kizilkaya and Konat (2019) examined the stationarity of Turkey's electricity consumption using data from 1950–2017, ADF and KPSS traditional unit root/stationarity tests, and Fourier KPSS stationarity test. According to the findings obtained from the study, they concluded that the electricity consumption series is not stationary. That is, the shocks in the electricity consumption are permanent.

Akalp (2019) examined the relationship between Turkey's consumption of renewable energy sources and economic growth by using the ARDL method with data from 1990–2016 as well as capital and labor data. According to the findings obtained from the study, he concluded that there is a negative causal relationship between renewable energy consumption and economic growth in the long run. That is, the increase or decrease in renewable energy consumption decreases or increases economic growth, respectively.

Zeren (2019) studied the relationship between energy and economic growth for several countries, including Argentina, Australia, Brazil, Canada, China, Denmark, France, Germany, India, Indonesia, Japan, Kenya, Mexico, Norway, Pakistan, Switzerland, the Russian Federation, Turkey, the United Kingdom, and the United States. He used panel data analysis with data on renewable energy and nonrenewable energy from 1990–2016. According to the findings obtained from the analysis of the study, the author concluded that there is no statistically significant relationship between energy and GDP.

Yildirim et al. (2019) analyzed the relationship between energy consumption and economic growth for the BRICS-T countries with data for the period of 1990–2014, the Pedroni cointegration test, and second-generation panel cointegration. He examined the test using the Westerlund and Edgerton (2008) test and the FMOLS test. In line with the findings obtained from the analysis, they concluded that there is a two-way causality relationship between energy consumption and economic growth for BRICS-T countries. An increase in GDP causes an increase in energy consumption, and an increase in energy consumption causes an increase in GDP.

Ozsahin et al. (2019) analyzed the relationship between renewable energy consumption and economic development in BRICS-T countries with data for the period of 2000–2013 and cross-section dependency and homogeneity tests. Pedroni (1999) and Westerlund (2005) analyzed using panel CUSUM cointegration and panel ARDL tests. They concluded that there is a positive long-term relationship between renewable energy consumption and economic development.

Duran (2020) analyzed the factors determining energy consumption (e.g., direct foreign investments, energy prices and economic growth) for BRICS-T data for the period of 1992–2018 and econometric analyses. According to the findings obtained by the author from the study, all three variables of foreign direct investments, energy prices and economic growth are in a long-term relationship with energy consumption, foreign direct investments are significant for all countries, economic growth is significant for Turkey and China, energy prices are for Russia, It concluded that it was significant in South Africa and China.

Gokcu (2021) examined the relationship between total renewable energy consumption, economic growth, and carbon dioxide emissions for Turkey in the short and long term by using the Granger causality test and the Structural Vector Auto-Regression (SVAR) and ARDL methods and data from 1972–2018. The author found that there was no relationship between these three variables in the causality test, a positive relationship between these three variables using the SVAR method, a positive relationship between renewable energy consumption and economic growth using the ARDL method, and a negative relationship with carbon dioxide emissions.

Karakurt (2021) developed regression models using data and time series from 1965–2019 to predict future oil consumption for BRICS-T countries. He concluded that the total oil consumption of the BRICS-T countries would increase by 70% in the next twenty years.

The relationship between economic growth and energy consumption is an important issue for developed and developing countries. Many studies have also been carried out on testing the stationarity of energy consumption. For this reason, some studies in the literature made with different analyzes for different countries and different periods are shared above. However, despite many studies on the subject, no consensus has been reached.

3. Data Set and Method

In this study, I aimed to determine whether the renewable energy consumption for BRICS-T countries includes unit root. This involved using the renewable energy consumption data set as a percentage of the total final energy consumption obtained from the World Bank database. With annual data covering the period of 1990-2015, traditional ADF and fractional frequency Fourier ADF unit root test was carried out (Bozoklu et al., 2020). The values of country-based descriptive statistics for the renewable energy consumption series in this study are presented in Table 1.

	Brazil	Russia	India	China	South Africa	Turkey
Average	45.601	3.600	48.435	22.896	17.249	17.684
Median	45.429	3.607	50.706	25.522	17.128	17.019
Maximum	49.864	4.038	58.652	34.083	19.121	24.510
Minimum	41.477	3.227	36.021	11.695	15.570	11.607
Standard Deviation	2.441	0.224	7.208	8.476	0.979	4.480
Distortion	0.051	0.091	-0.408	-0.150	0.154	0.261
Flatness	1.844	2.098	1.839	1.301	1.985	1.572
Jarque – Bera	1.459 (0.482)	0.917 (0.632)	2.182 (0.335)	3.225 (0.199)	1.219 (0.543)	2.503 (0.285)

Note: Values in parentheses indicate probability values.

Table 1. Descriptive Statistics of Variables

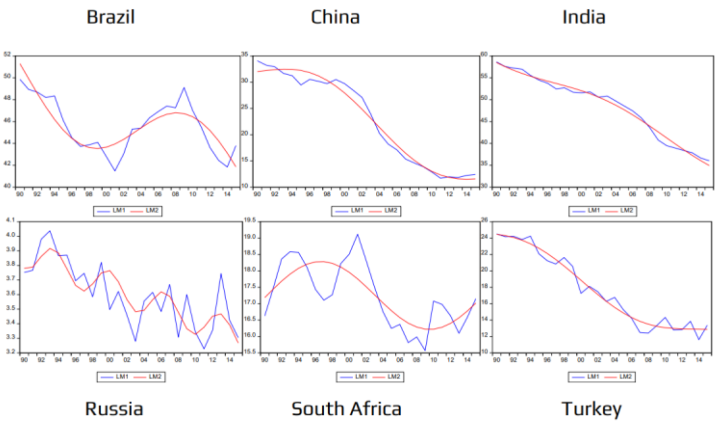
According to the Jarque–Bera normality test results in Table 1, it is seen that the renewable energy consumption series has a normal distribution for the BRICS-T countries. In addition, it is seen that the renewable energy consumption for the selected period is the least in Russia, the highest in India and Brazil. The average of renewable energy consumption in the other three countries is around 20%.

3.1. Fractional Frequency Fourier ADF Unit Root Test (Bozoklu et al., 2020)

In this study, Fractional Frequency Fourier ADF Unit Root Test proposed by Bozoklu et al. (2020) was used. This test is based on the Enders and Lee (2012) test. The difference between the test proposed by Bozoklu et al. (2020) and the Enders and Lee (2012) test is that the frequency numbers are fractional rather than integers. Perron (1989) emphasized that when there are structural breaks in series, ignoring them may lead to the rejection of the unit root and become the pioneer of unit root tests that take structural changes into account. However, unit root tests that consider such traditional structural breaks allow structural breaks through dummy variables and therefore only capture the dynamics of sudden changes. Therefore, to capture smooth transitions and changes rather than sudden changes, Fourier-based unit root tests have been developed, which allow a number of functional structural breaks unknown to the literature (Becker et al., 2006; Christopoulos & Leon-Ledesma, 2010, 2011; Enders & Lee 2004, 2012; Omay, 2015). The number, position, and shape of the Fourier functions included in the model allow a large number of smooth changes that have no effect on the power of the test. Bozoklu et al. (2020) noted that the Fourier test predicts the following model to apply the ADF unit root test:

$$\Delta y_t = \alpha_1 + \alpha_2 t + \alpha_3 \sin\left(\frac{2\pi kt}{T}\right) + \alpha_4 \cos\left(\frac{2\pi kt}{T}\right) + \rho y_{t-1} + \sum_{i=1}^{p} \delta_i \, \Delta y_{t-i} + e_t \qquad (1)$$

Here, t is the trend term, T is the number of observations, $\pi = 3.1416$, k is a specific frequency, and p is the appropriate lag length. Bozoklu et al. (2020) used the Akaike information criterion to determine the appropriate lag length. In addition, similar to the study of Omay (2015), the appropriate k frequency $(\tilde{k})$ value that gives minimum sum squares residual (e.g., SSR) in the range of [0.1,0.2,0.3,...,5] is selected. As in the previous Fourier-based tests, in this test, the basic hypothesis of $\alpha_3 = \alpha_4 = 0$ is tested using the familiar F-test to test nonlinearity. Again, as in other Fourier-based unit root tests, the statistical significance of the ρ coefficient is used to test the basic hypothesis stating that there is a unit root. Bozoklu et al. (2020) used Monte Carlo simulations and studied critical values for the k frequency values in the [0.1,0.2, . . . ,5] range. By comparing the obtained test statistics with these critical values, it is decided whether the analyzed series contains a unit root.



4. Empirical Findings

In this study, which tested the renewable energy consumption stationarity for the BRICS-T countries, fractional frequency Fourier ADF unit root test results are reported in Table 2 and Table 3 as follows (Bozoklu et al., 2020). Both test results are reported according to the fixed and trend models.

	l	ADF Test Statistics	Critical Values		
			%1	%5	%10
Brazil	1	-2.177 (0.480)	-4.394	-3.612	-3.243
Russia	0	-4.549 (0.006)***	-4.374	-3.603	-3.238
India	0	-1.209 (0.887)	-4.374	-3.603	-3.238
China	2	-2.250 (0.442)	-4.416	-3.622	-3.249
South Africa	1	-2.861 (0.191)	-4.394	-3.612	-3.243
Turkey	0	-2.041 (0.552)	-4.374	-3.603	-3.238

Note: l denotes the appropriate lag length. Parentheses indicate the probability value and *** indicates the significance at the 1% level.

Table 2. ADF Unit Root Test Results for Renewable Energy Consumption in BRICS-T Countries

According to the ADF unit root test results in Table 2, it was found that only Russia among the BRICS-T countries has a stationary renewable energy consumption at the level of 1%. It has been found that other countries have unit root.

	Frequency	Min. SSR	Fourier ADF	Critical Values			F test statistics
				%1	%5	%10	
Brazil	1.7	15.325	-2.971	-4.819	-4.195	-3.871	7.890*
Russia	3.9	0.397	-3.231	-4.315	-3.646	-3.301	8.206*
India	1.6	5.868	-3.752	-4.859	-4.249	-3.929	9.615**
China	1.7	9.192	-6.142***	-4.819	-4.195	-3.871	33.817***
South Africa	3.2	5.116	-1.631	-3.727	-3.034	-2.697	1.626
Turkey	0.9	15.955	-3.401	-4.936	-4.337	-4.034	9.172**

Note: *, **, and *** indicate the significance at the 10%, 5%, and 1% levels, respectively. The critical values for the F test statistic are 7.78, 9.14, and 12.21 at the 10%, 5%, and 1% levels, respectively (Enders & Lee, 2012).

Table 3. Fractional Frequency FADF Unit Root Test Results for Renewable Energy Consumption in BRICS-T Countries

According to the fractional frequency Fourier ADF unit root test results obtained from Table 3 and suggested by Bozoklu et al. (2020), unlike the ADF unit root test results from BRICS-T countries, only China's renewable energy consumption is stationary at the 1% level. It has been found that other countries have unit root. The appropriate fractional frequency values of the BRICS-T countries were 1.7, 3.9, 1.6, 1.7, 3.2, and 0.9, respectively. In addition, according to the F test results showing the significance of the Fourier terms, it is seen that the trigonometric terms are meaningful for the other countries, excluding South Africa. For this reason, the familiar ADF test results for South Africa should be considered. Table 2 shows that renewable energy consumption for South Africa is not stationary.

5. Conclusion

Countries place importance on the investments they will make and the policies they will implement to increase their welfare level, production, and employment. Because of the rapidly increasing energy demands in the world and the limited, uneven distribution and exhaustion of nonrenewable energy resources, the importance of strategies, plans, and policies for the correct and healthy use of renewable energy resources is increasing day by day.

In this study, the stationarity of renewable energy consumption for the rapidly developing BRICS-T countries is analyzed using annual data for the period of 1990–2015. The traditional ADF unit root test; the test of Bozoklu et al. (2020), which is based on the test of Enders and Lee (2012) but with a fractional frequency; and the Fourier ADF unit root test were used. According to the obtained unit root test results, the traditional ADF unit root test results indicate stationarity for Russia, whereas the fractional frequency Fourier ADF unit root test indicates stationarity for China. Therefore, it is concluded that renewable energy consumption for other countries is not stationary. That is, they contain a unit root. This shows that the shocks in renewable energy consumption are permanent. The fact that shocks to energy consumption are permanent means that future values of energy consumption cannot be predicted using past values.

For energy, which will continue to be important for countries in the future and which is an indicator of development and international power, governments should lead energy resources and the production of technology that can use these resources. They should further increase energy efficiency and investment. Also they should supportive incentive policies should be implemented for the discovery and use of domestic resources, and especially renewable energy resources.

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