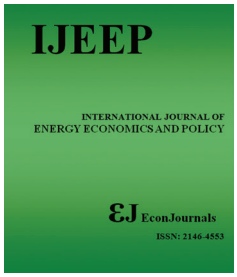

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An Analytical Study on the Stability Properties of Energy Consumption from Fossil Fuels: A Panel Stability Test and Zivot-Andrews Unit Root Test Approach in the Context of BRICS Nations

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ABSTRACT

This study examines the stationarity properties of fossil fuel energy consumption in BRICS countries - Brazil, Russia, India, China, and South Africa - utilizing panel stationarity tests alongside the Zivot-Andrews unit root test. Conducted with annual data spanning from 1995 to 2023, the analysis first assesses cross-sectional dependence and investigates the interdependencies of energy consumption shocks across the nations. Following this, second-generation unit root tests are implemented based on the initial findings. The panel unit test results indicate that while oil and coal consumption exhibit stationary characteristics, natural gas consumption does not. Further country-specific analyses reveal the presence of structural breaks in fossil fuel consumption patterns. The findings suggest that the dynamics of energy consumption in BRICS countries are significantly influenced by economic transformations and policy shifts. This study highlights the necessity of accounting for structural breaks when assessing long-term trends in energy consumption and offers crucial insights for policymakers tasked with formulating sustainable energy policies.

Keywords: Fossil Resources, Environmental Sustainability, Panel Unit Root Tests, Zivot-Andrews Unit Root Test, BRICS
JEL Classifications: C13, C20, C22

1. INTRODUCTION

The BRICS countries - Brazil, Russia, India, China, and South Africa - occupy a strategically significant position within the global economy and energy markets, collectively accounting for a substantial portion of the world's energy demand. The term "BRIC" was first introduced by economist Jim O'Neill in a 2001 report to encapsulate the emerging economies of Brazil, Russia, India, and China. This concept has evolved and is now commonly referred to as "BRIC," "BRIC countries," "BRIC economies," or "The Big Four" (O'Neill, 2001; Elango, 2023). O'Neill's article, "Building Better Global Economic BRICs," catalyzed heightened interest in these nations, prompting a comprehensive analysis by Goldman Sachs. Notably, the "Dreaming with BRICs" report published in 2003 projected these countries' transformative potential to the global economy by 2050, forecasting that by this date, China would emerge as the world's largest economy, followed by the United States, India, Japan, Brazil, and Russia (Wilson and Purushothaman, 2003). BRIC transitioned into an official organization in 2006 and subsequently expanded in 2011 with the inclusion of South Africa, thus adopting the designation "BRICS" (Thussu, 2018). A notable advancement in its institutional framework occurred during the 6th BRICS summit held in Brazil in 2014, where member nations reached an agreement to establish a New Development Bank (NDB), which commenced its operations on February 27, 2016 (NDB, 2025).

Today, BRICS countries represent 41% of the global population, 24% of global GDP, and 16% of international trade, thereby exerting considerable influence on global power dynamics due to

their economic heft (BRICS, 2021; Chatterjee and Naka, 2022). However, the rapid industrialization and urbanization occurring within these nations have led to a continuous increase in energy demand, intensifying reliance on fossil fuels and contributing significantly to global environmental challenges.

BRICS countries exhibit considerable diversity in their energy production and consumption profiles. China stands as the world's largest energy consumer, sourcing approximately 60% of its total energy needs from coal. Meanwhile, India's energy demand is on a persistent upward trajectory, driven by a burgeoning population and rapid industrial growth, although it remains heavily reliant on fossil fuels for its energy supply. Russia, endowed with vast fossil fuel reserves, functions as both a major consumer and a significant exporter in the global energy market. Brazil is actively diversifying its energy portfolio, investing in biofuels and hydroelectric power alongside fossil fuel utilization. South Africa, conversely, remains one of the highest regional carbon emitters, predominantly relying on coal for its energy production (Elango, 2023).

Energy consumption derived from fossil resources, particularly oil, is widely recognized as a significant contributor to global climate change (Issayeva et al., 2023; Yesbolova et al., 2024). Furthermore, fossil fuel consumption remains a critical indicator of national economic performance (Dyussembekova et al., 2023; Niyetalina et al., 2023; Bekzhanova et al., 2023; Sabenova et al., 2024; Aidarova et al., 2024; Abdibekov et al., 2024; Ibyzhanova et al., 2024; Sultanova et al., 2024; Lukhmanova et al., 2025). To assess the long-term implications of fossil fuel consumption for economic stability, it is essential to analyze the stationarity characteristics of energy consumption data. A key question arises concerning whether the effects of shocks on oil consumption are temporary or permanent. If the oil consumption series proves to be stationary, this implies that such shocks are transient, and the series will revert to its prior state in the short term. Conversely, non-stationarity in oil consumption indicates that shocks are lasting in nature (Apergis and Payne, 2010; Solarin and Lean, 2016). Understanding the stationarity of energy consumption is vital not only for formulating effective energy policies but also for informing economic forecasts. If the shocks to energy consumption are permanent, considering the importance of energy for other economic sectors, the basic macroeconomic variables can be expected to inherit this permanence. This structure of the non-stationary oil consumption variable can be transferred to the other variables, changing the stationarity characteristics of many macroeconomic variables. Should energy consumption demonstrate non-stationary behavior, historical patterns will hold limited predictive power over future demand trajectories. In other words, a non-stationary oil consumption series cannot predict future oil demand. In this scenario, it becomes necessary to explore alternative explanatory variables to develop accurate forecasts of future energy consumption (Lean and Smyth, 2009).

Moreover, the examination of energy consumption stationarity is intrinsically linked to sustainable development goals. Many nations have initiated policies aimed at enhancing renewable energy investments while reducing reliance on fossil fuel sources to mitigate carbon emissions. The effectiveness of these policies, however, is contingent upon the stationarity of fossil energy consumption. Specifically, if fossil energy consumption is non-stationary, interventions designed to improve environmental quality may yield lasting effects. Policies to improve environmental quality can be successful only if fossil energy consumption is not stationary and if policy shocks have permanent effects. Conversely, should fossil energy consumption be stationary, the impact of such policy interventions may dissipate rapidly (Destek and Sarkodie, 2020). Furthermore, Perron (1989) highlighted that neglecting structural breaks during unit root analysis could result in erroneously categorizing a stationary series as non-stationary, subsequently leading to flawed inferences and predictions within regression models.

Given this backdrop, analyzing the stationarity properties of fossil fuel consumption among BRICS countries using the Fourier Panel Stationarity Test and the Zivot-Andrews Unit Root Test is of paramount importance for elucidating the long-term dynamics of energy consumption. Particularly, determining whether the responses to shocks in energy markets are temporary or permanent is critical for the development of effective energy policies. This study seeks to establish a robust scientific framework that informs and guides energy policy considering the dependence of BRICS nations on fossil fuels.

2. LITERATURE REVIEW

The literature presents a substantial body of research examining various dimensions of the BRICS economies, particularly focusing on the stationarity properties of energy consumption series. This section aims to summarize key studies pertinent to the research topic.

Narayan and Smyth (2007) conducted a comprehensive analysis to determine whether the shocks to energy consumption across 182 countries were permanent or temporary. Utilizing annual energy consumption data spanning from 1979 to 2000, the authors sourced their data from the World Bank and the U.S. Energy Information Administration (EIA). Their methodological approach involved the application of traditional unit root tests, specifically the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. To account for potential structural breaks, they subsequently employed the unit root tests with breaks, as developed by Zivot and Andrews (1992) and Lumsdaine and Papell (1997). The findings indicated that while traditional tests suggested a lack of stationarity in energy consumption for most countries, the incorporation of structural breaks revealed stationary behavior in several instances. This study underscores the necessity of considering structural breaks when evaluating the effectiveness of energy policies, highlighting the heterogeneous dynamics of energy consumption across different countries.

Mishra et al. (2009) investigated the permanence of fluctuations in per capita energy consumption among Pacific Island nations. Employing annual energy consumption data from 1980 to 2006 obtained from the World Bank and EIA, the researchers initially applied traditional unit root tests (ADF and PP) and subsequently compared results with the Im, Pesaran, and Shin

(IPS) and Maddala and Wu tests specifically designed for panel data. Their results indicated that while traditional unit root tests primarily suggest non-stationarity in most countries, the panel unit root tests uncovered stationary behaviors in certain contexts. This study emphasizes the long-term implications of shocks to energy consumption in small island nations, advocating for the formulation of energy policies that are informed by the unique dynamics of each country.

Apergis and Payne (2010) focused on the United States, analyzing whether the shocks to oil consumption across various states were permanent or temporary. Utilizing annual data from 1960 to 2007 sourced from the U.S. Energy Information Administration (EIA), the authors began their analysis with traditional unit root tests (ADF and PP), and later evaluated the implications of structural breaks through the unit root tests developed by Lee and Strazicich (2003) as well as Clemente et al. (1998). Their findings revealed that when structural breaks were disregarded, oil consumption exhibited non-stationary behavior, implying that shocks were permanent. However, the inclusion of structural breaks within the model demonstrated that oil consumption became stationary in many states, suggesting that the shocks could indeed be temporary. This study reinforces the critical importance of incorporating structural breaks in the assessment of energy policy effectiveness.

Ji et al. (2015) analyzed the effects of structural oil shocks on production, exchange rates, and inflation in BRICS countries. Using a monthly dataset from 1995 to 2014, the researchers obtained oil prices, production data, exchange rates, and inflation statistics from the World Bank and International Monetary Fund (IMF) databases. They utilized the Structural Vector Autoregression (SVAR) model to examine the dynamic effects of supply, demand, and speculative oil shocks on macroeconomic variables. The findings revealed that structural oil shocks resulted in varying macroeconomic responses across BRICS countries. Notably, oil supply shocks significantly impacted production, while demand shocks had a greater effect on inflation and exchange rates. The study emphasizes the importance of structural models in understanding the influence of energy market fluctuations on BRICS economies.

Solarin and Lean (2016) investigated whether fluctuations in oil consumption were permanent or temporary across various countries. Using annual oil consumption data from 1965 to 2013 sourced from the BP Statistical Review of World Energy database, the researchers first examined the stationarity of the oil consumption series using traditional unit root tests (ADF and PP tests). They then applied the Kapetanios, Shin, and Snell (KSS) nonlinear unit root test to explore potential nonlinear structures within the series. Subsequently, they evaluated the effects of multiple structural breaks with the Breuer, McElroy, and Shell (BMS) panel unit root test. The findings indicated that shocks in oil consumption were predominantly permanent, suggesting that changes in oil consumption have long-term effects. However, in some countries, nonlinear tests indicated that the oil consumption series were stationary, implying that shocks could be temporary. Therefore, the study highlights that the stationarity of oil consumption varies by country, necessitating tailored energy policy approaches based on each country's specific energy consumption dynamics.

Cai and Menegaki (2019) explored the integration characteristics of clean energy consumption in emerging economies. They used an annual dataset spanning 1980 to 2016, with clean energy consumption data sourced from the World Bank and International Energy Agency (IEA) databases. The researchers initially applied traditional unit root tests (ADF and PP tests) before employing the Fourier Quantile Unit Root Test to account for nonlinear structures and different distribution characteristics. The findings revealed that traditional tests showed non-stationarity in clean energy consumption for most countries, while the Fourier Quantile approach indicated that some countries achieved stationarity. The study underscores the importance of nonlinear methods in assessing the long-term dynamics of energy consumption.

Destek and Sarkodie (2020) analyzed whether fluctuations in coal, oil, and natural gas consumption were permanent or temporary in OECD countries. Utilizing annual energy consumption data from 1965 to 2017 obtained from the BP Statistical Review of World Energy and OECD databases, the researchers first checked the stationarity of the energy consumption data using classical unit root tests (ADF and PP tests). They then analyzed potential structural breaks in the series using Perron's (1989) unit root test with breaks. Following that, they conducted a more comprehensive evaluation by applying the Fourier unit root test, which considers nonlinear fluctuations and multiple structural breaks. The findings indicated that fossil fuel consumption is largely non-stationary, suggesting that shocks to energy consumption are permanent. However, about structural breaks in some OECD countries, it was concluded that energy consumption can be stationary, indicating that shocks may be temporary. Ultimately, the study emphasizes that the stationarity of fossil fuel consumption varies from country to country, thus highlighting the need for country-specific evaluations of the long-term effects of energy policies.

Fendoğlu (2021) analyzed the stationarity properties of renewable energy consumption in BRICS-T countries. Using an annual dataset covering the period from 1990 to 2018, the study sourced renewable energy consumption data from the World Bank and the International Energy Agency (IEA) databases. The research employed traditional unit root tests, specifically the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. Subsequently, the Fractional Frequency Fourier Unit Root Test was applied to account for structural breaks and non-linear trends. The findings revealed that traditional tests indicated non-stationarity for renewable energy consumption in most countries. However, the Fractional Frequency Fourier test demonstrated that some countries achieved stationarity. The study underscores the importance of using advanced econometric methods when assessing long-term trends in renewable energy consumption.

Kızılkaya (2022) examined the stationarity properties of oil consumption in OECD countries, focusing on whether the shocks to oil consumption were permanent or temporary. The study utilized annual oil consumption data for the period from 1965 to 2020, drawing upon the BP Statistical Review of World

Energy dataset. Initially, traditional unit root tests, such as ADF and PP tests, were applied. Subsequently, the Lee and Strazicich (2003) two-break unit root test and the Fourier unit root test were employed to account for structural breaks. The findings indicated that traditional tests suggested non-stationarity in oil consumption for most OECD countries; however, when structural breaks were considered, some countries exhibited stationarity. The study emphasizes the need to account for structural breaks when evaluating the long-term impacts of energy policies.

Li and Guo (2022) investigated the asymmetric effects of oil prices and shocks on inflation in BRICS countries. Utilizing a monthly dataset from 1990 to 2020, the study sourced oil price and inflation data from the World Bank and the International Monetary Fund (IMF) databases. Rather than using a traditional linear Autoregressive Distributed Lag (ARDL) model, the researchers applied a multi-threshold nonlinear ARDL (MTNARDL) model to examine the differing impacts of positive and negative oil price shocks on inflation. The findings revealed that oil prices affected inflation asymmetrically in BRICS countries, with variations across different nations. It was concluded that increases in oil prices had a stronger effect on inflation than decreases. This study highlights the importance of utilizing nonlinear models to comprehend how fluctuations in energy prices impact macroeconomic stability.

3. METHODS

In this study, the initial step involved expressing the descriptive statistics of the data using measures such as mean, standard deviation, median, minimum, and maximum values. The distributional statistics were represented by the coefficients of skewness and kurtosis. Additionally, a time path graph was utilized to illustrate the behavior of the series over time.

Before conducting the stationarity test in panel data, the presence of cross-sectional dependency is examined. In this study, the cross-sectional dependency test is crucial for determining whether a shock in fossil-based energy consumption in BRICS countries impacts fossil-based energy consumption in other countries. When the number of periods (T) in the dataset exceeds the number of cross-sectional units (N) (i.e., $T > N$), the Breusch and Pagan (1980) LM test and the Pesaran et al. (2008) LM_{adj} tests are employed. Conversely, when the number of periods is smaller than the number of cross-sectional units (i.e., $T < N$), the Pesaran (2004) CDLM test and the Pesaran CD tests are applied. Based on the results, either first-generation unit root tests or one of the second-generation unit root tests can be conducted (Baltagi, 2008).

Assuming no structural break exists and that there is no cross-sectional dependence, the first-generation unit root tests used include those by Levin et al. (2002), Breitung and Das (2005), Hadri (2000), Maddala and Wu (1999), Im et al. (2003), and Choi (2001). Among the second-generation unit root tests, the most common are those by Bai and Ng (2004), and Pesaran (CADF-2006, CIPS-2007). The CADF test is particularly significant for assessing the stationarity of cross-sectional units.

Changes in the economic structure, transformations in energy production and consumption industries, and the emergence of environmental sustainability as a critical issue bolster the hypothesis of a structural break in fossil-based energy consumption. Zivot and Andrews proposed a method for testing structural breaks through a mathematical model. Their approach includes three models: the first tests for a structural break with the assumption that the break occurs in the constant, the second tests for a break in the slope, and the third tests for breaks in both the constant and the slope (Zivot and Andrews, 2002).

4. DATA AND FINDINGS

In today's world, particularly in the context of environmental sustainability, the consumption of energy generated from renewable and clean sources is becoming increasingly significant. As fossil fuel consumption declines and global energy demand increases, it is reasonable to expect fossil energy consumption to at least remain stable. This study examines fossil energy consumption behavior in BRICS countries (Brazil, Russia, India, China, and South Africa). By categorizing fossil energy sources into three separate series - oil, coal, and gas - we aim to gain deeper insights into the energy structures of these countries. The research variables and their brief definitions are outlined in Table 1. The study covers the years from 1995 to 2023, providing a comprehensive data period to assess both the overall situation over time and the changes in global energy policies. This allows for more statistically meaningful analysis of structural breaks in the methods used.

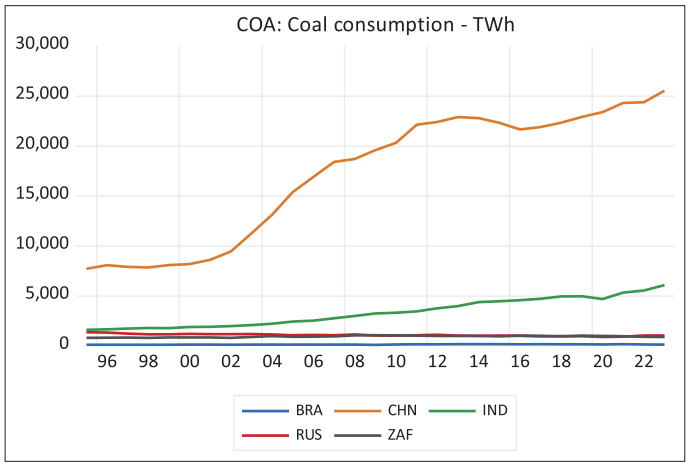
Table 2 presents descriptive statistical information on coal consumption, one of the fossil energy sources, across BRICS countries. An examination of average statistics reveals positive changes in coal consumption for all countries. Notably, Brazil shows the lowest change in coal-based energy consumption, while China shows the highest. The general average for the five countries is 4,563.020. The median statistics also indicate that Brazil has the lowest change, while China has the highest change. The skewness for all countries falls between −1 and +1, suggesting that coal-based energy consumption in these countries is distributed relatively close to a normal distribution.

Graph 1 illustrates the time path for coal consumption (COA) by country. Upon reviewing the graph, it is evident that China has experienced a rapid and consistent increase in coal-based energy consumption since 2002. India shows a steady but modest rise in consumption from 1996 to 2022. In contrast, Brazil, Russia, and South Africa appear to have stable consumption rates around their averages. Based on the descriptive statistics in Table 2, it can be concluded that coal-based energy consumption has increased over the years in China and India, while remaining unchanged in the other BRICS countries.

Table 3 presents descriptive statistics for energy consumption derived from natural gas, which is one of the fossil energy sources, across BRICS countries. Analyzing the average statistics reveals that there is a positive change in energy consumption for all countries. Among these, Brazil exhibits the lowest increase in

natural gas consumption, while China shows the highest. The overall average across the five countries is 1,237.519. In terms of median statistics, South Africa shows the lowest change, while Russia experiences the largest change. Notably, the skewness for all countries falls between −1 and +1, indicating that the change in energy consumption from natural gas is distributed relatively close to a normal distribution.

Graph 1: The time path graph for coal consumption (COA)



Graph 2 illustrates the time path for gas consumption (GCT) by country. Upon examining the graph, it is evident that China has experienced a rapid and steady increase in natural gas consumption since 2002. Russia shows an overall increase in average consumption from 1996 to 2022, albeit with some fluctuations. Brazil and India display only slight increases, while South Africa shows a stationary trend around the average. In summary, based on the descriptive statistics in Table 3, it can be concluded that energy consumption from natural gas has increased over the years in China and Russia, while remaining relatively unchanged in the other BRICS countries.

Table 4 provides descriptive statistics for energy consumption derived from oil, another fossil energy source, across BRICS countries. Like natural gas, the average statistics indicate a positive change in consumption for all countries. South Africa shows the lowest change in oil consumption, while China demonstrates the highest change. The general average among the five countries is 2,010.585. Regarding median statistics, South Africa again records the lowest change, while China shows the largest change. The skewness statistics for all countries remain between −1 and +1, suggesting that the changes in coal-based energy consumption are also distributed close to a normal distribution.

Table 1: Research variables and sources

Code	Country	Variable	Description	Source
BRA	Brazil	COA	Coal consumption - TWh	https://ourworldindata.org
CHN	China	GCT	Gas consumption - TWh	https://ourworldindata.org
IND	India	OCO	Oil consumption - TWh	https://ourworldindata.org
RUS	Russia			
ZAF	South Africa			

Table 2: Descriptive statistics for the COA variables

Country	Mean	Median	Maximum	Minimum	Standard Deviation	Skewness	Kurtosis
BRA	164.1991	159.0938	204.9810	129.2072	21.91168	0.435365	1.969546
CHN	17207.53	19605.02	25538.52	7736.850	6464.674	−0.431313	1.529810
IND	3362.465	3268.266	6105.902	1631.613	1386.082	0.307413	1.749081
RUS	1116.769	1093.336	1388.346	914.2343	112.6347	0.526501	3.051685
ZAF	964.1330	976.4878	1091.169	828.5981	84.89797	−0.224426	1.729508
ALL	4563.020	1093.336	25538.52	129.2072	7063.274	1.870270	5.041247

Table 3: Descriptive statistics for the GCT variables

Country	Mean	Median	Maximum	Minimum	Standard Deviation	Skewness	Kurtosis
BRA	242.3838	256.6089	429.3654	52.30495	121.3425	−0.164475	1.728704
CHN	1411.936	902.2402	4048.381	178.7955	1270.954	0.779893	2.270953
IND	423.0977	478.0684	626.1031	180.7783	152.9804	−0.153490	1.486496
RUS	4079.117	4217.361	4544.993	3454.083	312.5930	−0.386411	1.967114
ZAF	31.06138	37.90870	47.47550	9.297571	13.94979	−0.606879	1.591575
ALL	1237.519	358.9080	4544.993	9.297571	1612.129	1.094760	2.409275

Table 4: Descriptive statistics for the OCO variables

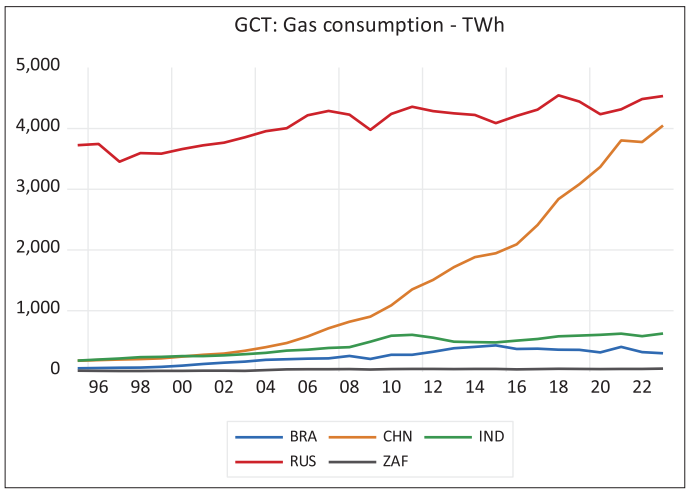
Country	Mean	Median	Maximum	Minimum	Standard Deviation	Skewness	Kurtosis
BRA	1219.669	1228.752	1529.594	859.9551	175.7626	−0.138040	2.037646
CHN	5001.365	4580.298	9090.510	1825.631	2217.937	0.200432	1.755129
IND	1856.558	1806.790	2936.974	901.3517	627.7382	0.207319	1.733475
RUS	1680.905	1611.649	2003.207	1456.214	178.5873	0.246799	1.578409
ZAF	294.4268	297.6924	347.1934	241.2607	28.46098	−0.109229	2.148505
ALL	2010.585	1493.819	9090.510	241.2607	1895.431	1.947416	6.423208

Graph 3 presents the time path graph for the OCO series by country. Upon examination, it is evident that since 2000, China has experienced a rapid and consistent increase in oil-based energy consumption. In contrast, other countries have shown a lower-level increase in oil consumption from 1996 to 2022. When considered alongside the descriptive statistics in Table 4, it can be concluded that, during the analyzed period, oil consumption in BRICS countries has significantly risen in China over the years, while other nations have seen a modest rise.

The findings concerning cross-section dependency and unit root tests for the research data are provided in Table 5. The Breusch-Pagan LM test was used to assess cross-section dependency, confirming its presence across all three variables. Following this, the CIPS test method - one of the second-generation unit root tests - was employed to examine stationarity. Results from the CIPS test indicate that the OCO and COA series are stationary at the 0.05 significance level, whereas the GCT variable shows a unit root, indicating non-stationarity.

The findings from the individual stationarity examination of coal, gas, and oil-based fossil energy consumption in BRICS countries, as assessed using the CADF test with consideration for cross-section dependency, are detailed in Table 6. The results show that the gas consumption series is stationary for Brazil, while oil and coal consumption series are non-stationary. In China, all three fossil resource series are non-stationary. In India, the oil consumption series is stationary, but both coal and gas consumption series are non-stationary. Russia's oil and coal consumption series are stationary, while gas consumption is not. Similarly, South Africa shows non-stationarity in all three fossil resource consumption series, mirroring the findings for China. The collective non-stationarity of gas consumption across all countries suggests a commonality in energy consumption resources among these nations.

Graph 2: The time path graph for gas consumption (GCT)



Graph 3: The time path graph of oil consumption (OCO)

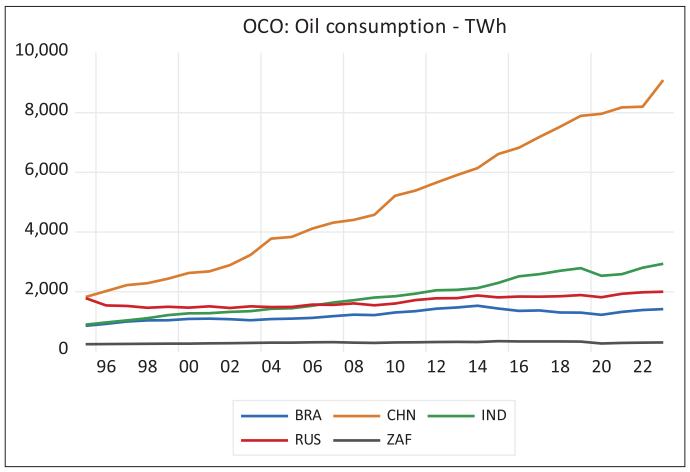


Table 5: Cross-section dependency and CIPS panel unit root test findings for the research data

Variable	Breusch-Pagan LM		CIPS unit root test	
	Statistic	Prob,	Statistic	Prob,
OCO	182.6709	0.0000	−3.71962	<0.01
COA	160.8442	0.0000	−2.4028	<0.05
GCT	213.411	0.0000	−1.54641	≥0.10
CIPS unit root test Critical values:				
1%			−2.58	
5%			−2.33	
10%			−2.21	

Table 6: Cross-sectional ADF unit root test (CADF) findings

Cross-section	OCO		COA		GCT	
	t-stat	P-value	t-stat	P-value	t-stat	P-value
BRA	−3.8773	<0.05	−3.4786	<0.05	−0.5910	≥0.10
CHN	−2.5080	≥0.10	−1.8767	≥0.10	−1.5488	≥0.10
IND	−3.7063	<0.05	−0.3920	≥0.10	−1.9257	≥0.10
RUS	−6.2174	<0.01	−4.5387	<0.01	−2.3113	≥0.10
ZAF	−2.2891	≥0.10	−1.7280	≥0.10	−1.3553	≥0.10
CADF Critical values:						
1%	−4.16					
5%	−3.37					
10%	−2.98					

The findings of Zivot-Andrews Unit Root Test with structural breaks for the fossil energy consumption of BRICS countries from petroleum sources are given in Table 7.

i. Brazil's structural break in 2016 ($P < 0.10$) according to model A, 2014 ($P < 0.05$) according to model B and 2012 ($P < 0.05$) was found to be statistically significant. It is also seen that it is stationary according to model C and has a unit root according to models A and B.
ii. China has a unit root according to all three models. In addition, the break point in 2008 according to model A was found to be statistically significant.
iii. India has a unit root according to all three models. In addition, the break point in 2015 according to models A and C was found to be statistically significant.
iv. Russia is stationary according to all three models. In addition, the break point in 2011 was found to be statistically significant according to models A and C.
v. In South Africa, the break dates are significant for all three models, and according to the critical value of the table regarding whether there is a unit root, there is a unit root for all three models.

According to the CIPS test findings, it was concluded that petroleum-based fossil energy consumption is stationary, and according to the CADF test findings, China and South Africa have a unit root, while Brazil, India and Russia are stationary. Although the results are similar according to the ZA test, the structural break dates were also found to be significant.

The Zivot-Andrews Unit Root Test findings of BRICS countries' coal-based fossil energy consumption with structural breaks are given in Table 8.

i. According to the critical value of the table, Brazil has a unit root for all three models. In addition, structural breaks in 2011

Table 7: The findings of Zivot-Andrews unit root test for oil consumption (OCO)

Country/Models	Break Date	t-Statistic	Prob,*	5% critical value:
BRA				
İntercept (model A)	2016	−3.7700	0.0605	−4.93
Trend (model B)	2014	−4.3333	0.0210	−4.42
Both (model C)	2012	−5.1454	0.0322	−5.08
CHN				
İntercept (model A)	2008	−4.6042	0.0473	−4.93
Trend (model B)	2002	−4.0466	0.1136	−4.42
Both (model C)	2001	−3.9798	0.2501	−5.08
IND				
İntercept (model A)	2015	−4.5867	0.0197	−4.93
Trend (model B)	2006	−3.9080	0.1519	−4.42
Both (model C)	2015	−4.4235	0.0182	−5.08
RUS				
İntercept (model A)	2011	−7.4804	0.0028	−4.93
Trend (model B)	2019	−5.5205	0.8302	−4.42
Both (model C)	2011	−7.0592	0.0017	−5.08
ZAF				
İntercept (model A)	2019	−4.3428	0.0025	−4.93
Trend (model B)	2017	−4.0724	0.0070	−4.42
Both (model C)	2015	−4.4437	0.0383	−5.08

Table 8: The findings of Zivot-Andrews unit root test for coal consumption (COA)

Country/Models	Break Date	t-Statistic	Prob,*	5% critical value:
BRA				
İntercept (model A)	2011	−3.8032	0.0070	−4.93
Trend (model B)	2019	−3.0743	0.0778	−4.42
Both (model C)	2012	−4.0450	0.0089	−5.08
CHN				
İntercept (model A)	2015	−3.1461	0.0065	−5.34
Trend (model B)	2012	−5.8257	0.0009	−4.42
Both (model C)	2010	−5.6046	0.0115	−5.08
IND				
İntercept (model A)	2019	−3.1139	0.0687	−4.93
Trend (model B)	2003	−3.1009	0.2039	−4.42
Both (model C)	2003	−2.9927	0.7336	−5.08
RUS				
İntercept (model A)	2005	−5.1229	0.1728	−4.93
Trend (model B)	2019	−5.3817	0.0804	−4.42
Both (model C)	2019	−6.1010	0.0207	−5.08
ZAF				
İntercept (model A)	2003	−3.1222	0.0088	−4.93
Trend (model B)	2011	−3.9662	0.0017	−4.42
Both (model C)	2008	−5.2469	0.0035	−5.08

Table 9: The findings of Zivot-Andrews unit root test for gas consumption (GCT)

Country/Models	Break Date	t-Statistic	Prob,*	5% critical value:
BRA				
İntercept (model A)	2018	−1.4496	0.1499	−4.93
Trend (model B)	2016	−3.3337	0.0018	−4.42
Both (model C)	2013	−4.4124	0.0012	−5.08
CHN				
İntercept (model A)	2018	−1.7101	0.0088	−4.93
Trend (model B)	2017	−0.6089	0.0797	−4.42
Both (model C)	2018	−1.3572	0.0326	−5.08
IND				
İntercept (model A)	2009	−4.6448	0.0077	−4.93
Trend (model B)	2011	−3.8538	0.0267	−4.42
Both (model C)	2009	−5.5063	0.0076	−5.08
RUS				
İntercept (model A)	2004	−4.8878	0.0183	−4.93
Trend (model B)	2008	−5.7437	0.0014	−4.42
Both (model C)	2006	−5.9777	0.0196	−5.08
ZAF				
İntercept (model A)	2004	−6.3372	0.0000	−4.93
Trend (model B)	2008	−3.4416	0.0062	−4.42
Both (model C)	2004	−6.1568	0.0000	−5.08

($P < 0.05$) according to model A, 2019 ($P < 0.10$) according to model B and 2012 ($P < 0.05$) according to model C were found to be statistically significant

ii. According to the critical values in the table, China exhibits a unit root according to model A but is stationary according to model B and model C. Structural breaks in 2015, 2012, and 2010, relatively according to model A, B, and C, were found to be statistically significant

iii. India demonstrates a unit root across all three models. Additionally, structural breaks in 2003 and 2019 were not found to be statistically significant

iv. Russia is considered stationary according to all three models, with a statistically significant break point in 2019 according to models B and C

v. In South Africa, the break dates are significant for all three models. According to the critical values in the table, South Africa exhibits a unit root for all three models.

The findings of the CIPS test indicate that petroleum-based fossil energy consumption is stationary, while the CADF test findings reveal that China, India, and South Africa have a unit root, whereas Brazil and Russia are stationary. Although the results align with the ZA test, the structural break dates are also found to be significant.

The Zivot-Andrews Unit Root Test findings of BRICS countries' gas-based fossil energy consumption with structural breaks are summarized in Table 9.

i. Brazil is stationary according to all three models, with significant break points at the 0.05 level according to models B and C. Consequently, Brazil experienced structural changes in gas-based fossil fuel consumption in 2013 and 2016

ii. China is also stationary according to all three models, with break points that are significant at the 0.05 level for models A and C, and at the 0.10 level for model B. This indicates that 2017 and 2018 were critical years for fossil fuel consumption in China

iii. India have a unit root according to all three models. Additionally, structural breaks are significant across all models, confirming the persistence of the unit root structure in India, although there is a unit root in 2009 and 2011

iv. In Russia, the break dates are significant for all three models. According to model B, it has a break point in 2008 and is deemed stationary, while according to models A and C, it is non-stationary coinciding with the break point

v. South Africa shows significant break dates for all three models. According to the critical values, South Africa has a break point in 2004 according to models A and C, indicating stationarity, while model B shows non-stationarity at the break point.

According to the CIPS test findings, the gas-based fossil energy consumption has a panel unit root, and according to the CADF test findings, five countries have a unit root. According to the ZA test, India has a unit root in all three models with a structural break, and the other four countries are stationary with structural breaks.

5. CONCLUSION AND RECOMMENDATIONS

This study investigated the changes in fossil-based energy consumption, which is crucial for the ecological sustainability of the world, over the years using the unit root test method, specifically for the BRICS countries. The cross-sectional dependency test indicates that consumption shocks (sudden changes in fossil-based energy consumption) occurring in any of the five BRICS countries will also affect the others. When examining the overall situation with the panel unit root test, it was found that oil and coal-based energy consumption is stationary, while gas-based energy consumption shows a unit root. Given the constant increase in energy consumption during the analyzed period, it appears that energy consumption from oil and coal is generally being replaced by energy from gas or other sources in BRICS countries.

Upon country-by-country examination, the results from the CADF test (which does not consider structural breaks) and the ZA

test (which does account for structural breaks) show significant differences. Notably, structural breaks were found to be significant in almost all countries for the three energy consumption sources: oil, coal, and gas. This underscores the necessity of a thorough analysis of the energy policy framework and economic changes before and after the break dates in the BRICS nations. In this study, only the individual energy consumption at the level was examined for panels and countries. Analyzing the stationarity behavior of fossil-based energy consumption in the first difference would provide deeper insights into the energy dynamics of the BRICS countries.

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