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Testing the Convergence Hypothesis in Primary Energy Consumption in Turkey: The Case of High-Income Countries

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ABSTRACT

This study investigates whether Turkey's per capita primary energy consumption converges to that of high-income countries using linear unit root tests over the period 1965-2023. The analysis applies a variety of methods, including the Lee and Strazicich (2003) test, Narayan and Popp (2010) test, Lumsdaine and Papell (1997) test, and the conventional ADF test. According to the results of the Lee and Strazicich test, the energy convergence series is stationary at the 1% significance level in Model AA and at the 10% significance level in Model CC. These findings suggest that Turkey may exhibit signs of energy consumption convergence with high-income countries. However, the results of other methods, including Narayan and Popp (2010), Lumsdaine and Papell (1997), and the ADF test, reveal that the series has a unit root, indicating non-stationarity. This inconsistency highlights a lack of definitive evidence supporting energy consumption convergence. The divergence in findings among different methodologies underscores the need for more robust and comprehensive analyses to thoroughly evaluate the energy convergence hypothesis. Addressing this issue could contribute to a better understanding of Turkey's energy consumption dynamics relative to high-income countries.

KEYWORDS

Convergence hypothesis; Energy convergence; Linear unit root test; Turkey

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1. Introduction

The convergence hypothesis posits that disparities in per capita real income among countries may diminish over time. This concept, first debated in the 18th century, garnered significant academic attention, particularly in the 1980s. Defined by Abramovitz (1986), the hypothesis is framed within Solow's (1956) Neoclassical Growth Theory, enabling an analysis of the relationship between economic growth and the reduction of income inequality (Tıraşoğlu, 2013). At the core of the convergence hypothesis in the neoclassical growth model lies the principle of diminishing returns to reproducible capital. In this approach, poorer countries with lower capital-to-labor ratios are naturally inclined to grow faster due to the higher marginal productivity of capital (Tüzemen and Tüzemen, 2015). The increased interest in these discussions can be attributed largely to the availability of long-term datasets and advancements in econometric techniques (Ceylan, 2010). In recent years, the topic has centered on whether the income levels of poorer countries converge with those of wealthier nations. This question is not only pertinent to economic growth but is also directly linked to human welfare and the validity of alternative growth theories, driving considerable academic interest (Islam, 2003). The convergence hypothesis suggests that poorer economies will catch up to wealthier ones in terms of per capita income, facilitated by technology transfers under liberal trade regimes. The hypothesis relies on assumptions such as perfect competition, technological change, and the absence of externalities. Violating any of these assumptions can hinder evidence of convergence and lead to divergence instead (Safdar et al. 2020).

Debates surrounding the validity of the convergence hypothesis have diversified the scope of research on the topic, resulting in the identification of different types of convergence. These types of convergence are as follows:

a. Micro and Macro Convergence

b. Intra-Country and Inter-Country Convergence

c. Convergence in Income Levels, Growth Rates, and Total Factor Productivity

d. Unconditional (Absolute) and Conditional Convergence

e. Conditional and Club Convergence

f. β and σ Convergence

g. Deterministic and Stochastic Convergence (Savacı and Karşıyakalı, 2016)

In this study, since deterministic and stochastic convergence are addressed, a brief explanation of these concepts is provided. Deterministic convergence refers to the stationarity of the logarithm of a relative variable at the level, whereas stochastic convergence pertains to the stationarity of the logarithm of the ratio of a variable to the group average at the level. One advantage of this approach is that the results are not contingent upon a specific criterion for evaluating convergence, thereby enhancing their reliability (Esenyel, 2017).

Economic welfare or development is a multifaceted concept measurable through various indicators, and discussions about these indicators hold a significant place in the economic literature. Traditionally, per capita GDP (Gross Domestic Product) is regarded as the best representation of economic development and welfare levels (Maza and Villaverde, 2008). However, assessing the level of development with a single metric is not always sufficient, as other indicators may also provide insight into economic and social progress. Among these alternative indicators, per capita energy consumption stands out prominently. Historically, the steam engine in the 18th century initiated the Industrial Revolution, mass production became widespread with electricity in the 19th century, and automation advanced with electronics and information technology in the 20th century. In the 21st century, production has been transformed by artificial intelligence and cloud technologies. Throughout this process, the demand for energy has continuously increased, making it an indispensable element of production (Karademir, 2023). In this context, it becomes evident that energy consumption is not only directly associated with economic growth but also with societal welfare levels and the capacity to achieve sustainable development goals. Consequently, studies examining whether countries' energy consumption converges with that of high-income countries are of critical importance.

2. Literature

This section of the study presents a literature review of academic research on energy consumption convergence. It has been observed that the number of studies on energy convergence has increased rapidly in recent years, particularly with the advancement of econometric analysis methods. Energy consumption is directly related to several critical areas, such as economic growth, sustainable development, and environmental impacts. Therefore, understanding the dynamics of energy consumption among countries is of great importance for evaluating the effectiveness of energy policies and achieving global energy targets. Energy consumption convergence refers to the similarity of long-term energy consumption patterns among countries, which serves as an important indicator in a world order characterized by deeper economic integration, accelerated technological transfer, and improved energy efficiency.

Mike and Kızılkaya (2021) investigated whether per capita energy consumption among OECD countries exhibits convergence using a panel stationarity test that accounts for both sharp and smooth structural breaks for the 1965–2019 period. Their findings reveal that the per capita energy consumption series is stationary for 18 countries, indicating that the convergence hypothesis holds for these countries. Narayan and Smyth (2007) examined the degree of stationarity in per capita energy consumption for 182 countries during the 1979–2000 period using the ADF unit root test and panel unit root tests. According to the ADF test results, convergence was observed in 56 countries. However, the panel unit root test results suggested no evidence of convergence in per capita energy consumption among the countries. Meng et al. (2013) explored the convergence of per capita energy consumption among 25 OECD countries using LM and RALS-LM unit root tests. Their results provide strong support for convergence in per capita energy consumption across OECD countries. Mishra and Smyth (2017) analyzed sectoral convergence of per capita energy consumption in Australia. Employing LM and RALS-LM unit root tests, they found evidence of convergence in six out of the seven sectors analyzed. Akarsu and Berke (2020) examined the existence of "absolute and conditional beta (β) convergence" in per capita total electricity consumption across Turkish provinces from 1986 to 2013 using spatial panel data analysis. Their findings indicated the presence of absolute β convergence in per capita electricity consumption among Turkey's provinces. Fallahi and Voia (2015) investigated the convergence of per capita energy consumption in 25 OECD countries for the 1960–2012 period by constructing confidence intervals for subsamples. Their results demonstrated convergence in energy consumption for 13 countries. Mishra and Smyth (2014) analyzed energy consumption convergence in ASEAN countries using Panel KPSS and Panel LM unit root tests. According to the Panel KPSS stationarity test results, convergence was not observed for the Philippines in individual country analyses. However, convergence was confirmed for ASEAN-5 countries in group analyses. The LM unit root test results supported the convergence hypothesis for both ASEAN-4 and ASEAN-5 countries. Karademir (2023) examined whether per capita primary energy consumption in G-20 countries converged during the 1965–2021 period using the ADF unit root test and the Nahar-Inder (2002) test. The ADF test indicated convergence for two countries, while the Nahar-Inder test found evidence of convergence for 16 countries. Hasanov and Telatar (2011) investigated the stochastic behavior of per capita total primary energy consumption for 178 countries. Their analysis applied conventional unit root tests as well as tests accounting for nonlinearity and structural breaks. The findings suggest that most series are stationary and emphasize the importance of considering nonlinearity and structural breaks in energy economic analyses. Romero-Avila and Omay (2022) conducted a study covering 110 countries using per capita energy consumption data from 1971 - 2019 and employed six different nonlinear panel unit root tests. According to the results, two of these panel tests indicated that stochastic convergence holds among high-income and upper-middle-income countries. Akram et al. (2020) examined per capita energy consumption in India at the sectoral level from 1971 - 2017. In the study, two-stage LM and three-stage RALS-LM unit root tests were applied. The findings from the LM and RALS-LM tests showed that convergence holds for most sectors, except for a few. Esenyel (2017) analyzed per capita energy consumption in

Turkey, OECD, and EU countries from 1960 - 2014. The study applied traditional ADF, PP, KPSS, and structural break tests, including ZA, LP, LM, and NP unit root tests. The results indicated that there is no convergence between Turkey's energy consumption and those of the OECD and EU countries.

3. Methodology

3.1. Data and empirical model

This study utilizes annual data for the period 1965–2023 to analyze per capita primary energy consumption (measured in kWh) for both Turkey and the group of high-income countries. The data were sourced from the Our World in Data data distribution platform. To analyze the convergence of energy consumption, the data were transformed using the methodology adopted by Meng et al. (2013), as follows:

$$y_{it} = ln\,(\frac{Per\ capita\ primary\ energy\ consumption\ in\ Turkey}{Average\ per\ capita\ primary\ energy\ consumption\ in\ high-income\ countries})$$

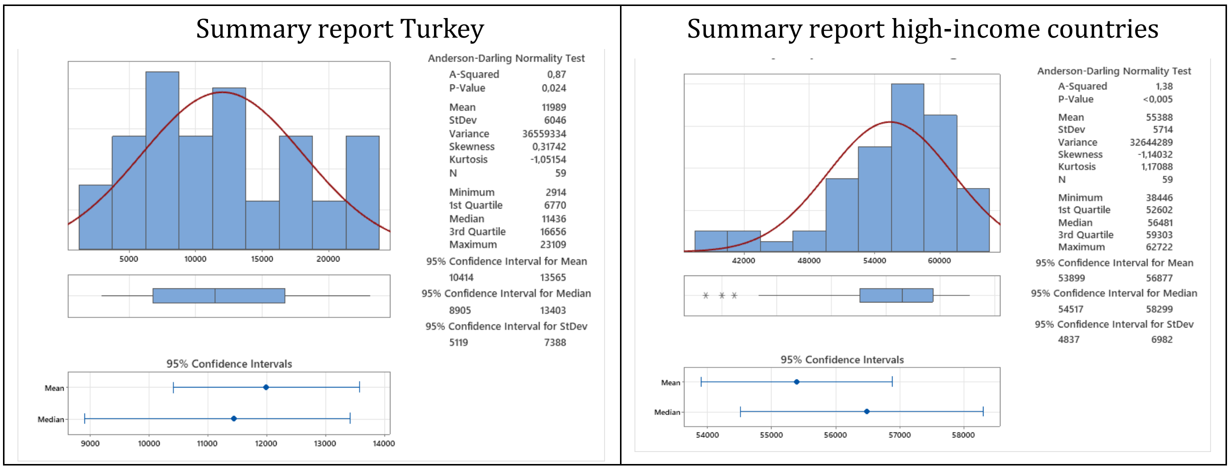

Figure 1. Summary report.

When examining the skewness and kurtosis values of a variable, it is expected that the skewness value be 0 and the kurtosis value be 3 for a normal distribution. A negative skewness value indicates that the series is left-skewed with a longer right tail, while a positive skewness value suggests that the series is right-skewed with a longer left tail. Referring to Figure 1, it is evident that the Turkey variable exhibits right skewness, whereas the high-income countries variable demonstrates left skewness. Regarding the kurtosis values, as all variables have values below 3, this indicates that the variables are less peaked compared to a normal distribution.

3.2. Econometric method

In the literature, several tests are available to examine the linearity of time series (McLeod and Li, 1983; Tsay, 1986; Lee et al. 1993). However, these tests do not account for the stationarity of the series, which reduces their power when the variables are non-stationary (Eyüboğlu and Eyüboğlu, 2020). In 2007, Harvey and Leybourne introduced a test that addresses this issue by testing the linearity of the series without assuming the stationarity of the examined series. Subsequently, in 2008, Harvey and colleagues introduced a test that provides better finite sample properties, size, and power compared to the Harvey and Leybourne (2007) test.

3.2.1. Linearity test

Harvey and Leybourne (2007) proposed the use of the following Model 1, which allows for the coexistence of I(0) and I(1) processes. In Equation 1, the hypotheses are as follows:

$H_0: \beta_2 = \beta_3 = \beta_5 = \beta_6 = 0$; $H_a: \beta_2 \neq \beta_3 \neq \beta_5 \neq \beta_6 \neq 0$. This model is designed to test the linearity of the time series without assuming the stationarity of the processes.

$$y_t = \beta_0 + \beta_1 y_{t-1} + \beta_2 y_{t-1}^2 + \beta_3 y_{t-1}^3 + \beta_4 \Delta y_{t-1} + \beta_5 (\Delta y_{t-1})^2 + \beta_6 (\Delta y_{t-1})^3 + \varepsilon_t \quad (1)$$

In the Harvey and Leybourne (2007) study, the test statistic is defined as: $W_T = \frac{RSS_1 - RSS_0}{RSS_0/T}$; $W_T^* = \exp(-b|DF_T|\text{-}1)W_T$. In this equation, b is a non-zero constant, and DFT is the standard ADF t-statistic obtained from the restricted regression. RSSi represents the sum of squared residuals for the Hi hypothesis, and T is the number of observations. The Harvey and Leybourne (2007) test statistic follows a X_4^2 distribution.

For the application of the Harvey et al. (2008) test, the models to be used under the assumptions of stationarity (I(0)) and non-stationarity (I(1)) of the time series are as follows:

Stationary I(0) Case Model:

$$y_t = \beta_0 + \beta_1 y_{t-1} + \beta_2 y_{t-2}^2 + \beta_3 y_{t-3}^3 + \sum_{j=1}^{p} \beta_{4j} \Delta y_{t-j} + \varepsilon_t \quad (2)$$

Non-Stationary I(1) Case Model:

$$\Delta y_t = \varphi_1 \Delta y_{t-1} + \varphi_2 (\Delta y_{t-1})^2 + \varphi_3 (\Delta y_{t-1})^3 + \sum_{j=1}^{p} \varphi_{4j} \Delta y_{t-j} + \varepsilon_t \quad (3)$$

In the equation, Δ represents the difference operator, and p indicates the number of lags.

$$W_\varphi = (1-\varphi)W_0 + \varphi W_1 \quad (4)$$

The W0 and W1 test statistics, calculated for the stationary and non-stationary cases, respectively, are used to compute the Harvey et al. (2008) W_φ test statistic. The W_φ test statistic follows a X_2^2 distribution (Güriş et al. 2018).

3.2.2. Augmented Dickey Fuller unit root test

The Augmented Dickey-Fuller (ADF) test is a statistical test used to determine whether a time series contains a unit root. Developed by Dickey and Fuller (1979), this test is an extended and improved version of the Dickey-Fuller unit root test. The hypotheses of the ADF test are as follows:

H1: a ≥ 0 not stationary

Ha: a < 0 stationary

$$\Delta y_t = \delta y_{t-1} + \sum_{i-1}^{p} \beta_i \Delta y_{t-i} + \varepsilon_t \quad (5)$$

$$\Delta y_t = \mu + \delta y_{t-1} + \sum_{i-1}^{p} \beta_i \Delta y_{t-i} + \varepsilon_t \quad (6)$$

$$\Delta y_t = \mu + \beta t + \delta y_{t-1} + \sum_{i-1}^{p} \beta_i \Delta y_{t-i} + \varepsilon_t \quad (7)$$

3.2.3. Lee ve Strazicich (2003) unit root test

The foundation of structural break unit root tests lies in break dummies. By incorporating various break dummies, tests are developed to allow for single, double, or multiple structural breaks (Mert and Çağlar, 2019). Model AA permits double breaks in the intercept, while Model CC allows double breaks in both the intercept and trend.

Model AA:

$$\Delta y_t = \mu + \beta_t + a y_{t-1} + \varphi DU1_t + \theta DU2_t + \sum_{i=1}^{k} d_i \Delta y_{t-1} + \varepsilon_i \quad (8)$$

The dummy variables in Model AA are as follows:

$$DU_1 = \begin{Bmatrix} t > TB_1 & 1 \\ otherwise & 0 \end{Bmatrix}$$

$$DT_1 = \begin{Bmatrix} t > TB_1 & t - TB \\ otherwise & 0 \end{Bmatrix}$$

Model CC:

$$\Delta y_t = \mu + \beta_t + a y_{t-1} + \varphi_1 DU1_t + \theta_1 DU1_t + \varphi_2 DU2_t + \theta_2 DU2_t + \sum_{i=1}^{k} d_i \Delta y_{t-1} + \varepsilon_i \quad (9)$$

The dummy variables in Model CC are as follows:

$$DU_2 = \begin{Bmatrix} t > TB_2 & 1 \\ otherwise & 0 \end{Bmatrix}$$

$$DT_2 = \begin{Bmatrix} t > TB_2 & t - TB \\ otherwise & 0 \end{Bmatrix}$$

TB1 and TB2 represent the first and second breakpoints, respectively. DU is a dummy variable representing a break in the intercept, while DT represents a break in both the intercept and the trend. The null hypothesis suggests that the series contains a unit root without structural breaks, whereas the alternative hypothesis indicates that the series is stationary with two structural breaks (Mammadov, 2024).

3.2.4. Narayan-Popp unit root test

Narayan and Popp (2010) proposed a new ADF-type unit root test that allows for a maximum of two structural breaks in the level (Model AA) and trend (Model CC). The test equations for the two models are as follows:

Model AA:

$$y_t^{M1} = \rho y_{t-1} + \alpha_t + \beta^* t + \theta_1 D(T_B')_{1,t} + \theta_2 D(T_B')_{2,t} + \delta_1 DU_{1,t-1}' + \delta_2 DU_{2,t-1}' + \sum_{j=1}^{k} \beta_j \Delta y_{t-j} + e_t \quad (10)$$

$\alpha_1 = \psi^*(1)^{-1}[(1-\rho)\alpha + \rho\beta] + \psi^*(1)^{-1}(1-\rho)\beta$, where $\psi^*(1)^{-1}$ 1 ψ (1) – representing the mean lag, $\beta^* = \psi^*(1)^{-1}(1-\rho)\beta$, $\phi = \rho - 1$, $\delta_i = -\phi\theta_i$ ve $D(T_B')_{i,t} = 1(t = T_{B,i}' + 1), i = 1,2$.

Model CC:

$y_t^{M2} = \rho y_{t-1} + \alpha^* + \beta^* t + \kappa_1 D(T_B')_{1,t} + \kappa_2 D(T_B')_{2,t} + \delta_1^* DU_{1,t-1}' + \delta_2^* DU_{2,t-1}' + \gamma_1^* DT_{1,t-1}' + \gamma_2^* DT_{2,t-1}' + \sum_{j=1}^{k} \beta_j \Delta y_{t-j} + e_t$; Here, $\kappa_i = (\theta_i + \gamma_i), \delta_i^* = (\gamma_i - \phi\theta_i)$, and $\gamma_i^* = -\phi\gamma_i, i = 1,2$. For the Narayan and Popp (2010) test, the hypotheses are as follows:

$$H_0: \rho = 1;\ H_a: \rho < 1$$

When deciding on stationarity, the null hypothesis is rejected if the absolute value of the calculated t-statistic exceeds the critical values (Mert and Çağlar, 2019).

3.2.5. Lumsdaine and Papell unit root test

The Lumsdaine and Papell (1997) (LP) unit root test is an extension of the Zivot-Andrews (ZA) test, designed to account for two structural breaks. The regression equations used in the LP unit root test are as follows:

Model AA (Two Breaks in Level):

$$\Delta y_t = \mu + a y_{t-1} + \beta t + \theta_1 DU1_t + \theta_2 DU2_t + \sum_{i=1}^{k} d_i \Delta y_{t-i} + \varepsilon_t \tag{11}$$

Model CA (Two Breaks in Level, One Break in Trend):

$$\Delta y_t = \mu + a y_{t-1} + \beta t + \theta_1 DU1_t + \theta_2 DU2_t + \vartheta_1 DT1_t + \sum_{i=1}^{k} d_i \Delta y_{t-i} + \varepsilon_t \tag{12}$$

Model CC (Two Breaks in Both Level and Trend):

$$\Delta y_t = \mu + a y_{t-1} + \beta t + \theta_1 DU1_t + \theta_2 DU2_t + \vartheta_1 DT1_t + \vartheta_1 DT2_t + \sum_{i=1}^{k} d_i \Delta y_{t-i} + \varepsilon_t \tag{13}$$

The shadow variables appearing in the equations are defined as follows. Here, TB1 and TB2 represent the break dates.

$$DU1_t = \begin{cases} 1, & t > TB1 \\ 0, & otherwise \end{cases}$$

$$DU2_t = \begin{cases} 1, & t > TB2 \\ 0, & dotherwise \end{cases}$$

$$DT1_t = \begin{cases} t - TB1, & t > TB1 \\ 0, & otherwise \end{cases}$$

$$DT2_t = \begin{cases} t - TB2, & t > TB2 \\ 0, & otherwise \end{cases}$$

The models are estimated for all possible values of the break dates TB1 and TB2, and the break pair is determined based on the smallest t-statistic of the α coefficient. The hypotheses for the LP unit root test are set up in a similar way to those for the ZA unit root test. The null hypothesis states that the series contains a unit root without structural breaks, while the alternative hypothesis suggests that the series is stationary with two structural breaks (Esenyel, 2017).

4. Results and Discussion

The electricity and energy series obtained by applying the transformation used in the study by Meng et al. (2013) will be analyzed in the first stage to determine whether they are linear, using the test by Harvey et al. (2008) and Harvey and Leybourne (2007).

Table 1. Nonlinearity test.

Variable	Harvey et al. (2008)	Harvey and Leybourne (2007)		
		%1	%5	%10
Energy Convergence	3.25	1.82	1.77	1.75

Notes: The Harvey and Leybourne (2007) linearity test follows a chi-squared distribution with 4 degrees of freedom, while the Harvey et al. (2008) linearity test follows a chi-squared distribution with 2 degrees of freedom. The critical values at the 1%, 5%, and 10% significance levels for the Harvey and Leybourne (2007) test are 13.28, 9.49, and 7.78, respectively. For the Harvey et al. (2008) test, the corresponding critical values are 9.21, 5.99, and 4.6.

Looking at the table 1 for the Harvey and Leybourne (2007) and Harvey et al. (2008) tests, since the calculated values for both tests are smaller than the corresponding table values, it is concluded that the series are linear. For the linear unit root tests, the Augmented Dickey Fuller (ADF) 1979 test and the break-point unit root tests, which internally determine structural breaks, including those by Narayan and Popp (2010), Lee and Strazicich (2003), and Lumsdaine and Papell (1997), will be applied.

Table 2. Augmented Dickey Fuller (ADF) unit root test.

Variable	Constant	Constant and trend
Energy Convergence	-1.048023 (0.7302)	-3.006435 (0.1394)

Based on the ADF test results, it is evident that the variable contains a unit root at the level values in both test outcomes. Following the standard unit root analysis, unit root tests incorporating structural breaks were conducted. According to the results of the structural break unit root test by LP (1997), it is observed that the energy convergence series contains a unit root at the level values across all models. Similarly, the results of the NP (2010) unit root test indicate that the series contains a unit root at the level, yielding results consistent with those of the LP (1997) test.

Table 3. Linear unit root tests results.

Variable	Break-Years and T-Statistic	LP 1997			LS 2003		NP 2010	
		Model AA	Model CA	Model CC	Model AA	Model CC	Model AA	Model CC
	TB1	1974	1993	1978	1993	1993	1978	2000
Energy Convergence	TB2	1998	2001	1998	1998	2001	2000	2005
	T-Statistic	- 5.4879	-4.8065	-5.911	-4.3895***	-5.0618*	-2.228	-2.908

*Notes: * indicates significance at the 10% level, ** at the 5% level, and *** at the 1% level*

Based on the LS (2003) test results presented in the table, the null hypothesis of a unit root in Model AA is rejected at the 1% significance level, while in Model CC, it is rejected at the 10% significance level, indicating that the series is stationary.

5. Conclusion

The purpose of this study is to examine whether Turkey's per capita primary energy consumption converges to that of high-income countries during the 1965–2023 period. The convergence hypothesis suggests that low-income countries can close the gap by growing faster than higher-income countries. In this process, countries are categorized according to their level of development, with developing countries aiming to achieve developed country status through economic progress. In this study, the convergence hypothesis was analyzed using linear unit root tests. The analysis results varied depending on the methods employed. According to the Lee and Strazicich (2003) test, the energy convergence series was found to be stationary in certain models, whereas the Narayan and Popp (2010), Lumsdaine and Papell (1997), and conventional ADF test results indicated non-stationarity. This highlights a complex picture regarding energy consumption convergence and underscores the need to carefully assess the impact of different methodologies on the results.

Overall, the findings make it challenging to draw a definitive conclusion regarding the convergence of Turkey's energy consumption to that of high-income countries. The inconsistency among different test results particularly points to the necessity for more comprehensive analyses.

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Conflict of interest

The author claims that the manuscript is completely original. The author also declares no conflict of interest.

Author contributions

Conceptualization: Taleh Mammadov; Investigation: Taleh Mammadov; Methodology: Taleh Mammadov; Formal analysis: Taleh Mammadov; Writing – original draft: Taleh Mammadov; Writing – review & editing: Taleh Mammadov.

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