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Is there convergence or divergence in per capita energy consumption in sub-Saharan African countries?

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Abstract. *All energy-related issues, including energy and energy economics, are issues that countries, policymakers, and researchers have been showing growing interest in. The demand for energy resources in the economies of all countries is growing, while access to energy resources is becoming more difficult, and the value of energy resources is increasing. It is becoming even more difficult for developing countries to access and utilize energy resources. This study examines the existence of convergence in per capita energy consumption for sub-Saharan African countries. The convergence analyses for 19 sub-Saharan African countries were conducted using annual data for the period 1971-2013. According to the Kapetanios, Shin and Snell (2003) test, per capita energy consumption converged in Angola, Benin, Mozambique, South Africa, and Tanzania. According to the nonlinear Güriş (2017) unit root test based on the Flexible Fourier Form, per capita energy consumption converges in South Africa, Zambia, and Zimbabwe. No evidence of convergence in per capita energy consumption was found in 12 sub-Saharan African countries.*

Keywords: energy consumption, convergence, energy consumption convergence, nonlinear unit root test, sub-Saharan African countries.

JEL Classification: C12, C22, Q43.

1. Introduction

Energy is one of the vital issues that attract the attention of policymakers and researchers. Energy and energy use are important for the functioning of world economies. The demand for all types of energy is gradually increasing with the growing population, improving living standards and economic development in all economies. However, while it is easy for some countries to access and have energy, it may not always be easy for some countries and/or groups of countries. For this reason, there is a growing interest in studying energy and energy-related issues. One such issue is the study of the existence of convergence in energy consumption.

Solow (1956) introduced the concept of convergence within the framework of neo-classical economic theory. Convergence is defined as closing the gap between countries in indicators such as per capita income, economic growth rate and total factor productivity growth over time. Moreover, convergence can also be defined as the ability of low-income countries to catch up with relatively high-income countries over time in terms of per capita income (Hepsağ and Tıraşoğlu, 2018: pp.53).

The concepts of stochastic and deterministic convergence have emerged in the literature using time series methods to examine the validity of the convergence hypothesis. The concept of stochastic convergence based on unit root tests was proposed by Carlino and Mills (1993). Stochastic convergence means that shock to the income of a given country relative to the average income across a group of countries will be temporary. Failure to reject the unit root hypothesis proves the existence of stochastic divergence, while rejection of the unit root hypothesis proves the existence of stochastic convergence (Dawson and Strazicich, 2010: pp.909-910).

The idea of basic convergence is based on the understanding that if poorer countries grow faster than richer countries, convergence in living standards between countries will occur. Poor countries can do this, i.e., grow faster than richer countries. As a result, they can catch up with richer countries for various reasons. For example, poor countries can borrow existing advanced technology from rich countries. Another situation is that divergence will occur because relatively poor countries grow more slowly than rich countries. An important reason for this is the instability and unreliability of energy supply in poor countries. Energy availability is vital for the functioning of any modern economy. Therefore, countries that experience unstable energy supply can have much lower growth rates than countries that do not (Anoruo and DiPietro, 2014: pp.568).

Energy convergence is vital for ensuring sustainable energy consumption and reducing carbon dioxide emissions. It is also important how energy consumption varies in relation to GDP growth. Many countries have adopted policies to reduce energy intensity and improve energy efficiency. If a country has rapid energy convergence and growth rates are partially consistent, this indicates that targets involving growth in energy consumption are feasible. Moreover, the reduction in inequalities in per capita energy consumption across countries is evidence of the success of such policies (Mishra and Smyth, 2014: pp.181).

As in all economies, there is a growing demand for energy in sub-Saharan African economies, which will continue to do so. It is important to examine the existence of convergence in energy consumption for these countries and to develop policies accordingly. Akram, Rath and Sahoo (2020) state that the energy convergence literature can be classified into two parts. The first is country-level per capita energy convergence studies, and the second is disaggregated and sector-level per capita energy convergence studies. This study examines the convergence in per capita energy consumption at the country level for sub-Saharan African countries.

The remainder of the study is organized as follows: Section 2 presents the literature review on energy convergence. Section 3 describes the econometric methodology used in the implementation. Section 4 presents the data and results of the implementation for sub-Saharan African countries. Section 5 provides a discussion of the results.

2. Literature Review

The concept of convergence is an important issue that attracts the attention of many fields, especially economics. There are many empirical studies on convergence in the literature. However, there is a more limited literature examining convergence in energy consumption, which occupies a very important place in the world economy. In this context, studies that have contributed to the literature on convergence in energy consumption are analyzed in detail here.

One of the first studies to examine the convergence of energy consumption is the study by Maza and Villaverde (2008). Maza and Villaverde (2008) analyzed the convergence in per capita electricity consumption for 98 countries. In addition to σ and β convergence, nonparametric techniques were used in the analyses for the period 1980-2007. The study's main finding is that there is a weak convergence in electricity consumption. According to Maza and Villaverde (2008), this reduction in disparities is related to three issues: first, the rapid economic changes experienced by some developing countries; second, the energy conservation policies implemented by most developed countries following the first oil shock; and, third, the growing awareness of energy issues in rich countries. Meng et al. (2013) analyzed the convergence in per capita energy use in 25 OECD countries between 1960 and 2010. The study performed the analyses using the LM and RALS-LM unit root tests, allowing two endogenously determined structural breaks. Meng et al. (2013) found mixed results for unbroken, one-break and two-break tests for the convergence in per capita energy use in OECD countries.

Anouro and DiPietro (2014) examined the convergence in per capita energy consumption for 22 African countries using data for the period 1971-2011. The study used first-generation panel unit root tests and second-generation panel unit root tests were used in the study. In addition, the panel KSS panel unit root test was used in the study. According to the standard panel unit root test results, energy consumption per capita converges as a group for 22 countries. According to the results obtained from the SPSM procedure, per capita energy consumption converges in 15 countries, while there is no convergence in the other seven countries. Mishra and Smyth (2014) examined the convergence in per capita energy consumption among five ASEAN countries. The study focused on the period 1971-2011. The panel KPSS stationary test and panel LM one and two structural break unit root tests were used in the implementation part of this study. The empirical results support convergence in per capita energy consumption among five ASEAN countries.

Payne et al. (2017) examined the per capita renewable energy consumption characteristics of the states in the United States. The analyses used data for the period 1970-2013. Payne et al. (2017) used cross-sectional, two-break LM, and RALS-LM tests. As a result of the cross-sectional tests, it was concluded that the per capita consumption of renewable energy in the US states has converged. However, it is concluded that stochastic convergence is supported under structural breaks for most US states. Hao and Peng (2017) examined whether per capita energy consumption converges for 30 provinces in China. The study used the data for the period 1994-2014. In addition, panel data methods and spatial econometric methods were used in the implementation. The empirical results indicate that there are both absolute and conditional β-convergences in per capita energy consumption across provinces. In addition, there is also evidence for an inverted U-shaped relationship between per capita energy consumption and per capita GDP. Fallahi (2017) examined convergence in per capita energy consumption across 109 countries. The study used annual data for the years 1971-2013 were used in the study. In this study, in addition to the full sample of countries, convergence exists in seven groups of countries (Africa, America, Asia, Europe, Middle East, OECD and OPEC countries). The study's analyses are conducted using the pair-wise approach of Peseran (2007). Accordingly, the results based on 7962 pairs of countries are more favorable to the existence of convergence in energy use. Moreover, the rate of convergent divergence increases as we move from the global picture to regional subgroups, except for Europe.

Solarin et al. (2018) examined the validity of convergence in renewable energy consumption in OECD countries. The study used annual data for the period 1965-2014 for 27 OECD countries. In this study, they used a more flexible approach based on fractional integration instead of the classical unit root test. As a result of the analyses, the convergence in renewable energy consumption is found in 8 countries using parametric methods and in 14 countries using semi-parametric methods. Another study that examines energy convergence is Cai and Menegaki (2019). Cai and Menegaki (2019) examined the convergence of clean energy consumption for 21 OECD countries and 14 developing countries. The study considered data for the period 1965-2016. Unit root tests with breaks, first generation and second-generation panel unit root tests and panel unit root tests with structural breaks were used to examine clean energy consumption. According to the results of the analyses, convergence was found to be valid in 22 out of 35 countries. Moreover, the empirical results suggest that not only sharp breaks but also smooth breaks should be considered. Pan and Maslyuk-Escobedo (2019) examined the stochastic conditional convergence in per capita energy consumption for 26 low-income, lower-middle-income and upper-middle-income African countries. The study used data for the period 1971-2014. The analyses used conventional panel unit root tests and RALS-LM unit root tests that account for breaks. Although the study finds evidence supporting stochastic conditional convergence for most countries, it finds divergence for four countries, including DR Congo, Senegal, Egypt and Botswana.

Another recent study examining energy convergence is that of Liu and Lee (2020). Liu and Lee (2020) examined convergence in energy consumption for 107 countries using data from 1971-2014. In this study, the researchers used the sequential panel selection method. Traditional panel unit root tests and panel CSR unit root tests were used in the analyses. According to the results, convergence holds for about seventy percent of the countries examined. Moreover, the study finds that high-income and upper-middle-income countries converge earlier than lower-middle-income and low-income countries.

An analysis of the empirical studies shows that there is no common decision on the validity of convergence in energy consumption. This may be because of the countries and/or groups of countries examined, the time period examined, and the analytical techniques used.

3. Econometric Methodology

Different econometric methods examine the convergence of per capita energy consumption. In this study, the Kapetanios, Shin and Snell (2003) (KSS) and Güriş (2017) tests, which are strong nonlinear unit root tests, are used to analyze the existence of convergence. These tests are preferred because they allow a smooth transition between regimes, are considered more appropriate for the economic structure, and have better power than the previous tests. The KSS (2003) study developed a test that allows testing the nonlinear stationary exponential smooth transition autoregressive (ESTAR) process against the unit root null hypothesis (Güriş et al. 2016: pp.134). The test of KSS (2003) considered the nonlinear version of the linear ADF test for nonlinear stationarity (Bahmani-Oskooee and Hegerty, 2009: pp.644). In their study, KSS (2003) expressed the univariate first-order smooth transition autoregressive (STAR) model as follows.

$$y_t = \beta y_{t-1} + \gamma y_{t-1}\Theta(\theta; y_{t-d}) + \varepsilon_t$$

$\varepsilon_t \sim iid(0,\sigma^2)$, β and γ indicate unknown parameters and y_t is a zero-mean stochastic process. In the KSS (2003) test, the exponential transition function is restricted between zero and one and the exponential STAR model is expressed as follows.

$$y_t = \beta y_{t-1} + \gamma y_{t-1}\left[1 - \exp(-\theta y_{t-d}^2)\right] + \varepsilon_t$$

If $\phi = 0$ and $d = 1$ in the test, then the ESTAR model is as follows:

$$\Delta y_t = \gamma y_{t-1}\left[1 - \exp(-\theta y_{t-1}^2)\right] + \varepsilon_t$$

The equation denotes the time series adjusted for mean and trend while the unknown parameters. The hypothesis tests of the test are $H_0 : \theta = 0$ and $H_1 : \theta > 0$. It is impossible to test the null hypothesis directly when it cannot be defined under it. To overcome this problem, the *t*-type test statistic is used. The auxiliary regression with the *pth* order generalized Taylor series approach can be shown as follows in the test.

$$\Delta y_t = \sum_{j=1}^{p} \rho_j \Delta y_{t-j} + \delta y_{t-1}^3 + error$$

In the KSS (2003) test, the *t*-statistic can be calculated as $t_{NL} = \hat{\delta} / s.e.(\hat{\delta})$ for $\delta = 0$ against $\delta < 0$ The asymptotic critical values for the raw, de-meaned, and de-trended data in the test are tabulated.

The KSS (2003) test assumes that the location parameter *c* is zero. The nonlinear unit root test developed by Kruse (2011) suggests that non-zero location parameters are more likely in real-world cases. The test procedure that allows non-zero location parameter *c* in the exponential transition following the KSS (2003) study is as follows (Tıraşoğlu, 2019: pp.56).

$$\Delta y_t = \gamma y_{t-1}(1 - \exp\left\{-\theta(y_{t-1} - c)^2\right\}) + \varepsilon_t$$

Applying the first-order Taylor approximation in the test procedure, around $\theta = 0$ $G(y_{t-1};\theta,c) = (1 - \exp\left\{-\theta(y_{t-1} - c)^2\right\})$ and the test regression is denoted as follows:

$$\Delta y_t = \delta_1 y_{t-1}^3 + \delta_2 y_{t-1}^2 + \delta_3 y_{t-1} + \sum_{j=1}^{p} \varphi_j \Delta y_{t-j} + \varepsilon_t$$

The power of the test can be further improved by applying $\delta_3 = 0$. Therefore, the equation takes the following form.

$$\Delta y_t = \delta_1 y_{t-1}^3 + \delta_2 y_{t-1}^2 + \sum_{j=1}^{p} \varphi_j \Delta y_{t-j} + \varepsilon_t$$

In the Kruse (2011) test, $\beta_1 = \theta\gamma$ and $\beta_2 = -2c\theta\gamma$. The test consists of the null hypothesis $H_0 : \delta_1 = \delta_2 = 0$ of a unit root and the alternative hypothesis of $H_1 : \delta_1 < 0, \delta_2 \neq 0$ a perfectly stationary ESTAR process. The Kruse (2011) test τ statistic is calculated as follows.

$$\tau = t_{\delta_2^{\perp}=0}^2 + 1(\hat{\delta}_1 < 0) t_{\delta_1=0}^2$$

The critical values of the τ statistic for the test are tabulated by Kruse (2011).

Hu and Chen (2016) are interested in the unit root test against the local explosive or local unit root but globally stationary ESTAR process. Hu and Chen (2016) stated that the null hypothesis will be $H_0 : \delta_1 = \delta_2 = \delta_3 = 0$ against $H_1 : \delta_1 \neq 0, \delta_2 \neq 0, \delta_3 < 0$. This test problem is not standardized because two parameters are two-sided under H_1 , and the other one is one-sided. This test problem is not standardized because it is two-sided under two parameters, and the other one is one-sided. Hu and Chen (2016) proposed a modified Wald test by applying the method of Abadir and Distraso (2007) to solve this situation. This test statistic is as follows.

$$\tau = \tau_1^2 + 1_{\tau_3 < 0} \tau_3^2$$

Hu and Chen (2016) expressed the adjusted asymptotic distribution of the τ statistic $\tau \Rightarrow A(W(r)) + B(W(r))$. Here, A(.) and B(.) are the standard Brownian motion function of W(r).

Christopoulos and Leon-Ledesma (2010) provide a new perspective on the KSS (2003) test. In this test, a new unit root procedure is proposed that combines Fourier transform and nonlinearity. Güriş (2017) extends the work of Christopoulos and Leon-Ledesma (2010) and develops a new nonlinear unit root test procedure using the Fourier function. The structural breaks proposed by Hu and Chen (2016) in this test procedure are modeled by the Fourier function. In addition, nonlinear corrections are modeled through the ESTAR model. This test procedure eliminates two major problems encountered in unit root tests (Güriş, 2017: pp.1-12).

In the Güriş (2017) test, the nonlinear deterministic component is determined in the first stage.

$$y_t = \alpha_0 + \alpha_1 \sin\left(\frac{2\pi k * t}{T}\right) + \alpha_2 \cos\left(\frac{2\pi k * t}{T}\right) + v_t$$

Here, *t* is the trend term, T is the sample size, and . is the optimal frequency obtained from the equation by assigning values between 1 and 5 to k. The error terms of the equation are obtained as follows.

$$v_t = y_t - \alpha_0 + \alpha_1 \sin\left(\frac{2\pi k * t}{T}\right) + \alpha_2 \cos\left(\frac{2\pi k * t}{T}\right)$$

In the second stage, test statistics are estimated from the following equation using the error terms obtained in the first stage.

$$\Delta v_t = \delta_1 v_{t-1}^3 + \delta_2 v_{t-1}^2 + \sum_{j=1}^{p} \varphi_j \Delta v_{t-j} + \varepsilon_t$$

This equation is used in the Güriş (2017) test, and the test statistics are calculated using the $\tau = \tau_1^2 + 1_{\tau_3 < 0} \tau_3^2$ formula in Hu and Chen (2016).

In the third stage, the relevant hypothesis tests are performed using the *F* test $F\left(\tilde{k}\right)$. If the null hypothesis is rejected, it is concluded that the variable is stationary around a broken deterministic function. The critical values of the *F* test are tabulated in Becker, Enders and Lee (2006).

Güriş (2017) compared the power analysis of this new test with the test of Hu and Chen (2016). It is concluded that this newly developed test is much more powerful, especially when k=2 and k=3. In addition, the critical values for different sample sizes are tabulated in the study.

4. Empirical Results

This part of the study empirically examines the convergence in per capita energy consumption in 19 sub-Saharan African countries. The data used in the study were obtained from the World Development Indicators database on the World Bank website. The data used in the implementation covers the period 1971-2013. The following formula was applied to the data to analyze the convergence in energy consumption.

$$y_{it} = \ln\left(\frac{Per\,Capita\,Energy\,Consumption_{it}}{Average\,Per\,Capita\,Energy\,Consumption_t}\right)$$

The equation transforms each country's per capita energy consumption series into a relative per capita energy consumption measure. Here, *yt* denotes the relative energy consumption. The KSS (2003) and Güriş (2017) nonlinear unit root tests are used in the analyses, and the results are tabulated below.

Table 1. *KSS (2003) Nonlinear Unit Root Test Results*

Country	Lag	Test Statistics
Angola	1	-3,3080**
Benin	0	-2,6946***
Cameroon	2	-0,0443
Congo, Dem. Rep	0	-1,7118
Congo, Rep.	0	-0,6745
Cote d'Ivoire	0	-1,6500
Ethiopia	2	-0,7743
Gabon	3	-2,0861
Ghana	0	-1,0971
Kenya	2	-0,6663
Mauritius	3	-1,7258
Mozambique	0	-3,1005**
Nigeria	2	-2,0641
Senegal	0	-2,2876
South Africa	3	-2,7244***
Tanzania	1	-3,6689*
Togo	0	-1,5684
Zambia	0	-0,9058
Zimbabwe	1	-1,7492

Note: The lag lengths are selected by Akaike Info Criterion. The *, ** and *** denotes 1%, 5% and 10% significance level respectively. Test critical values were obtained from the studies by KSS (2003).
Source: Author.

The KSS (2003) nonlinear unit root test for sub-Saharan African countries was conducted in a de-meaned form. Accordingly, the null hypothesis of unit root is rejected for five countries. In other words, according to the KSS (2003) test, it was concluded that per capita energy consumption in Angola, Benin, Mozambique, South Africa and Tanzania converged.

Table 2. *Güriş (2017) Nonlinear Unit Root Test Results*

Country	k	F statistics	Lag	Test Statistics
Angola	1	12,8045	2	2,9326
Benin	1	8,5579	0	7,8135
Cameroon	1	37,7958	0	11,3671
Congo, Dem. Rep	1	34,0300	0	3,2456
Congo, Rep.	1	17,7265	0	1,1569
Cote d'Ivoire	1	24,3259	0	7,4932
Ethiopia	1	47,8516	2	8,7075
Gabon	1	49,3010	2	8,4324
Ghana	1	20,2298	0	1,3338
Kenya	1	33,3987	2	1,0743
Mauritius	1	95,4853	1	3,9101
Mozambique	1	21,0872	3	2,4545
Nigeria	1	77,6354	3	7,4861
Senegal	1	14,4242	0	6,0195
South Africa	1	44,7531	0	15,7123***
Tanzania	1	14,5996	2	10,7966
Togo	1	91,4041	0	1,4352
Zambia	1	25,2178	1	28,6990*
Zimbabwe	2	12,7002	0	15,6447**

Note: *k* denotes the frequency selected for the approximation. The lag lengths are selected by Akaike Info Criterion. The *, ** and *** denotes 1%, 5% and 10% significance level respectively. Test critical values were obtained from the studies by Becker et al. (2006) and Güriş (2017).
Source: Author.

According to the nonlinear unit root test of Güriş (2017), the null hypothesis of unit root was rejected in only three countries. It was concluded that per capita energy consumption converged in South Africa, Zambia and Zimbabwe, while it diverged in the other 16 countries.

According to the results obtained, it is concluded that there is a convergence in energy consumption only in South Africa at the end of both tests. Similarly, the existence of divergence in 12 countries is a common result according to both tests.

According to the implementation results, assuming the same level of technology, the countries where convergence is valid will approach the same long-run value of per capita energy consumption in the long run. Industrialization can cause convergence with political and economic relations in the globalizing world.

5. Conclusion

Energy is one of the vital resources for all countries' economies from the past to the future. The demand for all types of energy is increasing with the increasing population, improving living standards and economic development in the economies of all countries. One of the noteworthy energy-related issues is the examination of convergence or divergence in energy consumption for countries, regions or even cities. Energy convergence has been studied in the literature using various econometric methods for specific time periods.

This study examines the existence of convergence in per capita energy consumption for 19 sub-Saharan African countries. The study uses annual data for the period 1971-2013. Two nonlinear unit root tests are used in the empirical analysis. The first of these tests is the KSS (2003) nonlinear unit root test with an exponential smooth transition autoregressive (ESTAR) process. The second is the Güriş (2017) nonlinear unit root test, an extension of the KSS (2003) test for the Flexible Fourier Form. Güriş (2017) proposes a new unit root test that allows for nonlinearity and the presence of multiple smooth temporary breaks. This test developed by Güriş (2017) was compared with previous tests, and it was concluded that it is, in fact, more applicable.

As a result of the empirical analysis, the Kapetanios, Shin and Snell (2003) test showed that the per capita energy consumption converged in Angola, Benin, Mozambique, South Africa, and Tanzania. According to the test result of Güriş (2017), it was concluded that per capita energy consumption converged in South Africa, Zambia, and Zimbabwe. According to these two test results, there is no evidence of convergence in per capita energy consumption in 12 sub-Saharan African countries.

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