The Relationship Between Energy Intensity and GDP per Capita in Eastern African Countries (EAC): Evidence from Co-integration and Granger-Causality Investigation Analysis

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Abstract

The link between economic performance and energy efficiency is a continuing debate. This paper investigates the long-term equilibrium and causal relationship between energy efficiency and GDP per capita in East African countries for the period between 1990 and 2021. The analysis of EAC countries do not provide clear evidence of convergence in the sense that poor economies tend to grow faster than rich ones in per capita terms. The co-integration test indicates a long-run equilibrium relationship between GDP and energy intensity. In particular, the result based on Johansen shows that the energy intensity level of primary energy and GDP per capita are co-integrated in Rwanda, Burundi and Uganda while the co-integration based on Pedroni occurs in Burundi and Rwanda. The Granger causality shows that there is a unidirectional relation running from GDP to primary energy use in all countries except Kenya. South Sudan is observed to have a bidirectional relationship between variables. Finally, we find that the long-run coefficient of GDP per capita is negative and significant, indicating a change in trend of energy intensity. The results suggest that economic growth in EAC countries can be supported by promoting growth in productivity of the energy industries.

Keywords
Energy intensity, GDP per capita, Co-integration; Convergence, Energy consumption.

1. Introduction
Over the last decade, the ratio of people lacking access to modern energy services has fallen by 10%–down from almost 25%, even though the global population has expanded considerably. Referring to BP's "Statistical Review of World Energy 2020", energy based on coal accounts for 36% and occupies the first source of power generation in the world for the year 2019, the growth of carbon emissions has slowed but is still high. To process the world transition towards sustainable green and low carbon development by reducing dependency on fossil fuel in the short term has become very difficult. The traditional view about energy-saving policies seeks to make a trade-off between the stability of economic growth and to sustain the environment. To achieve green economy growth, long term development and improvement, some countries have set targets to achieve reductions by 2030 and making carbon emission neutrality by 2060 (Zhou et al. 2021). Energy efficiency plays a

big role in this improvement. Energy efficiency is defined as the use of less energy to produce the same quantity of outputs (Bullard and Herendeen 1975). These advances are not spread evenly geographically because a big part of sub-Saharan Africa still is without access to modern energy services and the way forward in expanding energy access to all people has lagged behind population increase even though the research done on in this region shows abundant energy resources compared with the rest of world. Global investigation towards energy intensity has been carried out in terms of its trend as a macro indicator of energy intensity or energy efficiency and shows that energy intensity improved by 2% as of 2016 but this is not enough to address the problem related to climate change and to meet goals determined in the Paris Agreement (Nemecek et al. 2009) and (Enerdata 2018). For Sub-Saharan African countries in particular, the energy intensity is very low despite vast grid extension during last decade (IRENA 2019). Assessment based on the region showed that this rate is still low in the East African Community (EAC) and the region continues to be marginalized compared to the rest of world. The East African Community (EAC) as a regional intergovernmental organisation is made up of six countries including Burundi, Tanzania, Kenya, Rwanda, Uganda and South Sudan. This region has abundant resources including wind, solar, hydropower and geothermal but it highly depends on biomass energy and has a poor national electrification rate (Chisika and Yeom 2021). Energy efficiency in this region constitutes a major problem for economic growth and development (Nondo, et al. 2010). With economic growth in the EAC region, the lack of energy resources for different services is becoming a major obstacle. The main challenges facing this region are related to increase access to modern service, to address the human heath due to environmental degradation, to develop infrastructure related to the energy sector and to meet rising energy demand (Tharani 2017). Solving the mentioned challenges of energy access can facilitate industrial development as well as create new opportunities for clean energy and efficient energy services (Chisika and Yeom 2021). Economically, the EAC is one of the fastest growing regions in Africa. In this region, studies on energy efficiency and economic performance are few and have limited analysis despite the importance of the topic. Supporters of energy efficiency agree that a great number of countries are motivated about the link between energy efficiency and economic growth. But the actual connection between economic growth and energy efficiency is continuing and there is little consensus on this matter. The key indicator of energy intensity is energy efficiency and most studies use this indicator to study its relation to economic growth (Davoodi 2012). In EAC there are no empirical studies which have evaluated the contribution of energy efficiency towards economic growth by using time series data. Adopting convergence (or divergence) of EAC to the GDP per capita gives some useful information about EAC' competitiveness. If the country members of EAC are converging to the same level, it reveals that their competitiveness is getting closer. On the other hand, if divergence occurs, then some of the countries (with the higher competitiveness) accelerate while other are left behind. Then it would be interesting to explain reasons for such behaviour (Te Velde 2008).

1.1 Objectives

To fill the mentioned gap, the paper is guided by the following objectives.

a. To investigate the relation between gross domestic product per capita (GDP per capita) and energy intensity in the region,
b. To analyse whether the energy intensities of EAC countries tend to grow faster than rich countries.

The work is arranged as follows: In the next section we present a brief review of relevant empirical studies on the issue followed by data and the econometric model in section three. In section four, the empirical findings are presented. The final section is on conclusions and policy implications.

2. Literature review

Following the work done by Kraft and Kraft for the period of 1978, the review of literature shows that the relationship between energy consumption and economic growth has been undertaken by many scholars in different time of period like (Melike Elif Bildirici and Kayikci 2012);(M. Bildirici and Özaksoy 2016);(M. Bildiriciand Ersin 2015a) and (M. Bildirici and Ersin 2015b);(Campo and Sarmiento 2013);(Soytas and Sari 2009); (Dogan and Walker 2014);(Kahsai et al. 2012); (Mehrara et al. 2015);(Kouakou 2011).The outcomes of their results are not conclusive. Zhang and Broadstock (2016) on the causality between energy consumption and economic growth for China in a time-varying framework find that, in light of structural change, China's energy consumption is trend-stationary and thus forms no cointegration with GDP. Belke et al. (2011) evaluated the role of energy use as a key driver of economic growth by using the Granger causality test in India during 1970-71. The outcome suggests that economic growth fuels more demand for both crude oil and electricity consumption. Others studies have investigated the influence of different components of energy on the major components of economic growth with the use of causality tests; none is found to be significantly significant (Poveda and (Chontanawat et al. 2006); (Troster et al. 2018) and (Odhiambo 2009). Pokhrel and Khadka (2019) undertook a multi-country nuclear energy study and found a long run equilibrium link between real GDP, real gross capital formation, labour force and energy consumption. Their results also support the feedback hypothesis on the relationship between economic growth and nuclear energy. Further, the relationship between energy intensity and economic growth was undertaken by many researchers and using the two-way causal relationship between variables. Their findings revealed that there is a long co-integration link among variables resulting in tendency to diminish energy intensity. They also find that there is a unidirectional causality running from energy intensity to economic structure. Phoumin and Kimura (2014) conducted research in the Asian countries to examine the link between energy intensity and income level, they concluded that energy intensity has a relationship with income level. Twerefou et al (2018), who examine the trade-off between energy efficiency and economic performance in G20 countries, obtained the contribution between variables under investigation. Panel Granger causality tests indicate that there is a unidirectional causality running from energy intensity to economic performance but not vice versa. The results obtained in many empirical studies about the relationship between parameters and based on σ- convergence and β-convergence show that output is necessary but not sufficient condition for convergence (R. J. Barro and Sala-I-Martin 1992); (Abosedra et al.2009); (Bilgili et al.2016) and (Ozturk and Bilgili 2015). Additionally, these studies examine specifically whether cross-country variation in energy intensity is getting smaller (σ-convergence) and if less efficient nations reduce their energy intensity faster than more efficient ones (β-convergence). Voigt et al. (2014) and (Burke et al.(2018) find convergence across developing and developed countries while others argue for a more nuanced picture of convergence in energy intensity. Le et al. (2017) do not find evidence for global convergence for a group of 97 countries. For the subgroup analysis, they find that there is non-convergence for the Middle East, OECD as well as Europe sub-groups. They demonstrated that developing counties tend to converge at ahigher level of energy intensity, while for developed countries at least two different levels of convergence are observed. Esen and Bayrak (2017) and (Esen and Bayrak 2017) demonstrated that the divergence in energy efficiency is mostly associated with economies that are lacking in economic progress. Özcan et al. (2018) demonstrated an impact of energy efficiency on long-run economic growth. Consider that when the quantity of output is not reduced, energy reduction will not affect economic performance due to the fact that technological advancement will improve energy productivity (Troster et al. (2018). The result will be observed in improvement if economic productivity and capital investment are promoted. The work done revealed that there are two basic factors through which energy efficiency facilitate energy use to increase. For the first instance, energy costs contain a large quantity of the total cost of energy services, and the second is that the quantity of energy services produced maintains a large amount of economic activity.

The study between energy intensity and economic performance was also evaluated by referring to the growth theory and the co-integration method. The research carried out in China report a unidirectional Granger causality running from energy intensity to economic growth (Regionales and Espa 2018). Based on methodology, this study found that there is a long-term co-integration relationship between variables resulting in the decline of energy consumption. Wu (2010) found a considerable reduction of energy intensity in China due to an improvement of energy efficiency, and that the effect of structural changes in the economy is very limited. Özcan in the research based on the ASEAN and East Asia countries found a relationship between income level and energy intensity.Twerefou et al.((2018) demonstrated that energy efficiency or energy intensity of primary energy is adriver of economic growth and development of infrastructures for education and health. Mačerinskienė and Kremer-Matyškevič (2017) developed a research for the 29 most developing countries and found that lower levels of energy intensity are associated with higher total factor productivity in the manufacturing sector. Özcan and Özkan (2018) evaluated the dynamic relationship between economic growth, CO2, energy consumption and trade of Group of Twenty (G20) by using time series data and found a long run relationship between variables. Zeng and Zhou (2021) by using the panel data for 19 nations to investigate the effect of foreign direct investment on clean energy use, economic growth and carbon emission reported that FDI inflows increase energy use in G20 and lead to the growth of economy, although the study found no relation to clean energy user carbon emissions.In general, the research conducted between economic growth and energy consumption have demonstrated that there is a long run association between as well as mixed(Apergis and Payne 2010); (Ucan et al. 2014); (Twerefou et al. 2018); (Kouton 2021); (Maji et al. 2019); (Dritsaki and Dritsaki 2014); (Dritsaki and Dritsaki2014);(Mehrara and Rafiei 2014) ; (Troster et al.2018); (Paul and Bhattacharya 2004) ; (Pempetzoglou 2014); (Costantini and Martini 2010) ; (Aklin et al. 2017) and (Ngwakwe 2021).

3. Methodology

3.1. The model

Considering the above discussion, many of the time series studies cited above reflect two basic limitations regarding co-integration and causality tests between energy consumption and economic growth. To test a long-run co-integration relationship between parameters requires both series to be integrated either for the order one, named I(1), as any inference on variables under the study regarding the energy-economic growth nexus is conditional on the assumption that both series are I(1). If the series are not co-integrated for I (1) and are integrated of different orders, there is no test for a long-run relationship to be carried out. However, considering that unit root and co-integration tests result in low power against the alternative, these tests can be misplaced and can suffer from pre-testing bias (Breitung and Pesaran2008); (Pesaran, Shin, and Smith 2001) and (Breitung and Pesaran 2008). Additional, (Toda and Yamamoto 1995) observed that the conventional F-statistic used to test for Granger causality may not be valid when the test does not have a standard distribution even if the time series data are integrated or co-integrated. According to the empirical literature in economic growth and energy consumption, it is suitable to form a long-run relationship between energy intensity and economic growth as follows:

$$ENER_t = \beta_0 + \beta_1 GDP_t + \mu_t$$

GDP and ENER represent real GDP per capita and energy efficient respectively. The errorterm,u_t, is assumed to satisfy the conditions of being independently and identically distributed with a zero mean and a constant variance. We calculate aggregate energy intensity as total final energy consumption divided by total GDP (GDP per capita times population). The long-run income equation is given by

$$\frac{\partial ENER}{\partial GDP} = \beta_1$$

Energy intensity is the indicator that allows not only comparing the overall energy efficiency performance between countries but also the analysing of the kind of convergence for under developing countries. The concept of convergence in matter of economy was inaugurated by Barro (R. J. Barro and Sala-I-Martin 1992). They make differentiation between β-convergence and σ-convergence. the neoclassical theory of economic growth postulates that national economics converge to the same level due to the diminishing returns to physical capital, finally GDP growth is assumed to be negative and related to the initial GDP per capita. This is called the ‘’catch up effect’’ caused by beta convergence. This type of convergence is called β-convergence and it was defined by Barro and Sala-I-Martin. The concept of σ-convergence was also originated from the neoclassical theory of the economic growth, resulted from the countries converge to the same economic level (expressed as GDP per capita, PPP). As condition, if the variance of the data set for sample countries of their economic level declines during a given period, then it is called σ-convergence among countries. Another force behind the convergence is technology spill over among countries. This type of convergence is called β-*convergence*

$$\frac{1}{T}\log\left(\frac{Y_{i,T}}{Y_{i,0}}\right) = \alpha + \beta \log Y_{i,0} + \lambda Z_t + \omega_t$$

The above equation is the average growth of GDP per capita as Purchasing Power per party P, Y_{it} and $Y_{o,t}$ *are initial and final GDP* during a period of time (*T* years);α is a constant and a linear combination of initial GDP per capita and $Z_t$is a set of endogenous factors, while $\omega_t$is an error term. Index *I* denotes countries and $\beta$and λ are regression coefficients. The β-convergence occurs if β< 0.The concept of σ-*convergence* came from the theory of neoclassical of the economic growth, involving the countries converge to the same economic level estimated by making reference to the GDP per capita, PPP. If the variance (dispersion) σ^2forgiven a set of countries to which their economic level declines during a given period, then there is σ-*convergence* among countries, and countries are heading towards some ‘steady and homogenous state’ in the future. The countries are sigma-convergent between time *t* and *t* + *k* if the following condition is fulfilled: $\sigma_t^{\,2} > \sigma_{t-K}^{\,2}$, the practical use σ-convergence is referred by the variation coefficient of GDP per capita(PPP) of a set of countries considerable time in a given time: $V = \frac{S}{\overline{X}}$ (Equation 4)Where $s = \sqrt{\sigma^2}$ is the standard deviation and $\overline{X}$ is the arithmetic mean of GDP per capita(PPP) of a set of countries or regions.

3.2. Econometric methodology

3.2.1 The unit root and co-integration test

The existence of a long-term relationship between the parameters is analysed with Equation (1). The vector error-correction model is used to capture the Granger causality between parameters. This is done by adopting a three-step procedure. First, it is necessary to check the order of integration of each variable, due to the fact that co-integration tests are only valid if the variables have the same order of integration (Fuller 1988). The three-unit root tests, namely Augmented Dickey-Fuller (ADF), the Phillips-Perron (PP) and ADF - Choi Z-stat, are used to investigate the stationary and the integration order of the variables (Fuller 1988) and (Phillips and Perron 1988). In terms of decision, tests designed on the basis of the null hypothesis that a series is *I* (1) have a low power compared with marginal error or confidence interval of rejecting the null. Hence, ADF tests are applied in order to obtain robust results (Smyth and Narayan 2015). Second, if all of the series of the same order are integrated, the Johansen maximum likelihood method is used to test the co-integration relationship between the variables in Equation (1) (Johansen and Juselius 1990) and (Johansen 1988). After getting co-integration between the parameters, OLS used to estimate Equation (1); the parameters obtained by using OLS estimator are termed super-consistent. The evidence of co integration confirms the long-run equilibrium relationships between the variables, and thereby, Granger causality exists between them in at least one direction (Engle et al. 1987).Finally, when all of the variables are co-integrated with the *I* (1), the error correction model (ECM) is used for correcting any disequilibrium in the co-integration relationship among parameters, captured by the error-correction term (ECT) in estimated results, as well as testing for long-run and short-run causality among the co-integrated variables. The ECM for Equation (1) is modelled as follows:

$$\Delta GDP_t = \gamma_{10} + \sum_{i=1}^{m_1} \gamma_{11t} \Delta GDP_{t-1} + \sum_{i=1}^{k_1} \gamma_{12t} \Delta ENER_{t-1} + \theta_1 ECT_{t-1} + \omega_{1t}$$

$$\Delta ENER_t = \gamma_{20} + \sum_{i=1}^{m_2} \gamma_{21t} \Delta ENER_{t-1} + \sum_{i=1}^{k_2} \gamma_{22t} \Delta GDP_{t-1} + \theta ECT_{t-1} + \omega_t$$

$$ECT_{t-1} = GDP_{t-1} - \beta_0 - \beta_1 ENER_{t-1}$$

is derived or obtained from the long-term co-integration relationship mentioned in Equation (1). The sign Δ is the first-difference operator; the optimum lag lengths m_i and k_i are determined on the basis of Akaike's information criteria (AIC); and ωit are the serially uncorrelated error terms. The parameter θ_1 is interpreted as being terms as the speed of the adjustment coefficient which measures the speed at which the values of GDP come back to long-term equilibrium levels, once ENER violates the long-run equilibrium relationship. The negative sign of the estimated speed of adjustment coefficient is in accord with the convergence toward long run equilibrium. The term ECM demonstrated by Equation (3) involves both the explained variables with their own lags and the previous disequilibrium in terms of ECT_{t-1}. This specification can used to test the short-run and long-run causality among co-integrated variables. In terms of short-run causality in Equation (3), the causality runs from energy consumption to the real GDP per capita if the joint null hypothesis, $\gamma_{12i} = 0$, ∀*I* is rejected via a Wald test, whereas the causality runs from real GDP to energy consumption if the joint null hypothesis $\gamma_{21i} = 0$, ∀*I* is rejected. With respect to long-run causality when the null hypothesis $\theta_1 = 0$ is rejected, energy consumption responds to deviations from the long-run disequilibrium. If the null hypothesis $\theta_2 = 0$ is rejected, then the GDP per capita responds to deviations from the long-run equilibrium. The strong Granger-causality runs from energy consumption to real output if the null hypothesis $\gamma_{21i} = \delta_2 = 0$, ∀*i*is rejected. Finally, the strong Granger-causality runs from the GDP to energy consumption if the null hypothesis $\gamma_{22t} = \theta_2 = 0$ ∀*I* is rejected.

4. Data Collection

Annual data on energy intensity and real GDP for the period between 1990 and 2021 were collected from the World Bank Development Indicators Database (WDI: 2021). The data collected do not include South Sudan because it started to exist during ten years ago while evaluating the long term equilibrium between parameters requires the long term period for each sample country. The real GDP per capita is measured in US dollars at 2005 constant price. Energy intensity refers to total primary energy supply (TPES) per thousand US dollars of GDP. The ratios are calculated by dividing each country's annual TPES by each country's annual GDP expressed in constant 2005 prices and converted to US dollars using purchasing power parities (PPPs) for the year 2005. TPES is expressed in tonnes of oil equivalent. Energy intensity is measured by the quantity of energy required per unit output or activity. In other words, Energy intensity is a measure of an economy's energy efficiency and shows how much energy is needed to produce a unit of gross domestic product (GDP). It is expressed in kilograms of oil equivalent per EUR 1 000 of GDP.

5. Results and Discussion

5.1 Numerical Results

5.1.1. Econometric results

The results of unit root test presented in table1 show the stationary results for both energy intensity per capita and GDP per capita through two different unit root tests, namely ADF Fisher Chi-square and ADF - Choi Z-stat. The lag lengths are selected using AIC and the two series appear to contain a unit root in their first difference and second difference at the 5% significance, but the levels statistics are not statistically significant except Rwanda. Thus, the study fails to reject the null hypothesis at 5% level.

Table 1. Fisher-ADF Unit Root Test

Countries	Method	Levels		First difference		Second difference	
		Statistic	Prob.**	Statistic	Prob.**	Statistic	Prob.**
Burundi	ADF - Fisher Chi-squ.	2.9013	0.5745	23.4444	0.0001	39.0277	0.0000
	ADF - Choi Z-stat	-0.05605	0.4777	-3.90941	0.0000	-5.43171	0.0000
Rwanda	ADF - Fisher Chi-sq.	10.5805	0.0317	24.2308	0.0001	50.2561	0.0000
	ADF - Choi Z-stat	-1.91057	0.028	-3.87181	0.0001	-6.34516	0.0000
Tanzania	ADF - Fisher Chi-squ.	4.70399	0.319	21.8038	0.0002	23.621	0.0001
	ADF - Choi Z-stat	-0.43084	0.3333	-3.70697	0.0001	-3.92481	0.0000
Uganda	ADF - Fisher Chi-squ.	1.35581	0.8518	25.4031	0.0000	27.2202	0.0000
	ADF - Choi Z-stat	1.33506	0.9091	-4.03863	0.0000	-4.29778	0.0000
Kenya	ADF - Fisher Chi-squ.	4.44158	0.3495	22.6733	0.0001	36.6508	0.0000
	ADF - Choi Z-stat	-0.29641	0.3835	-3.81374	0.0001	-5.09661	0.0000

** Probabilities for Fisher tests are computed using an asymptotic Chi-square distribution. All other tests assume asymptotic normality. H0: Presence of a unit root (individual unit root process) Maximum lag 2

Note: All unit roots have a null hypothesis in that the series has a unit root against the alternative of being stationary. The null of the unit root test is rejected at a 1% and 5% level. The lag lengths are selected using AIC.

The analysis of results based on co-integration test in table 2, 3 and 4are estimated by using the Johansen co-integration test; Pedroni Co-integration Test and Granger Causality Tests. The trace statistic and Eigen value tests reject the null hypothesis of no co-integration for Rwanda at 1% level of significance. They also show that the variables are co-integrated in Burundi and Uganda. The use of the Pedroni co-integration test shows that in Rwanda and Burundi intensity and GDP per capita are co-integrated. The co-integration result suggests causality, at least in one direction, but it does not indicate the direction of the causal relationship. In order to find the directional causality, the ECM causality test is performed. The short run analysis shows that energy intensity has an insignificant negative impact on GDP per capita. The FMOLS and the DOLS were used in order to investigate the nature of the long run. The results are reported in Appendix Tables 3 and 4 respectively. Both DOLS and FMOLS show that in the long run, energy intensity per capita has a negative and significant impact on GDP per capita (Table3). The full modified model shows that energy intensity is negatively associated with GDP per capita. The causality test (Table 3) indicates five significant outcomes, running from GDP per capita to intensity level of energy use.

Table 2. Johansen Co-integration Test

Rwanda	Trace Statistic	Hypothesized No. of CE(s)	Eigen value	Trace Statistic	0.05Critical Value	Prob.**
		None *	0.559477	22.95915	15.49471	0.0031
		At most 1	0.000176	0.004939	3.841466	0.943
	Max Eigen Value	Hypothesized No. of CE(s)	Eigen value	Statistic	0.05Critical Value	Prob.**
		None *	0.559477	22.95421	14.2646	0.0017
		At most 1	0.000176	0.004939	3.841466	0.943
Burundi	Trace Statistic	Hypothesized No. of CE(s)	Eigen value	Trace Statistic	0.05Critical Value	Prob.**
		None *	0.468476	27.39897	25.87211	0.0321
		At most 1	0.268593	9.07077	12.51798	0.176
	Max Eigen Value	Hypothesized No. of CE(s)	Eigen value	Statistic	0.05Critical Value	Prob.**
		None	0.468476	18.3282	19.38704	0.0707
		At most 1	0.268593	9.07077	12.51798	0.176
Tanzania	Trace Statistic	Hypothesized No. of CE(s)	Eigen value	Trace Statistic	0.05Critical Value	Prob.**
		None	0.182265	6.000803	15.49471	0.6955
		At most 1	0.013013	0.366744	3.841466	0.5448
	Max Eigen Value	Hypothesized No. of CE(s)	Eigen value	Statistic	0.05Critical Value	Prob.**

		None	0.182265	5.634059	14.2646	0.6605
		At most 1	0.013013	0.366744	3.841466	0.5448
Uganda	Trace Statistic	Hypothesized No. of CE(s)	Eigen value	Trace Statistic	0.05Critical Value	Prob.**
		None *	0.351724	15.95117	15.49471	0.0427
		At most 1	0.110061	3.381465	3.841466	0.0659
	Max Eigen Value	Hypothesized No. of CE(s)	Eigen value	Statistic	0.05Critical Value	Prob.**
		None	0.351724	12.56971	14.2646	0.091
		At most 1	0.110061	3.381465	3.841466	0.0659
Kenya	Trace Statistic	Hypothesized No. of CE(s)	Eigen value	Trace Statistic	0.05Critical Value	Prob.**
		None	0.259285	11.51724	25.87211	0.8441
		At most 1	0.105232	3.113328	12.51798	0.8628
	Max Eigen Value	Hypothesized No. of CE(s)	Eigen value	Statistic	0.05Critical Value	Prob.**
		None	0.259285	8.403911	19.38704	0.7839
		At most 1	0.105232	3.113328	12.51798	0.8628

Note: The optimal lag lengths are selected using AIC. * indicates the rejection of a null hypothesis at 5% level of significance
Max lag=2

Table 3. Pedroni Co-integration Test

COUNTRY	Dependent	tau-statistic	Prob.*	z-statistic	Prob.*
Burundi	ENERGY	-4.594068	0.0193	-45.09186	0
	GDP	-3.854854	0.0826	-27.18208	0.0067
Rwanda	ENERGY	-4.06708	0.0174	-61.4358	0
	GDP	0.074994	0.9909	0.146994	0.9906
Tanzania	ENERGY	-2.029503	0.5215	-7.930295	0.4492
	GDP	-1.752308	0.6565	-6.611596	0.5634
Uganda	ENERGY	-2.57458	0.2728	-5.37294	0.6771
	GDP	-1.51161	0.7597	-3.76993	0.8179
Kenya	ENERGY	-2.27572	0.4015	-8.47527	0.4057
	GDP	-1.17789	0.8649	-3.56342	0.8341

Data source: World Development Indicators

Table 4. Results of Causality Tests

Country	Null Hypothesis:	Obs	F-Statistic	Lag	Prob.	Decision
Burundi	GDP does not Granger Cause ENERGY	29	2.80445	2	0.0804**	Reject
	ENERGY does not Granger Cause GDP		0.31203	2	0.7349	Fail to Reject
Rwanda	GDP does not Granger Cause ENERGY	28	5.44122	3	0.0063*	Reject
	ENERGY does not Granger Cause GDP		0.58469	3	0.6317	Fail to Reject
Tanzania	GDP does not Granger Cause ENERGY	28	3.03315	2	0.0519**	Reject
	ENERGY does not Granger Cause GDP		1.16714	2	0.3458	Fail to Reject
Uganda	GDP does not Granger Cause ENERGY	30	2.52938	1	0.1234	Fail to Reject
	ENERGY does not Granger Cause GDP		6.39427	1	0.0176**	Reject
Kenya	GDP does not Granger Cause ENERGY	28	1.74959	1	0.1876	Fail to Reject
	ENERGY does not Granger Cause GDP		1.02493	1	0.4016	Fail to Reject

Note: The optimal lag lengths are selected using AIC. * and ** indicate a 1% and 5% level of significance, respectively.

5.2 Graphical Results

Figure1 shows the trend of each series for EAC, all of which have increased across time. In the most recent 20 years (2005-2021), all EAC countries have experienced growth in GDP per capita and a slight reduction in intensity of use (Figures 1and 2). Figure1and 2show the energy intensity is negatively related to GDP. In these tables, a high GDP per capita corresponds with a small intensity of energy use. The key indicator of energy efficiency is the energy intensity. So, the country is willing to reduce energy intensity by increasing energy efficiency. Rwanda has the lowest intensity and followed by Kenya; Uganda; Tanzania and Burundi successively (Figure2). This means that in these countries, energy intensity has decreased significantly since 2010 to acquire energy efficiency. The analysis of sigma convergence of all EAC countries is based on energy intensity which is calculated as the ratio of energy consumption to GDP, is a measure of energy efficiency of a nation's economy and a function of technological progress. For the evaluation of σ-convergence of countries of the EAC, the data from World Bank indicators were employed. The variation coefficient of GDP was evaluated for each year, and is shown in figure 1. As can be seen, with the only exception of Burundi country, the variation coefficient was non-decreasing during examined period, thus sigma divergence of EAC for GDP regions was somehow accelerating in time. The analysis made from figure two shows that the energy intensity yis not concerned beta converging for five countries. Additionally, there is no country to which might be considered as an outlier among five countries due to its spread (figure2). Even so, it is perhaps possible to discern a convergence. The spread in 1990 was from about 21 MJ/GDP (Uganda) to about 6 MJ/GDP (Rwanda); by 2020 the spread was from 12 MJ/GDP (Burundi) so technically that is a reduction from a spread of 15 to a spread of 11. All in all, what we are seeing here is that the energy intensity is coming down, that is very good for these economies. However, the energy intensity is not converging (or, more precising; only slightly converging). Beta convergence is generally considering whether the poor countries are catching up with the rich ones. Sigma convergence is whether the countries are in general converging. So, the figure 2 might be considered a sigma convergence question. Regardless, perhaps it is better to call it what it is, an analysis of the trend in energy intensity. From a beta-convergence perspective, we would hope to see that the country with the "worst" energy intensity, which perhaps we would consider to be Uganda because it started the period with the highest energy per GDP. This country did indeed have the fastest reduction in energy use per unit of GDP and it IS considered as an example of beta convergence. On the other hand, we have the case of Kenya, where according to the data the energy uses does not really drop; in the case of Kenya this cannot be considered a good development for its economy.

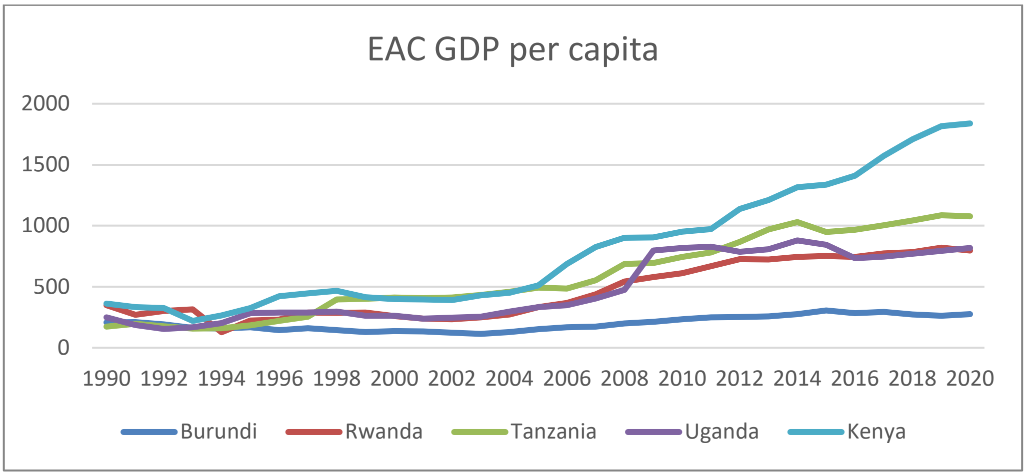

Figure 1. The evolution of variation coefficient, of GDP per capita (PPP) of EAC countries.

Data source: World Development Indicators

Figure1 shows the evolution of variation coefficient, of GDP per capita (PPP) of EAC countries.

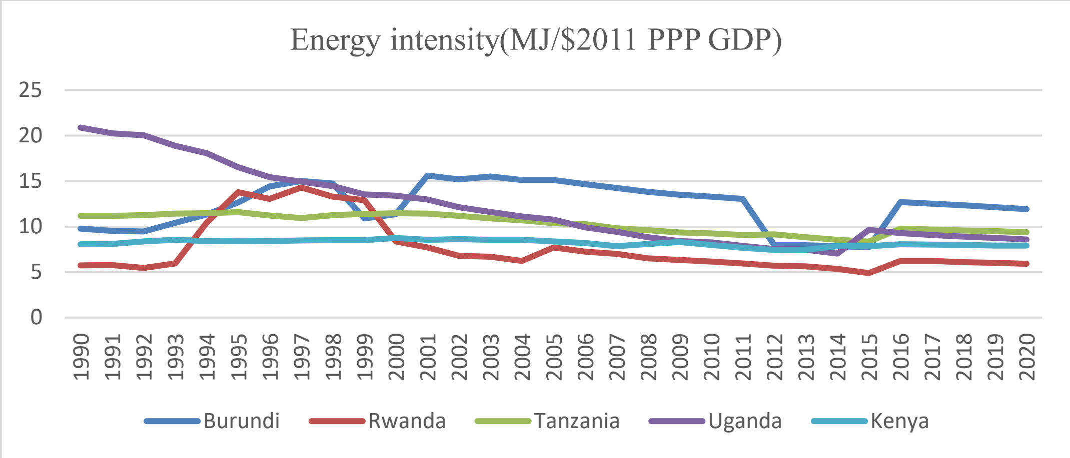

Figure 2. Energy Intensity Convergence

Data source: World Development Indicators
MJ/$ GDP2011 $1,000 GDP (constant 2005 PPP)

5.3 Proposed Improvements

This study shows that the way of poor countries or regions tend to grow faster than rich countries by adopting neoclassical growth model as a framework to study convergence over time in the levels of per capita income and product in EAC countries con not possibly achieved. It could be to adopt postclassical model incorporating technological advancement based on green energy consumption.

5.4 Validation

The analysis of long run equilibrium between parameters has usedco-integration tests for a long period and the decision based on the results did not contribute a lot for poor countries especially in Sub Saharan Africa Countries. It is better to validate the way of testing the data results.

6. Conclusion and Policy Implications

This study has investigated the long run causality between energy intensity per capita and GDP per capita in EAC during the period of 1990-2021. Fist, the main result of this study about convergence among EAC countries there is no beta convergence, meaning that these regions were not getting even richer during examined period and were continuing to lag behind developed countries. The study showed a decline of energy intensity. The reason behind the declines in these particular years is rather unclear, as 2012 was a year of economic crisis (GDP declined annually).Sigma convergence occurred among regions, and this trend was growing with time. Co-integration tests and the Granger causality test were used to examine the causal relationship between variables. The ADF Fisher Chi-square and ADF - Choi Z-stat were used to test for unit roots. The Johansen and Pedroni co-integration tests were applied to test long-run equilibrium relationship between variables. The Johansen co-integration test rejects the null hypothesis of no co-integration for Rwanda at 1% level of significance. It also shows that the variables are co-integrated in Burundi and Uganda. The use of the Pedroni co-integration test shows that for Rwanda and Burundi, intensity and GDP per capita are co-integrated. The results from Pedroni panel co-integration test indicates that there is a long-run relationship between energy intensity and GDP per capita in these countries. Similar results were obtained with the Johansen co-integration test and confirm the existence of long-run relationships between variables. The results of the Dynamic Least Squares (DOLS) and FMOLS reported in Appendix Tables 3 and 4. Table 3shows that in the long run, energy intensity per capita has a negative and significant impact on GDP per capita in the long run. Analysis of Granger causality indicates that in the short run, energy intensity is statistically insignificant with GDP per capita. However, a unidirectional relationship running from GDP per capita to energy intensity was observed in Rwanda, Burundi, Uganda and Tanzania.These results suggest that EAC countries could consider strategies to increase energy efficient in order to reduce unnecessary energy use and support enhanced economic growth.

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