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RESEARCH ARTICLE

Urbanization and transport energy consumption in African countries

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Abstract
Transport energy use contributes to pollution, so it generates negative externalities. This paper analyzes the effect of urbanization on the transport final energy consumption in African countries. To that end, the paper applies the panel threshold regression (PTR) model for a panel of 25 African countries over the period 1992–2017. The findings show that there is a significant positive relationship between total and per capita transport energy consumption and the share of the urban population in the total population. Thus, urbanization fosters transport energy consumption, either per capita energy consumption or total energy consumption. Therefore, the results from this study suggest that African countries should promote sustainable urbanization in terms of transportation.

Keywords Transport · Environmental Kuznets curve · Energy · Urbanization · Externality · Africa

Introduction

Urbanization can result in the surge in road transportation, leading to the increase in transport energy consumption (Wang et al. 2019). The process of structural transformation leads to the transfer of labor from the agricultural sector to the industrial sector, so it results in the increase in the share of urban population. Consequently, this may affect road transport energy consumption in such a way that the rise in the size of the urban population upsurges public and private vehicle and motor ownership, leading to the demand for transportation. Actually, energy is viewed as of paramount importance for the development of trade (both domestic and international trade) and economic growth (Pablo-Romero et al. 2017; Ahmed et al. 2016). Despite its importance for modern economic growth paradigm, energy use releases greenhouse gases (GHGs) in the atmosphere and therefore contributes to climate change which is an urgent issue the world has to tackle (Pablo-Romero et al. 2017; Ahmed et al. 2016). In the total energy mix to produce major goods and services worldwide, fossil fuels account for about 80% (Ahmed et al. 2016). It should be noted that, for instance, in the European Union (EU), transport is the sector with the fastest-growing energy consumption and GHG emissions, despite the advances in transport technologies (Pablo-Romero et al. 2017). So, the situation could be the same or even worse in developing countries in general and African countries in particular as these countries do not have the same level of transport technologies relative to European countries.

One of the main challenges is to reduce energy use, decouple GHG emissions from economic growth, and improve energy efficiency (Pablo-Romero et al. 2017). Actually, at the international level, there is an advocacy to limit climate change that is mostly caused by anthropogenic GHGs. According to Bildirici (2013), environmental sustainability constitutes a global concern in the strategy to reduce the negative consequence of economic growth. Indeed, in 2015, at the 21st Conference of the Parties (COP21) of the United Nations Framework Convention on Climate Change (UNFCCC)—the Paris climate conference—195 governments worldwide agree to set out an action plan to avoid climate change by limiting global warming to well below 2 ℃ (Burleson 2016). So, this involves among others to think about a sustainable urbanization plan including regarding the

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transport sector. It is worth to put emphasis on the fact that when it comes to climate change, all countries have common responsibilities, though these responsibilities are differentiated depending on the specific prosperity of the countries as contributing differently to the emissions of GHGs (Pablo-Romero and Sanchez-Braza 2017). In addition, the countries have to communicate their Intended Nationally Determined Contributions (INDCs) outlining the climate actions they intend to take and the targets they should reach under the new international agreement. Moreover, all countries are required, under the agreement, to review the INDCs every five years, being encouraged to gradually raise their targets (UNFCCC 2015).

The literature points out that the effect of urbanization on energy consumption across sectors (e.g., residential, industrial, transport, commercial, and public service sectors) is still unclear (e.g., Ali 2021; Wang et al. 2020; Pablo-Romero et al. 2017). So, this suggests the role of the specific context in the direction of this effect; the effect may be positive or negative, nonlinear, etc. To contribute to this debate, the objective of this paper is to analyze the effect of urbanization on the transport final energy consumption in African countries. Specifically, this paper aims to (i) analyze the effect of urbanization on total transport energy consumption in African countries and (ii) analyze the effect of urbanization on per capita transport energy consumption in African countries. Note that Africa is experiencing a relatively good economic growth. For instance, according to the African Development Bank (AfDB), between 2004 and 2013, Africa has witnessed a decadal average of 5% of economic growth, before Africa's growth has slowed down to around 3% since 2014 (AfDB 2020). However, the African continent is not homogenous in terms of economic growth; there is significant variation in growth between regions and countries (AfDB 2020); thus, the economic context differs between countries and regions in Africa. Though there are a few papers that investigate the effect of urbanization on energy consumption in Sub-Saharan Africa (e.g., Ali 2021), this paper focuses on transport energy consumption which is even less studied to the best of our knowledge. Moreover, the scope of this study is broadened to the African continent. The findings of this study can be useful to build a sustainable transportation in Africa.

The remainder of the paper is structured as follows. The "Transport sector in Africa" section presents the features of transport sector in African countries. The methodological approach used is presented in the "Material and methods" section. The "Results and discussion" section presents the empirical results and their discussion, and the "Conclusion and policy implications" section concludes the paper along with policy implications.

Transport sector in Africa

The development of all sectors of the economy is important to achieve a sustainable economic growth and poverty reduction in order to meet the needs of the current generation without compromising the long-run needs of the future generations (UNECA 2009). In addition, development in other sectors of the economy is linked and influenced by the transport sector (UNECA 2009). Therefore, adequate transport infrastructure is of paramount importance to achieve sustainable development and socioeconomic growth in Africa (IDEV 2014; UNECA 2009). The Independent Development Evaluation of the African Development Bank (IDEV 2014) argues that in terms of quality and quantity, the level of transport infrastructure provision in Africa is not adequate and there are disparities across regions and countries. Actually, the regional energy systems are underdeveloped and are not able to meet the populations' demand (Ouedraogo 2017). Ouedraogo (2017) points out that access to modern energy services remains limited in spite of the fact that energy resources are more than sufficient to meet domestic needs. In fact, the continent has great potential in terms of endowments in energy resources. Note that African countries have been experiencing economic growth since 2000, and this yielded a rise in energy consumption of 45% (IEA 2014).

In Africa, road transport constitutes the most dominant mode of motorized transport. It accounts for 80% of the goods traffic and 90% of the passenger traffic (UNECA 2009). Nevertheless, African countries are characterized by low densities of adequate roads. For instance, in 1997, African countries (excluding the Republic of South Africa (RSA)) had overall 171,000 km of paved roads, which is less than that of Poland. The situation evolves over years, although it still has to be improved. In 2001, African countries have overall around 2.06 million km of roads, which constitutes a road density of 6.84 km per 100 km^2 (UNECA 2009). Moreover, the average road-to-population ratio in Africa amounts to 26 km per 10,000 inhabitants, and there are huge disparities across regions and countries. Actually, Central Africa and Southern Africa have the highest road distribution, with 49.5 km and 56.3 km, respectively, for every 10,000 population. In 2005, African countries have overall 580,066 km of paved roads (about 22.7% of the total road network).

The state of other mode of transportation is similar to that of road transport. In 1997, overall, African countries have an average rail density of 2.7 km per 1000 km^2, compared to 400 km per 1000 km^2 for Europe. In 2005, the African continent had a total railway network of 90,320 km corresponding to 3.1 km per 1000 km^2, most of which is disjointed (UNECA 2009). However, there are disparities across regions; railway traffic is generally high in North Africa than in SSA. One percent of the global railway passenger traffic and 2% of goods are carried out by the railways, and maritime transport constitutes the most dominant mode of transport for moving freight from and to Africa, accounting for over 92% of the continent's external trade (UNECA 2009). Note that many countries in the continent are endowed with a number of rivers and lakes which have abundant potential of being inexpensive, energy-efficient, and environment-friendly inland waterways. Nonetheless, only a small number of them have been well developed for transportation (UNECA 2009).

The inadequate level of transport infrastructure in Africa leads to low levels of socioeconomic growth and has adversely impacted efforts to foster regional integration and ensure social inclusiveness (IDEV 2014). This situation in terms of transport infrastructure is due to the fact that before 2003, most SSA countries lack a transport policy (Mwase 2003). Indeed, such transport policy should include transport investment decisions, ownership patterns, and policy tools and instruments such as taxes, subsidies, rules, and regulations. Subsequent to the period of lack of a transport policy in SSA countries, such policy started to be developed through sector-wide approaches (SWAPs) consistent with holistic comprehensive development frameworks (CDFs) and poverty reduction strategy, and its implementation is through decentralized local governments (Mwase 2003). The aim of transport policy is to facilitate the development of transport infrastructure, coordinated and complementary transport systems, and links to further physical cohesion and market integration (UNECA 2009; Mwase 2003).

It should be emphasized that the African continent has witnessed progress in transport infrastructure development such as increase in the stock of paved road networks, stronger political will to foster regional integration, and increasing investments in the air transport and railways sub-sectors (IDEV 2014; UNECA 2009). Nevertheless, new development challenges emerge in the transport sector—including rapid urbanization, regional integration, social inclusiveness, fiscal space for sustainable funding, and resilience to climate change—as progress is achieved (IDEV 2014). The IDEV (2014) identified eight main challenges for the transport sector in Africa which are (i) accumulation of road maintenance backlogs, (ii) lack of stable and established construction industries and rising construction costs, (iii) lack of regulation (economic and technical) and coordination of private operators, (iv) lack of an overall strategy to guide the implementation of rural transport initiatives, (v) insufficient attention paid to the issue of urban transport (up until the last five years before 2014), (vi) need for improved connections to international markets, (vii) poor enabling environments for private sector concessions (roads, railways, ports, and airlines), and (viii) insufficient emphasis placed on important cross-cutting issues such as road safety. Consequently, it is necessary to adjust transport sector policy development in African countries by accounting for these challenges.

Material and methods

Model specification

This research makes use of the panel threshold regression (PTR) model (Hansen 1999; Wang 2015) to investigate the relationship between urbanization and transport energy consumption in Africa. The choice of this model is justified by the fact that the nonlinear relationship between economic development (in this study approximated by gross domestic product per capita) and transport energy consumption should be taken into account. This is important to be consistent with the environmental Kuznets curve (EKC) literature (Lokonon and Mounirou 2019; Grossman and Krueger 1991, 1995; Chowdhury and Moran 2012). Actually, the PTR model accounts for this nonlinear relationship. The simplest case of PTR with a single threshold (two regimes) can be specified as follows:

$$\begin{aligned}\text{logEnergy}_{it} = \alpha_i + \rho\text{logUrbanization}_{it} + \beta_1\text{logGDP}_{it}I\left(\text{GDP}_{it} \leq \gamma_1\right) \\ +\beta_2\text{logGDP}_{it}I\left(\text{GDP}_{it} > \gamma_1\right) + \delta' X_{it} + \epsilon_{it}\end{aligned} \quad (1)$$

where the dependent variable (logEnergy) is the logarithm of either total transport energy use or transport energy use per capita depending on the equation (as the paper is interested in these two indicators), logUrbanization refers to the logarithm of urbanization, logGDP_{it} denotes the logarithm of GDP per capita capturing economic development, γ_1 refers to a threshold parameter, GDP_{it} is the corresponding GDP per capita (constant 2010 US$), X_{it} is the vector of control variables beside GDP per capita which includes the logarithm of the share of agricultural employment in the total national employment in percentage and international oil price, and ϵ_{it} is the error term. The share of agricultural employment in the total national employment captures the different economic structures of each country, and this can affect the transport energy consumption (Pablo-Romero et al. 2017). Consumption of a given good is assumed to depend on its price, and this justifies the inclusion on the international oil price (Pablo-Romero et al. 2017; Rodriguez et al. 2016). In Eq. (1), the observations are divided into two regimes depending on whether the threshold variable GDP_{it} is smaller or larger than the threshold parameter γ_1. It should be noted that the threshold is endogenously determined by the model. The different regression slopes, β_1 and β_2, distinguish the two regimes, namely, the low regime and the high regime, respectively.

The econometric analyses involve several steps. The first step consists of testing the null hypothesis of linearity, that means testing $H_0 : \beta_1 = \beta_2$, against the alternative hypothesis of the threshold model in Eq. (1). If the null hypothesis is rejected, which means that the first threshold effect is proved, the same procedure can be applied to the general model to determine the number of thresholds necessary to capture the whole nonlinearity inherent to this relationship (between transport energy use and economic development captured by the per capita GDP). In this framework, the null hypothesis is to test a specification with r regimes against a specification with $r + 1$ regimes, and the procedure stops in the case the null hypothesis is not rejected.

Data and summary statistics

The data used in this paper are from several sources. GDP per capita, the share of agricultural employment in the total national employment, and urbanization are from the World Development Indicators (WDIs) of the World Bank. Energy data are from the International Energy Agency (IEA). The international oil prices are Brent crude oil price per barrel. The sample includes data from 25 African countries over the period 1992–2017 due to data availability. The countries include Algeria, Angola, Benin, Botswana, Cameroon, Republic of Congo, Cote d'Ivoire, Egypt, Ethiopia, Gabon, Ghana, Kenya, Mauritius, Morocco, Mozambique, Namibia, Nigeria, Senegal, South Africa, Sudan, Tanzania, Togo, Tunisia, Zambia, and Zimbabwe. The summary statistics of the variables are presented in Table 1. These statistics indicate that on average, total and per capita transport energy use amounts to 2528.872 thousand tons of oil equivalent and 101.668 kg of oil equivalent, respectively, with large disparities between the countries as pointed out by the standard deviations and the minimum and maximum values. These statistics show that on average 44.527% of the population live in urban settings, but the countries differ in terms of urbanization. The GDP per capita over the study period is US$ 2634.967, the poorest country of the sample in a certain year having an average GDP of US$ 164.337, while the richest country has an average of US$ 11,937.640. It appears that the agricultural sector plays an important role in terms of employment in Africa. Indeed, agriculture occupies 44.051% of active population in the African countries, with huge disparities across countries, the minimum being 4.600% and the maximum is 84.744%. The average international oil price over the study period is US$ 49.863.

Results and discussion

Results

As aforementioned, the null hypothesis of linearity is tested against the alternative hypothesis of the nonlinear model (threshold model). The results of the nonlinearity tests and the estimated threshold estimates for each of the two dependent variables as well as their corresponding 95% confidence interval are reported in Table 2. These results suggest that the test for a single threshold is significant at the 10% level of significance, whereas the test for a second threshold is not statistically significant irrespective of the dependent variable. Consequently, there is evidence of a single threshold in the relationship between transport energy and GDP per capita, with respect to the latter at the 10% level of significance. The thresholds (determined by the model) range between US$ 896.153 and US$ 904.237 and US$ 896.067

Table 2 Tests for nonlinearity and threshold estimates

	Total energy	Energy per capita
Test for single threshold		
First threshold (γ_1)	903.774	903.774
Confidence interval (95%)	[896.153, 904.237]	[896.067, 904.237]
F-stat	60.440	55.210
P value	0.070	0.0533
Test for double thresholds		
Second threshold (γ_2)	1539.316	1542.685
Confidence interval (95%)	[1525.563, 1542.685]	[1471.504, 1573.816]
F-stat	5.810	11.350
P value	0.940	0.687

Table 1 Summary statistics of the variables

Variables	Description	Mean	Std. Dev	Min	Max
Total energy	Total transport energy use in 1000 tons of oil equivalent (ktoe)	2528.872	4204.587	39.000	19,451.000
Energy per capita	Transport energy use per capita in kilograms of oil equivalent (kgoe)	101.668	92.818	4.667	392.016
Urbanization	Share of urban population in total population in %	44.527	15.283	13.116	88.976
GDP	GDP per capita in constant 2010 US$	2634.967	2477.777	164.337	11,937.640
Agricultural employment	Share in the total national employment in %	44.051	19.810	4.600	84.744
International oil price	Brent crude oil price in US$ per barrel	49.863	33.011	12.758	111.779

and US$ 904.237 for total transport energy use and transport energy use per capita, respectively. The threshold is US$ 903.774 either for total transport energy and per capita transport energy. This shows that the relation between transport energy consumption and economic growth is nonlinear in African countries, and not accounting this nonlinearity will bias the estimation results. Therefore, a single threshold model is used for the analyses, which corresponds to a model with two regimes rather than using a linear specification. Therefore, the effect of economic development should depend on the regime; that means below and above US$ 903.774 as GDP per capita.

The PTR estimation results are presented in Table 3. Urbanization has a positive and significant effect on both total and per capita transport energy use. Indeed, an increase of 1% in urbanization (the share of urban population in the total population) leads to 2.039% and 1.015% increase in total and per capita transport energy use, respectively. The findings highlight a differentiated relationship between transport energy and economic development based on the level of the latter. In model (1), when GDP per capita is less than US$ 903.774 (regime 1), there is a significant positive relationship between total transport energy and GDP per capita, and when GDP per capita exceeds this threshold, the positive effect of GDP per capita on total transport energy turns larger (regime 2). Similar result is found for transport energy per capita. The results suggest that economic development leads to more energy use for transportation, either per capita energy use or the total energy use, but this positive relationship is nonlinear. Actually, for the level of economic development lower than or equal to a given threshold (less than or equal to US$ 903.774), all other things being equal, an increase of 1% in GDP per capita increases the total transport energy and per capita transport energy by 0.588% and 0.489%, respectively. In addition, for the level of economic development higher than a given threshold (higher than US$ 903.774), all other things being equal, an increase of 1% in per capita GDP leads to an increase of the total and per capita transport energy of 0.659% and 0.550%, respectively. Therefore, the income elasticities of transport energy consumption turn out a bit larger beyond the threshold of US$ 903.774 of GDP per capita, although the elasticities are less than the unity. Transport energy is thus a normal good in African countries. The elasticity of international oil price is positive and significant in the two models, indicating that price rises increase total transport energy use and per capita transport energy use. Actually, the findings suggest that an increase of 1% in the international oil price leads to an increase of 0.143% and 0.066% in total and per capita transport energy use, respectively. Thus, transport energy use increases with international oil price, all other things being equal, but less proportionally.

Table 3 PTR estimation results

Variables	Total energy (model 1)	Energy per capita (model 2)
GDP per capita threshold (γ_1)	903.774	903.774
Log urbanization	2.039***	1.015***
	(0.189)	(0.170)
Control variables		
Log GDP per capita coefficients		
Regime 1 ($GDP_{it} \leq \gamma_1$)	0.588***	0.489***
	(0.087)	(0.078)
Regime 2 ($GDP_{it} > \gamma_1$)	0.659***	0.550***
	(0.085)	(0.077)
Log agricultural employment	−0.107	−0.077
	(0.088)	(0.080)
Log international oil price	0.143***	0.066***
	(0.024)	(0.022)
Constant	−5.732***	−3.587***
	(0.833)	(0.750)
F-stat	291.380	140.690
Prob > F	0.000	0.000
Observations	650	650

Standard errors in parentheses

***$P < 0.01$

**$P < 0.05$

*$P < 0.1$

Discussion

The positive elasticities of transport energy consumption with respect to urbanization are greater than the unity, suggesting that the increase in urbanization is associated with more and more transport energy use. Therefore, the rise in the size of the urban population leads even to the increase in the per capita transport energy consumption. As a result, this may increase the GHG emissions. These findings are in line with those of Wang et al. (2019), which reveal a significant positive contribution of urbanization to road sector energy consumption in Pakistan. In fact, in urban settings, people tend to have either their own motorcycles or vehicles, so this increases fuel consumption for transportation. Therefore, without a sustainable urban planning in terms of transportation, more urbanization will lead to more emissions of GHGs via more energy use for transportation, ceteris paribus.

These findings also show that in the African continent, transport energy (total and per capita) is still increasing with economic development, despite the presence of nonlinearity between these indicators. Thus, these findings do not support the validity of the transport energy-EKC hypothesis for the

African countries included in the analyses over the period of study regarding transport energy consumption. Therefore, African countries did not reach yet the turning point to make economic development improving with better environmental quality in the transport sector. The results of this paper are in some extent consistent with those of Zilio and Recalde (2011) and Pablo-Romero et al. (2017) that find the non-validity of the EKC hypothesis for energy consumption in Latin America and the Caribbean and transport energy in the EU, respectively. Actually, the EKC hypothesis posits a U-shaped relationship between per capita GDP and pollution (Grossman and Krueger 1991, 1995) and this kind of relationship is not found in the case of this study for the African countries. In the spirit of the EKC hypothesis, emissions of pollutants arising from economic activities such as the production of electricity and the operation of motor vehicles increase with economic activities, and business and households can control pollution level to some extent through the types of technologies used (cleaner technologies producing less pollution per unit of output) as a society becomes richer (Grossman and Krueger 1991). Therefore, this is not yet the case in Africa, where generally sustainable public transportation is not yet well developed. It should be noted that the results of international oil price is not in line with those of Pablo-Romero et al. (2017) that find the existence of a negative effect of price on transport energy use.

Conclusion and policy implications

This paper analyzed the effect of urbanization on the transport final energy consumption in African countries. For this purpose, a PTR model is used on data covering the period 1992–2017. The findings suggest that there is a significant positive relationship between total and per capita transport energy and urbanization. So, urbanization fosters transport energy consumption, either per capita energy consumption or total energy consumption. Moreover, there is a significant positive relationship between total and per capita transport energy and GDP per capita, and when GDP per capita exceeds a given threshold (US$ 903.774), the positive effect of GDP per capita on total and per capita transport energy turns larger. Thus, transport energy use in the African continent is still positively associated with per capita GDP (economic development). This situation needs to be reversed to slow down the emissions of GHGs from the transport sector. The international oil price has a positive and significant effect on both total and per capita transport energy use.

The findings from this study suggest that African countries should promote the use of the cleaner technologies that produce less pollution per unit of output in the transport sector. Moreover, sustainable urbanization should be promoted in terms of transportation. Actually, the development of public transport may have the potential to lower per capita transport energy use. It should be noted that a limitation of this research is the fact that the data used do not allow to distinguish between productive transport energy use and other transport energy use. Further paths of research could include the analysis of the validity of the EKC hypothesis for transport energy use by disaggregating transport energy between productive and other transport energy use.

Author contribution BOKL and HS contributed to the study conception and design. Material preparation, data collection, and analysis were performed by BOKL and HS. BOKL and HS participated in the write-up of the first draft of the manuscript, and both of them have commented on previous versions of the manuscript. BOKL and HS read and approved the final manuscript.

Data availability The data are available upon request.

Declarations

Ethical approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

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