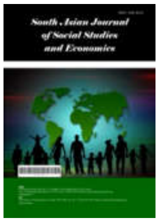

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Do Energy Poverty and Energy Consumption Drive CO_2 Emissions? Evidence from Sub-Saharan Africa

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Energy poverty is a multidimensional concept, but in the developing country context, it could refer to the lack or difficulty of people to access modern and reliable energy services. It refers particularly to access to electricity and to modern and clean cooking fuels. This limited access constitutes a serious hindrance to socioeconomic development and has adverse consequences on environment. The present study attempts to investigation the contribution of energy poverty and consumption to CO2 emissions in 20 Sub-Saharan Africa countries over 1996-2015. Using Feasible Generalized Least Squares (FGLS) and Panel-corrected standard errors (PCSE), our results broadly suggest non-significant effect of energy poverty on CO2 emissions. However, we found evidence that primary energy consumption drives CO2 emissions. To mitigate the adverse effects of energy consumption on environment, governments should design and implement policies to improve energy efficiency and promote renewable energies use.

Keywords: Energy poverty; energy consumption; CO_2 emissions; Sub-Saharan Africa.

1. INTRODUCTION

Energy is widely recognized as an essential factor for socio-economic development due to several reasons. Existing literature on the socio-economic effects of energy access for instance highlights some gains in many aspects and three types of impacts stand out: i) improved incomes

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due to the increase in non-agricultural activities, particularly on a small scale (development of artisanal production activities such as sewing, welding, hairdressing) and modern agricultural activities [1,2,3], which can generate relatively more inclusive growth, particularly if such activities reach a significant size; ii) improved access to education due to increased study time and lesson revision, and the possibility of using new information and communication technologies [4,5]; and iii) a decrease in respiratory diseases due to the increased use of relatively less aggressive fuels [6], which in turn would mitigate negative environmental effects.

However, the question of the sustainability of current production and consumption practices remains at the worldwide, especially in Sub-Saharan Africa (SSA). These practices may not be sustainable in the long term because they are largely based on non-renewable energies and/or on the traditional use of renewable energies, particularly biomass. In fact, on the one hand, the intensive exploitation of non-renewable resources is challenging in terms of availability in future. On the other hand, these non-renewable energy resources generate significant negative externalities (air pollution, deforestation) which are harmful for environment.

Furthermore, despite an energy mix dominated by traditional biomass and fossil fuels, SSA has so far made a limited contribution to climate change due to its relatively low level of industrial development compared to other regions of the world. Nevertheless, SSA is among the regions that may pay the highest price, given the key role that agriculture plays in the economies of most countries in the region. Despite the gradual decline in the contribution of agriculture to the GDP of SSA countries in general, the sector remains the largest provider of employment [7]. In addition, its level of economic development may make it less resilient to climate change. At the same time, the region should ensure an energy supply to meet the needs of one of the most rapidly growing populations in the world and of expanding industries. Therefore, balancing socioeconomic development through energy security with environmental protection would be more useful.

Several studies [8,9,10] highlight the fact that limited access of populations to modern energy (electricity, modern cooking fuels) is harmful to the environment through deforestation and air pollution due to the use of traditional biomass as the main energy source. Despite natural resource endowments that are an essential element in addressing energy issues, SSA is energy poor by international standards. In addition to the lowest consumption levels in the world, the region has the lowest access rates. Countries as Central African Republic and South Sudan, for example, had electricity access rates of less than 5% in 2019 [11]. And even if access is effective, people are confronted with reliability and affordability issues. The permanent power outages that are common in the countries of the region reflect the unreliability of the electricity networks according to [12]; and end-user energy charges are generally above the world-wide average in most African countries [7]. In addition, while the primary energy consumption levels in SSA are the lowest in the world (see Table 1 in appendix), they are largely dominated by non-renewable fuels. Do energy poverty and energy consumption in SSA countries explain the level of greenhouse gas emissions in these countries? This study proposes to examine this question using a sample of 20 SSA countries over the period 1995-2015. In others words, this study aims to assess the impact of lack of access to modern energy (electricity and cooking fuel) and primary energy consumption on CO_2 emissions in SSA. In addition to the issue of resource depletion, the relationship between energy access, energy consumption and environment degradation is usually looked at in terms of externalities. Energy sector is one of the main sectors that contribute to environmental damage. According to the [13], for example, it produced about 35% of direct greenhouse gas emissions. And despite international agreements on the environment and climate change, its contribution to these emissions continues to grow. This increase is due to population growth and urbanization on the one hand, and the expansion of the industrial sector on the other [14]. In SSA, for example, CO_2 emissions rose from 501 Mt in 1995 to 853 Mt in 2016, an increase of about 70% (WDI, 2020).

The rest of the study is structured as follows: the second section highlights the stylized facts, the third section provides a literature review, the fourth section is focused on the presentation of statistical and econometric tools, the fifth section presents the main results of our empirical analyses, and finally the last section concludes and gives some policy implications.

2. ENERGY CONSUMPTION AND ENVIRONMENT IN SSA: SOME STYLIZED FACTS

There is no consensus in the literature on the definition of energy poverty. Like poverty, energy poverty is a multidimensional concept. However, in the theoretical perspective, many scholars define energy poverty as the state of deprivation in which a household, or even an economic agent, is barely able to meet minimum energy needs [15,16,17]. However, in practice, there is no consensus on what is considered the minimum level below which a household can be classified as energy poor [18,19,20]. there is currently no universally accepted measure of energy poverty [21]. It can take different forms, including lack of access to modern energy services, unreliability where services exist, and concerns about the affordability of access.

In the 2010 World Energy Outlook, Organization for Economic Cooperation and Development (OECD) and International Energy Agency (IEA) [15] measure energy poverty at the household level using two criteria. These are lack of access to electricity and clean energy for cooking and the indicators of energy poverty are percentage of population without access to electricity on the one hand, and clean cooking fuels as Liquefied Petroleum Gas (LPG) and to some extent kerosene on the other hand. Thus, we will define energy poverty in this study using this approach.

2.1 Low Improvement in Modern Energy Access in SSA

According to access to electricity and clean fuel for cooking, SSA performs generally among the worst in the world. In fact, the region has in recent years recorded the highest proportion of the population without access to electricity in the world, as Table 2 in appendix shows. In 2018, for instance, the percentage of people without access to electricity in SSA was 55% compared to 6%, 7%, 3% in developing countries in Asia, the Middle East, Latin and Central America, respectively. However, many efforts have been made to bring the people of the SSA region out of the obscurity into which they are plunged with a particular attention to rural areas. These efforts are reflected in increased electrification rates in both urban and rural areas. The region's electrification rate has increased from 23% in 2000 to 45% in 2018, with about 150 million and 490 million people respectively having access to electricity (i.e. 340 million additional people had access between 2000-2018). In urban areas, for example, this rate has increased by 17 points of percentage in 2018 compared to 2008. In rural areas, it increased from only 12% in 2008 to 26% in 2018, an increase of 14 points of percentage.

In terms of access to modern cooking fuels, SSA also has the highest proportions of the population relying mainly on traditional biomass or charcoal for cooking needs (Table 3 in appendix). However, like the percentage of people without access to electricity, the percentage of people without access to clean cooking fuels has progressively decreased between 2000 and 2018, it fell from 90% to 83%.

2.2 SSA Contribution to Worldwide CO_2 Emissions

Overall, Africa has so far made a limited contribution to climate change, although the energy mix in most SSA countries is largely dominated by solid biofuels, waste and fossil fuels. For example, in 2018, Africa had about 17% of the world's population and contributed only about 4% of the world's CO_2 emissions in energy sector (about 1215 Mt CO_2), with power sector emission accounted for 480 Mt CO_2, followed by transport with 355 Mt CO_2 and industry (150 Mt CO_2) according to [21].

Total CO_2 emissions from energy sector in sub-Saharan African countries accounted for about 60% of CO_2 emissions in Africa, about 725 Mt CO_2 in 2018. With its power plant fired by coal, South African energy sector emitted about 420 Mt CO_2 equivalent to over 67.5% of total emissions in the region. Fig. 1 in appendix depicts the evolution of total CO_2 emissions in SSA over 1995-2016 and shows an increase trend.

Despite the fact that the energy sector in SSA contributes marginally to world emissions of CO_2, the region is among the most exposed to the effects of climate change due to many reasons including its heavy reliance on small-scale rainfed agriculture on the one hand and deep poverty, which leaves it with little capacity to successfully adapt to climate change on the other hand.

Furthermore, Fig. 2 (see appendix) shows a positive relationship between the share of population without access to electricity as well as clean cooking fuels and the variation of emissions of CO2 (in relative term).

3. LITERATURE REVIEW

3.1 Theoretical Framework

In economic perspective, the relationship between energy and environmental degradation is usually examined in terms of externalities. Indeed, the energy sector is one of the main sectors that is responsible for the damage done to the environment. As we mentioned earlier, in 2014 for example, energy sector produced about 35% of direct greenhouse gas emissions [13]. And despite international agreements on the environment and climate change, its contribution to these emissions continues to grow. This increase is due to population growth and urbanization on the one hand, and the expansion of the industrial sector on the other [14].

The concept of external effects or externalities is the reference economic concept from which environmental economics has developed. The disadvantages generated by environmental degradation in general (pollution, climate change) can be interpreted in terms of externalities. Economic theory assimilates the resulting loss of well-being to a loss of utility for economic agents. Therefore, when such losses are not taken into account by market regulation mechanisms, the problem of " management of natural capital" is raised. This is a situation of market failure. In his book "The Economics of Welfare", [22] defines externality as follows: the essence of the matter is that one person A, in the course of providing a service, for which payment is made, to a second person B, also brings benefits or disadvantages to other persons in such a way that a payment cannot be imposed on those who benefit nor compensation enforced for the benefit of those who suffer. The external effect can thus be positive (external economy) or negative (external diseconomy). Negative externalities represent the phenomenon of pollution generated from production to consumption of energy.

3.2 Empirical Evidences

The close link between energy and environmental issues, for example through greenhouse gas emissions and deforestation, is widely recognized. Empirical analyses that examine this relationship abound in the literature. Empirical work examining the energy-environment relationship includes economic growth. The idea is that, if economic growth is considered to be closely related to energy consumption, then higher rates of economic growth require higher energy consumption. This may lead to more pollution. However, these studies have mostly focused on investigating the causality and cointegration relationship between energy consumption (primary, electricity, etc.) and greenhouse gas emissions, especially CO_2. The results of these studies are relatively more consistent [23] examine the dynamic causal effects between pollutant emissions, energy consumption and production for a panel of BRIC countries over the period 1971-2005, excluding Russia (1990-2005). The results of this study establish a bidirectional causality between energy consumption and CO_2 emissions in the Granger sense. Using the same method of analysis (Granger causality), [24] assesses the causality between energy consumption, GDP growth and carbon emissions this time in eight Asia-Pacific countries from 1971 to 2005 using panel data. The results suggest a long-run equilibrium relationships between these variables. Furthermore, causality between energy consumption and CO_2 emissions was generally observed. In a study conducted in 30 SSA countries over the period 1980-2000, [25] reach the conclusion that energy consumption causes growth with negative environmental consequences in terms of CO_2 emissions in the Granger sense. [26] investigates the link between CO_2 emissions, energy consumption and economic growth with panel data from 14 Middle Eastern and North African countries from 1990 to 2011. The results using the generalized method of moments also establish a causal relationship from energy consumption to CO_2 emissions but without feedback effects. In contrast, using the same analytical technique, the work of [27] provides empirical evidence of a positive impact of energy consumption on economic growth. But with the consequence of high pollution in a sample of 58 countries over the period 1990-2012. Results of study conducted by [28] on the effects of ICT adoption on carbon emissions in SSA highlight the positive impact of energy consumption on CO_2 emissions.

Samad et al. [8] find that due to less air pollution associated with the adoption of a solar home system, morbidity of household members, especially women has reduced. The study of [10] concludes that household electrification leads to reduced indoor air pollution through reduced paraffin consumption. According to them, in the absence of electricity, most households in El Salvador use paraffin for lighting purposes, which in turn leads to harmful levels of soot emissions for those exposed. Following an electrification program in northern El Salvador, these authors used a dataset of fine particulate matter (PM2.5) concentrations in an experimental design. Two years after the baseline year, overnight PM2.5 concentration was on average 63% lower in households that were randomly encouraged to connect to the electricity grid compared to those that were not. [9] argue that access to modern cooking solutions helps to improve health and reduce premature mortality, particularly among women and children. In fact, women and children are mainly exposed to small particles in smoke that can reach levels well above the maximum recommended levels in households using traditional cooking methods.

4. METHODOLOGY

4.1 Specification of Model and Variables

The analytical framework for environmental issues is based on the Kuznet environmental curve hypothesis. In 1955, the work of the American economist Simon Kuznets led to an inverted U-shaped relationship between per capita income and social inequality, suggesting that in the short run, low income amplifies inequality, which then decreases as per capita income increases. In the early 1990s, this concept was applied to the growth and environmental quality debate. Instead of looking at economic growth as a threat to the environment and proposing to halt it, the EKC hypothesis assumes some kind of compatibility between environmental protection and future economic growth. However, the main shortcomings of EKC-based studies are that they implicitly assume a unidirectional causality from economic growth to environmental degradation [29], whereas there could be, for example, a possibility of bidirectional causality between the two variables.

Therefore, to assess the effect of energy poverty and energy consumption on CO_2 emissions in SSA, we formulate the following model:

$$lnENV_{it} = \alpha_0 + \alpha lnENER_{it} + \psi_1 lny_{it} + \psi_1 lny_{it}^2 + \Omega lnX'_{it} + \mu_i + \rho_t + \omega_{it} \qquad (1)$$

Where ENV refers to environment damage and proxies by CO_2 emissions. $ENER$ is our interest variables (energy variables): energy poverty and energy consumption. Energy poverty is captured by proportion of population without access to electricity and clean cooking fuels. Energy consumption refers to primary energy consumption (measured in kg of oil equivalent per capita). is GDP per capita (constant value 2010) y^2 is square of GDP per capita. X is a vector of other explanatory variables considered and includes trade openness (sum of exports and imports of goods and services measured as share of GDP), and financial development (measured as domestic credit to private sector as a share of GDP) and internet use (Individuals using the Internet in % of population). μ_i and ρ_i capture respectively individual specific effect and time fixed effect. ω is error term.

4.2 Estimation Techniques and Data Sources

4.2.1 Estimation strategy

Several econometric techniques are used to estimate equation (1). More specifically, these are pooled OLS, fixed effects and random effects. Several diagnostic tests are then conducted to choose the most appropriate estimator. First, we perform the Hausman specification test to choose between the fixed effect model and the random effect model. Then, the Wald and Wooldrige tests are applied to test for the existence of autocorrelation of the residuals and heteroscedasticity between the groups. In case of the presence of autocorrelation and heteroscedasticity, the initial models generate inconsistent, biased estimators. To solve these problems, the Feasible Generalized Least Squares (FGLS) and the Panel Corrected Standard Errors (PCSE) are used.

4.2.2 Data sources

This study covers 20 sub-Saharan African countries over the period 1996-2015. The selection of the period and countries of our sample is based on the availability of data, especially concerning the energy indicators.

Data come from two main sources. For the energy variables, the data comes from the [11] except for the energy consumption variable, for which the data was collected from the official World Bank database [30] as well as other variables of our model.

The data on access to modern cooking fuels is available for a five-year period and therefore to fit the other variables of our study to this time structure, we use the five-year frequency data which are non-overlapping averages over 5 years.

5. RESULTS AND DISCUSSIONS

5.1 Descriptive results

Some of the main descriptive resultsnare presented in this sub-section including the correlation matrix and some descriptive statistics.

First of all, it should be mentioned that we use data in non-overlapping five-year averages over the period 1996-2015, i.e. 4 observations: 1996-2000; 2001-2005; 2006-2010; 2011-2015. This means 4 observations per country and 20 countries, i.e. a total of 80 observations in the case where each variables used has all its observations, compared with 400 observations if the data were collected annually. This approach breaks down the periodic variabilities, making inter-individual variabilities the main source of the results obtained. Thus, in the presence of a micro-panel (4 < 20), stationarity tests are no longer useful.

The correlation matrix shows a strong correlation between indicators of our interest variable, which leads us to have a specification for each retained indicator, i.e. 3 specifications (see Table 4 in appendix). We set the admissible correlation threshold between two variables at 0.5 or less with a 10% tolerance. Based on this, we can include the selected control variables (GDP, internet access and financial development) in the same equation.

Table 5 in appendix shows that dependent variable (which is the level of CO_2 emissions in kilotons) varies between 675.46 and 476834.7 kilotons, with a standard deviation of around 94965.76 kilotons. The value of standard deviation reflects a strong disparity in CO_2 emissions among SSA countries.

5.2 Main findings

The presentation of the findings will be done in two steps in this sub-section. First, we present the baseline results from the pooled OLS, the fixed effects (FE) and random effects (RE) models. Second, we provide the results of the Feasible Generalized Least Squares (FGLS) and Panel Corrected Standard Errors (PCSE) estimations.

5.2.1 Baseline estimations

The results of the pooled OLS, fixed-effects (FE) and random-effects (RE) estimators are reported in Table 6 in appendix where energy poverty is captured as a recall by the percentage of population without access to electricity on the one hand and clean cooking fuel on the other hand. Per capita primary energy consumption is another energy indicator. These results show that the coefficient associated to the energy consumption variable is positive and significant at the 1% level for the pooled OLS estimators (1.09). Similarly, the coefficient of the electricity access variable is positive and significant at the 10% level for the fixed and random effects model estimators (0.18 and 0.19 respectively). These results suggest a stronger correlation between CO_2 emissions and the level of energy consumption compared to access to electricity.

Hausman specification test allowed us to select the most appropriate model between the fixed effects (FE) and random effects (RE) models. The probabilities obtained are shown in Table 7 in appendix. Based on these probabilities (all probabilities are below the 10% threshold value), the null hypothesis of no difference between the coefficients of the fixed-effects model and the random-effects model is rejected regardless of the specification considered. This suggests that the fixed effects estimator is the most appropriate.

Furthermore, serial autocorrelation and heteroscedasticity are investigated. Wald test for group heteroscedasticity suggests that the errors are heteroscedastic. In addition, the Wooldridge test generally shows a serial correlation between the errors (see Table 7 in appendix).

Consequently, the estimators obtained by the fixed effects and random effects models are biased and inconsistent. The estimators provided by Feasible Generalized Least Squares (FGLS) and Panel Corrected Standard Errors (PCSE) models allow to correct simultaneously serial autocorrelation and heteroscedasticity and therefore provide better estimators.

5.2.2 Feasible generalized least squares (FGLS) and panel corrected standard errors (PCSE) results

Results provide in Table 1 shows that per capita energy consumption has a positive and significant coefficient at the 1% level, regardless of the estimation method used (1.04 for FGLS and 0.74 for PCSE). The coefficient associated with the population without access to clean coking fuels is also found to be significant at the 10% level considering PCSE estimators (0.23).

Table 1. Effect of energy poverty and energy consumption on CO2 emissions

	Dependent variable : CO_2 emission s(log)					
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
		FGLS			**PCSE**	
NAE	0.055			0.131		
	(0.143)			(0.118)		
PEC		1.043***			0.743***	
		(0.278)			(0.181)	
NACCF			0.186			0.225*
			(0.214)			(0.122)
GDPPC	5.591***	6.491***	5.783***	6.754***	7.313***	7.311***
	(1.565)	(1.490)	(1.572)	(1.139)	(1.141)	(1.174)
GDPPC2	-0.335***	-0.429***	-0.338***	-0.422***	-0.490***	-0.448***
	(0.104)	(0.100)	(0.102)	(0.074)	(0.077)	(0.075)
Trade	-1.019***	-1.148***	-1.130***	-0.528***	-0.714***	-0.691***
	(0.337)	(0.347)	(0.369)	(0.200)	(0.200)	(0.210)
Internet	0.049	0.038	0.048	0.056***	0.025	0.045*
	(0.040)	(0.044)	(0.043)	(0.021)	(0.021)	(0.024)
FIDE	0.350**	0.291*	0.357**	0.294***	0.313***	0.317***
	(0.159)	(0.159)	(0,170)	(0.101)	(0.097)	(0.105)
Constant	-10.780*	-17.899***	-10.826*	-16.790***	-20.633***	-17.707***
	(5.815)	(5,786)	(6.007)	(4.298)	(4.334)	(4.375)
Observations	80	80	80	80	80	80
R-squared	0.897	0.864	0.876	0.897	0.864	0.876
Number of cid	20	20	20	20	20	20

*Note : NAE=Population without access to electricity, PEC=Primary energy consumption , NACCF= Population without access to clean cooking fuels. GDPPC= Gross domestic product per capita, FIDE= Financial development. The values in brackets are the robust standard errors.***, ** and * represent significance at the 1%,5% and 10% levels respectively. All variables are in log.*

However, this coefficient is relatively less important than that the one associated with per capita energy consumption (0.74). This suggests a positive and relatively larger effect of energy consumption per capita on CO_2 emissions. In fact, a 1% increase in the level of per capita consumption leads all other things being equal to a 1.04% and 0.74% increase in CO_2 emissions when considering the FGLS and PCSE estimators, respectively. However, following the PCSE estimators, an increase in the percentage of population without access to clean cooking fuel of one point of percentage would lead, all other things being equal, to an increase of 0.23% in CO_2 emissions. In addition, the coefficients of the other energy poverty indicator (percentage of population without access to electricity) are not significant.

These results could be justified by the fact that CO_2 emissions resulting from deforestation and pollution due to the use of traditional biomass by the population are relatively less important and to some extent marginal compared to the emissions attributable to the economic activity of some sectors like transport and industry. Regarding the level of per capita consumption, the strong correlation could be explained by the fact that consumption is largely dominated by fossil and fissile fuels in SSA. Indeed, according to [21], about 89% of the total electricity consumed in Africa is generated from non-renewable resources. Furthermore, this consumption is mainly directed towards sectors such as transport, industry. These results are broadly in line with those found by authors such as [28], [27] and [26] who find a significant positive effect of energy consumption on CO_2 in their studies.

Moreover, the effect of economic growth on carbon emissions is consistent with the EKC hypothesis. In fact, the coefficients on GDP per capita and GDP per capita squared are positive, negative and statistically significant respectively, regardless of the estimation method. The coefficient of the trade openness variable is negative and significant and this result can theoretically be explained by the factor endowment theory which predicts that the effect of trade openness on environmental quality depends on the capital-labor intensity in the countries. In fact, developing countries (such as SSA countries) that are well endowed with natural resources and labor will tend to specialize in the production and export of relatively less polluting products compared to developed countries.

The results of the analysis also suggest that the variables financial development, internet access rate (in terms of PCSE estimators) also have a potential to reduce CO_2 emissions

6. CONCLUDING REMARKS AND POLICY RECOMMENDATIONS

The present study aimed to evaluate the contribution of energy poverty as defined by the [15] and energy consumption to CO_2 emissions in SSA based on the theory of externalities. Indeed, [15] associates energy poverty with a lack of access to modern energy (electricity and clean cooking fuels). Accordingly, we used as an indicator of energy poverty the percentage of people without access to electricity on the one hand and the percentage of people without access to clean cooking fuels on the other hand. Our study covered a sample of 20 SSA countries and the period 1996-2015, and as an estimation technique we used Feasible Generalized Least Squares (FGLS) and Panel Corrected Standard Errors (PCSE).

The results of our analysis suggest that regardless of the estimation techniques used, only energy consumption have a positive effect on CO_2 emissions. To some extent energy poverty following the lack of access to clean cooking fuels has also a positive effect on CO_2 emissions in SSA. These results are broadly consistent with the findings of authors such as [28], [27] and [26] who conclude on a significant positive effect of energy consumption on CO_2 in their studies.

These results highlight the unsustainability of the current consumption mode and the damage it causes to the environment, hence making the more effective transition to modern renewable energy a priority. SSA governments should strengthen their efforts to increase people's access to modern energy, especially electricity, which is a powerful vector for sustainable development if the undesirable effects on the environment can be controlled and reduced to a minimum. To this end, policy makers should promote investment in renewable energy in order to fully exploit the potential that exists in most countries of the region, by deploying more off-grid power projects (solar photovoltaic systems, for example), especially in remote and less populated areas.

Furthermore, future studies could evaluate environmental consequences of energy poverty and energy consumption by dissociating renewable and non-renewable energies. In addition, country level analyses would allow for the control of country specificities.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX

Table 1. Primary energy consumption per capita in selected regions of the world over 1990-2018 (in tons oil equivalent)

Years	1990	1997	2004	2011	2018
World	1,52	1,50	1,62	1,75	1,81
North America	6,28	6,41	6,30	5,82	5,71
Latine America et Caribbean	0,92	1,10	1,15	1,35	1,34
Asia Pacific	0,60	0,75	0,95	1,27	1,43
Europe	3,40	3,20	3,34	3,13	3,03
Middle East	1,93	2,37	2,75	3,30	3,54
Africa	0,35	0,34	0,36	0,36	0,36
Sub Saharan Africa	0,27	0,26	0,27	0,25	0,24

Source: BP Statistical Review ofWorld Energy, June 2019.

Table 2. Evolution of non-access of clean cooking fuels in the world and in SSA over 2000-2018

	Years				
	2000	2005	2010	2015	2018
World	48%	45%	42%	37%	35%
Developing countries	63%	59%	55%	47%	45%
Central et Latin America	23%	18%	15%	12%	11%
Middle East	16%	9%	5%	5%	4%
Asia	67%	63%	57%	47%	43%
Africa	11%	15%	14%	12%	71%
Sub Saharan Africa	90%	89%	87%	85%	83%

Source: IEA (2020), Energy Access Outlook.

Table 3. Evolution of non-access of clean cooking fuels in the world and in $SA over 2000-2018.

	Years				
	2000	2005	2010	2015	2018
World	48%	45%	42%	37%	35%
Developing countries	63%	59%	55%	47%	45%
Central et Latin America	23%	18%	15%	12%	11%
Middle East	16%	9%	5%	5%	4%
Asia	67%	63%	57%	47%	43%
Africa	ti %	19%	14%	12%	11%
Sub Saharan Africa	90%	89%	87%	85%	83%

Source: IEA (2020), Energy Access Outlook.

Table 4. Correlation matrix of control variables

Variables	NAE	PEC	NACCF	GDPPC	FIDE	Internet	Trade
NAE	1						
PEC	-0.57*	1					
NACCF	0.72*	-0.72*	1				
GDPPC	-0.61*	0.78*	-0.89*	1			
FIDE	-0.64*	0.68*	-0.64*	0.54*	1		
Internet	-0.65*	0.48*	-0.55*	0.51*	0.52*	1	
Trade	-0.31*	0.13	-0.57*	0.47*	0.16	0.197	1

Note : NAE=Population without access to electricity, PEC=Primary energy consumption ,
NACCF= Population without access to clean cooking fuels. GDPPC= Gross domestic product per capita FIDE= Financial development. * represent significance at 1%.

Table 5. Descriptive statistics

Variables	Observations	Mean	Standard deviation	Minimum	Maximum
CO2	80	31325.04	94965.76	675.46	476834.7
NAE	80	61.04	25.37	1	94
PEC	80	704.04	622.67	129.02	2794.35
NACCF	80	73.30	26.14	6.9	95
GDPPC	80	2535.47	2759.28	267.21	11200.64
Trade	80	72.11	25.16	31.301	152.55
Internet	80	6.09	8.904	0.002	44.48
FIDE	80	24.902	30.94	0.702	150.47

Note : NAE=Population without access to electricity, PEC=Primary energy consumption , NACCF= Population without access to clean cooking fuels. GDPPC= Gross domestic product per capita, FIDE= Financial development.

Source: Authors' elaboration based on the World Development Indicators (WDI, 2020).

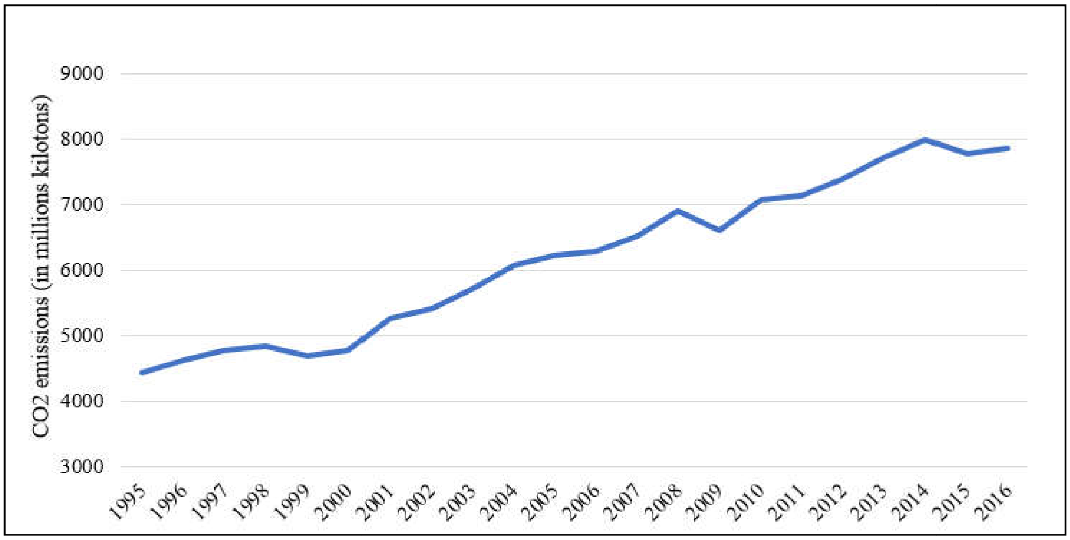

Fig. 1. Dynamic of CO_2 emissions over 1995-2016 in SSA

Source: Authors' elaboration based on the world development Indicators (WDI, 2020)

Table 6. Effect of energy poverty and energy consumption on CO2 emissions : Benchmark results

	Dependent variable : CO 2 emissions (log)								
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**
		Pooled OLS		**Fixed effects**				**Random effects**	
NAE	0.073			-0,012			0,004		
	(0.159)			(0,052)			(0,069)		
PEC		1.094***			0,252			0,194	
		(0.257)			(0,241)			(0,315)	
NACCF			0 .001			0,068			0,032
			(0.237)			(0,089)			(0,105)
GDPPC	5.57***	6.80***	5.69***	2,77**	2,79**	2,79**	3,07***	3,22***	3,10***
	(1.69)	(1.51)	(1.74)	(1,02)	(1,03)	(1,02)	(0,91)	(0,88)	(0,92)
GDPPC2	-0.33***	-0.49***	-0.34***	-0,12*	-0,12*	-0,12*	-0,155***	-0,17***	-0,15***
	(0.11)	(0.09)	(0.11)	(0,06)	(0,06)	(0,06)	(0,05)	(0,06)	(0,05)
Trade	-1.93***	-1.58***	-1.94***	0,022	0,035	0,034	-0,09	-0,12	-0,10
	(0.53)	(0.44)	(0.55)	(0,16)	(0,16)	(0,16)	(0,15)	(0,15)	(0,15)
Internet	0.029	0.014	0.026	0,04**	0,03**	0,04**	0,05***	0,04***	0,05***
	(0.07)	(0.07)	(0,07)	(0,02)	(0,02)	(0,02)	(0,02)	(0,01)	(0,01)
FIDE	0.45**	0.32*	0,43**	0,29***	0,28***	0,30***	0,33***	0,33***	0,32***
	(0.23)	(0.19)	(0,21)	(0,09)	(0,09)	(0,09)	(0,08)	(0,08)	(0,08)
Constant	-7.65	-17.74***	-7,64	-5,74	-7,53	-5,81	-5,88*	-7,22*	-5,87*
	(6.99)	(6.17)	(7,34)	(3,75)	(4,48)	(3,69)	(2,99)	(3,71)	(3.03)
Observations	80	80	80	80	80	80	80	80	80
R-squared	0.503	0.586	0,502	0,830	0,835	0,831			
Number of cid				20	20	20	20	20	20

*Note : NAE=Population without access to electricity, PEC=Primary energy consumption , NACCF= Population without access to clean cooking fuels. GDPPC= Gross domestic product per capita, FIDE= Financial development. The values in brackets are the robust standard errors.***, ** and * represent significance at the 1%,5% and 10% levels respectively. All variables are in log.*

Table 7. Choice of appropriate model

		Model specifications		
		1	**2**	**3**
Hausman test	χ2	11.52	11.1	11.78
	Prob	0.0736	0.0853	0.067
Wooldridge test for	F	3.656	3.563	3.35
serial autocorrelation	Prob	0.0711	0.0744	0.0829
Wald test for	χ2	49911.55	16251.35	1737.22
heteroscedasticity	Prob	0.000	0.000	0.000

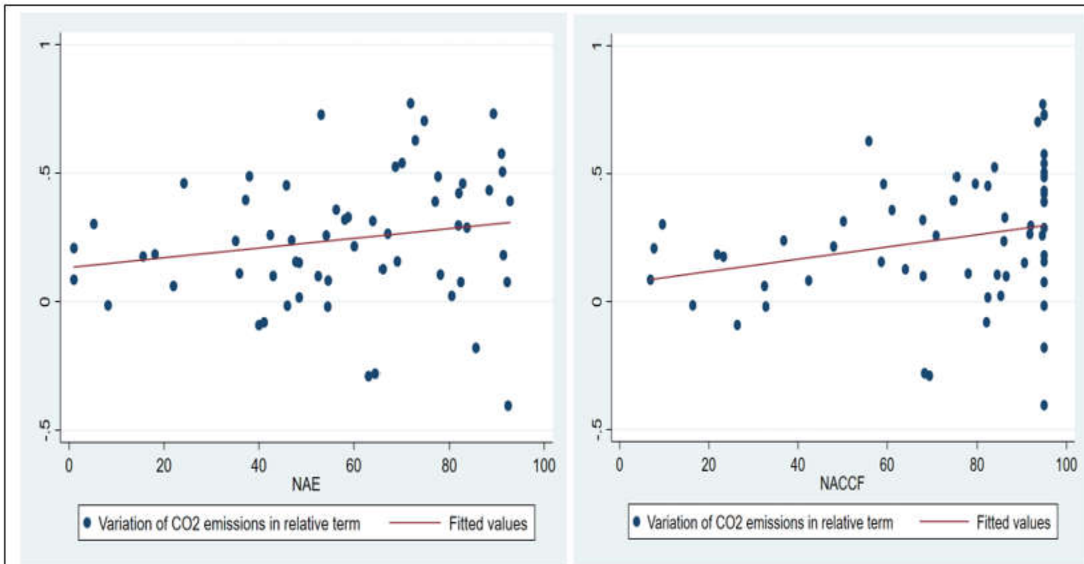

Figure 2 : Correlation between variation of CO_2 emissions (in relative term) and share of population without access to electricity (left side) and clean cooking fuels (right side).

Source: Authors' elaboration based on the WDI (2020) and IEA (2020).

Fig. 2. Correlation between variation of CO_2 emissions (in relative term) and share of population without access to electricity (left side) and clean cooking fuels (right side).
Source *Authors' elaboration based on the WDI, (2020) and IEA (2020)*

Table 8. Data description

Variables	Short names	Descriptions	Data sources
CO_2 emissions (metric tons)	CO_2	Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring.	WDI (2020)
Population without access to electricity	NAE	Electricity access entails a household having initial access to sufficient electricity to power a basic bundle of energy services (at a minimum), several lightbulbs, phone charging, a radio and potentially a fan or television .	IEA (2020)
Population without access to clean cooking fuels	NACCF	Access to clean cooking fuels means access to (and primary use of) modern fuels, including natural gas, liquefied petroleum gas (LPG), electricity and biogas, or improved biomass cookstoves (ICS) that have considerably lower emissions and higher efficiencies than traditional three-stone fires for cooking.	IEA (2020)
Primary energy consumption (kg of oil equivalent per capita)	PEC	Energy use refers to use of primary energy before transformation to other end-use fuels, which is equal to indigenous production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport.	WDI (2020)
GDP per capita (constant 2010 US$)	GDPPC	GDP per capita is gross domestic product divided by midyear population. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in constant 2010 U.S. dollars.	WDI (2020)
Financial Development	FIDE	Domestic credit to private sector refers to financial resources provided to the private sector by financial corporations, such as through loans, purchases of nonequity securities, and trade credits and other accounts receivable, that establish a claim for repayment.	WDI (2020)
Trade openness	Trade	Trade is the sum of exports and imports of goods and services measured as a share of gross domestic product.	WDI (2020)
Internet use	Internet	Internet users are individuals who have used the Internet (from any location) in the last 3 months. The Internet can be used via a computer, mobile phone, personal digital assistant, games machine, digital TV etc.	WDI (2020)

Source: Authors' elaboration based on the WDI (2020) and IEA (2020).

Table 9: Countries sample list

Angola	Democratic Republic of Congo	Mozambique	South Africa
Benin	Gabon	Namibia	Tanzania
Botswana	Ghana	Niger	Togo
Cameroon	Kenya	Nigeria	Zambia
Cote d'Ivoire	Mauritius	Senegal	Zimbabwe

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