GHG emissions and fossil energy use as consequences of efforts of improving human well-being in Africa

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ABSTRACT

This paper assesses the relationship between greenhouse gas emissions, fossil energy use and economic development, arguing that human development is not responsible for carbon dioxide emissions. To address the mechanism through which the latter relationship operates, a recursive system of three equations is estimated. The empirical results for a sample of 41 Sub-Saharan African countries observed over the period from 1990 to 2013 support our reasoning. Specifically, contrary to causality analyses which imply economic growth causing pollution, our recursive analysis indicates that greenhouse gas emissions are direct consequences of fossil energy use. Thus, economic growth is not to blame for carbon dioxide emissions. In terms of environmental policy for African countries, this study encourages efforts towards less polluting and renewable energies supply as well as investments in energy efficient technologies.

KEYWORDS

Human development, CO_2 emissions, fossil energies, recursive modelling, spillovers.

1. Introduction

Anthropogenic pressures, greenhouse gas (GHG) emissions and resulting environmental changes have motivated systematic studies on the human-nature dynamics. In environmental economics for instance, the relationship between pollutant emissions, energy use and economic growth is one of the most exhaustively discussed subjects. Thereby, economic growth is often identified among the drivers of environmental degradation. This has been the case in the recent studies by Bedir and Yilmaz (2016), Mardani et al. (2019) and Rafindadi and Usman (2019) on carbon dioxide (CO_2), where by directly linking GHG emissions to income level, these studies state that economic growth causes CO_2 emissions. Such a perspective, largely encountered in existing literature, fails to describe the mechanism through which the GHG emissions, energy and development nexus operates. This paper proposes a reassessment of the latter relationship for a sample of Sub-Saharan African (SSA) countries.

African countries are mostly endowed in mineral and energy resources and largely rely on the latter. While recent awareness on environmental pollution and climate change motivates global efforts in reducing fossil energies use, a continuous decline in renewable energy use is noted across SSA over the last 20 years (World Bank, 2020). Moreover, energy supply in Africa predominantly results from coal, oil and gas (Africa

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Energy Outlook, 2019), the consequences of which in terms of GHG emissions are well documented (Conti et al., 2016). Simultaneously, increasing access to electricity, life expectancy and school enrolment are observed (see Figures A.4, A.5 and A.6), motivating the question whether efforts of improving living conditions and human development finally resolve into fossil energy use in Africa. Though entire Africa is estimated to be responsible of circa 4% of the global CO_2 emissions (Sy, 2016), population growth, macroeconomic performances, increasing access to electricity and fossil energy consumption presume growing GHG emissions. In this context, we analyse the human development, energy and GHG emissions nexus for African countries, relying on three arguments.

Firstly, it is to observe, if economic production largely utilises renewable energies, economic development will not be identified as a driver of GHG emissions. Therefore, this paper realistically argues that economic growth is not to blame for pollutant emissions, whereas fossil energy use is. Discussing the causes of CO_2 emissions, it is essential to decouple economic growth from fossil energy use, since such a consideration will dictate environmental policies. For instance, assuming economic growth to be responsible for pollutant emissions justifies perspectives towards a 'de-growth' as a viable environmental policy. To the contrary, holding fossil energies use (and not economic growth) as a direct driver of GHG emissions promotes policies toward energy efficiency or energy transition. These observations motivate the present analysis in reconsidering the relationship between GHG emissions, energy and development. As described below (Figure 1), CO_2 emissions are to be specified as primarily driven by fossil energy use, the latter being promoted by efforts of improving living conditions (increasing access to electricity, production activities, urbanisation, ...)

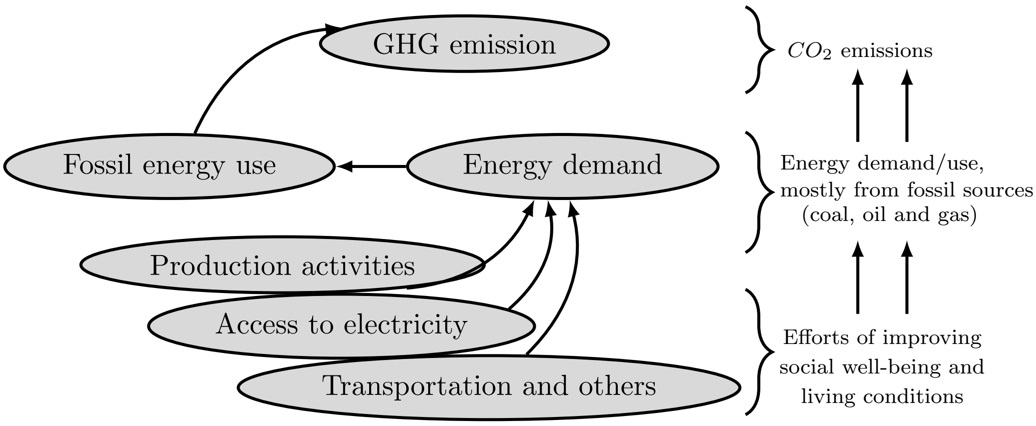

Figure 1. Synopsis of the GHG emissions, energy and human development nexus

Secondly, quality of life being at the heart of any development process, qualitative indicators of development should further be considered in investigating the relationship between GHG emissions, energy and development, especially in developing countries. For example, in SSA countries such as Equatorial Guinea, Gabon and Botswana, relatively high income levels are observed concurrently with very low levels of education and poor living conditions.[1] This observation can be extended

[1]Regarding GDP p.c., Eq. Guinea, Gabon and Botswana are respectively 60^{th}, 72^{nd} and 77^{th} in a total of 185 countries, 2017. They occupy the 144^{th}, 115^{th} and the 94^{th} rank in HDI (Worldometers and UNDP (2019)).

to other SSA countries to reveal the inappropriateness of using economic growth as indicator of human development in SSA. Qualitative indicators, including not only per capita GDP but also social dimensions such as life expectancy and education, seem more accurate proxies for living conditions (UNDP, 2019). Surprisingly, in existing literature, whether the research questions are the long-run dynamics, direction of causality (Huang et al., 2008; Joyeux and Ripple, 2011) or the drivers of GHG emissions and existence of an environmental Kuznets curve (Nguyen-Van, 2010; Azomahou et al., 2016), rare are the studies using qualitative measures of development, even so in the African context. This paper, in addition to a recursive modelling, intends to exploit Human Development Index (HDI) as indicator of development level.[2]

Finally, primary energies being directly harvested from natural resources, neighbouring Sub-Saharan African (SSA) countries sharing similar geographical characteristics, likely share comparable endowments in energy resources as well as correlated intensities in fossil energy use. Therefore, geographical characteristics or spillovers should be considered, when addressing primary energy use. Unfortunately, assessing the link between CO_2 emissions, energy and human development in Africa, the two existing studies (Ouedraogo, 2013; Aglina et al., 2016) disregard geographical spillovers in both primary energy use and CO_2 emissions. This study also intends to consider geographical spillovers in both primary energy use and CO_2 emissions.

This paper contributes to the empirical literature on GHG emissions, energy and human development in SSA in two ways. Primarily, contrary to Omri (2013); Nguyen et al. (2019) and Soukiazis et al. (2019) who advocate for simultaneity, this study relies on theoretical arguments to claim a recursive mechanism. It shows that efforts of improving human well-being and economic development are not to blame for CO_2 emissions. Furthermore, this study provides evidence of geographical spillovers in both fossil energy use and CO_2 emissions across SSA. Our sample selection follows a simple rationale. On the one hand, very few studies can be identified addressing GHG emissions, energy and human development for the entire SSA. Studies doing so have very limited samples. On the other hand, given their colonial history (mostly former colonies), their common socio-economic characteristics (countries at early stages of development) and most crucially their geographical characteristics (contiguity), SSA appears to be the ideal sample this recursive spatial analysis can be applied to.

The remainder of the paper is organised as follows. The next Section reviews the related literature. Sections 3 and 4 present the data and describe our econometric specification. Section 5 presents and discusses the results of our empirical analysis. In Section 6, we check our results for robustness and draw some conclusions in Section 7.

2. Related literature

Following the founding works by Grossman and Krueger (1991, 1995) and Shafik and Bandyopadhyay (1992), a large literature has assessed the relationship between CO_2 emissions, energy and income. This literature highlights the causal link between these variables and globally suggests that economic growth and energy use cause

[2]The UNDP (2019) defines HDI as a measure of average achievement in key dimensions of human development. Also, it considers that HDI 'should be the ultimate criteria for assessing the development of a country, not economic growth alone.'

environmental pollution (Halicioglu, 2009; Gassebner et al., 2010; Liddle, 2013). This paper addressing the link between GHG emissions, primary energy use and human well-being, we wish to narrow down this literature review to studies using qualitative measures of human development instead of GDP per capita.[3] Systematic and recent literature reviews of studies focusing on economic growth are presented by Ozturk (2010), Tiba and Omri (2017) and Mardani et al. (2019).

Besides economic growth, recent empirical studies have been questioning the role of qualitative measures of well-being (HDI, literacy rate and consumption) in energy consumption and GHG emissions. Although relatively short, this literature initiated, among others, by Pasternak (2000), Martinez and Ebenhack (2008) and Wu et al. (2010) enlightens the interactions between these phenomena. Pasternak (2000) and Martinez and Ebenhack (2008) analyses correlation between human development and energy use in most populated countries to conclude that large gains in human development are possible through access to energy in poor nations, as there is a significant association between electricity use and indicators of human development. Wu et al. (2010) note similarities in energy use and HDI inequalities across 129 countries from 1998 to 2007. Following these leading studies, Pîrlogea (2012) and Niu et al. (2013) use regression analysis to provide evidence on the role of energy and access to electricity in human well-being. Their results indicate that the higher the GDP per capita, the greater electricity consumption and the higher human development. Similarly, Roy et al. (2015) find results supporting a long-run relationship between energy and HDI which further suggest that energy use enhance social well-being. A takeaway appears in these studies. Similar to the income-energy nexus, a bidirectional causality (feedback hypothesis) appears between energy use and human well-being.

Given recent awareness on climate issues and increasing renewable energy use, a further aspect of the literature addressed how renewable energy use impacts social well-being. Overall, no convincing conclusion appears regarding the role of renewable energies in improving human development. On this, while Kazar and Kazar (2014) and Satrovic (2018) support the existence of a bidirectional causality between renewable energy and HDI, at least in the short-run, Wang et al. (2018) find no conclusive results. It can be observed that this specific area of environmental economics discussing human development and renewable energy consumption needs to be further explored. Regarding pollutant emissions and their link to energy and human development, inconclusive results are also noticeable. The existing studies on the latter topic also provide evidence indicating that energy use promotes human development, but remain inconclusive on how GHG emissions impact human well-being (Nguyen et al., 2019; Soukiazis et al., 2019; Rahman, 2020). On the same topic, Bedir and Yilmaz (2016) show that GHG emissions affect HDI only in four European countries (Iceland, Norway, Portugal, and Switzerland). In conclusion, contrary to energy use, which is shown to have a bidirectional causality with human development, the impact of GHG emissions on human well-being remains an open question.

In the case of countries at early stages of development, specifically SSA, even scarcer are studies considering qualitative measures of well-being when addressing

[3]This because the HDI appears to be a better indicator of human development and should be the ultimate criteria for assessing development (UNDP, 2019).

the pollutant emissions, energy use and development nexus. Consequently, only the studies by Ouedraogo (2013) and Aglina et al. (2016) were found. Considering human well-being indicators such as life expectancy and literacy rate, among others, Aglina et al. (2016) find positive impacts of energy consumption on human well-being. Similar results appear in the study by Ouedraogo (2013), who assesses the co-movement and the causality between energy use, electricity consumption and HDI in the Economic Community of West African States. The results specifically show a positive cointegration relationship between electricity consumption and HDI, implying that electricity consumption enhances human development.

Conclusively, though the renewable energy use and economic growth debate remains controversial, the literature shows that energy consumption and access to electricity drive human development. It is first to note that the specifications, even when exploiting simultaneous equations system, are less theory derived, leading to regressions models directly linking income to GHG emissions. Secondly, no specific attention has been given to fossil energy use in low-income countries, modelling the latter as a direct driver of pollutant emissions rather than production activities. Finally, questions regarding geographical spillovers in primary energy consumption and GHG emissions have been largely disregarded, notwithstanding their importance for energy policy. The recursive mechanism proposed by this paper to address the CO_2 emissions-energy-human development nexus aims to fill these gaps.

3. Model specification

3.1. Theoretical background

Theoretical models on energy and resources use show that economic activities rely not only on labour and capital but also on energy resources to indirectly cause environmental degradation. Thereby, Stern and Cleveland (2004) and Arbex and Perobelli (2010) for instance consider a production technology using labour (L), capital (K) and energy (E): $Y = AL^{\alpha_1}K^{\alpha_2}E^{\alpha_3}$. It is to observe that the latter formulation links production activities (income level) to energy consumption. Moreover, the existing literature suggests a bidirectional causality between energy use and income (Niu et al., 2013; Roy et al., 2015), implying that not only economic growth depends on energy, still, also energy consumption conversely depends on income level. Exploiting these observations but also the resources harvest function of Eliasson and Turnovsky (2004) as well as the semi-logarithmic energy-development function by Steinberger and Roberts (2010), energy use per capita (in log) can be directly expressed as depending on income per capita among other socio-economic characteristics: $\log EU_{pc} = a_0 + a_1 \log Y_{pc}$.[4] This equation constitutes the theoretical foundation for our regression model 2 linking energy use to human development.

Concerning GHG emissions, Conti et al. (2016) argue that 'because anthropogenic emissions of carbon dioxide result primarily from the combustion of fossil fuels, energy consumption is at the centre of the climate change debate'. Furthermore 'fossil-fuel systems, in particular, are the dominant contributors to the emissions

[4]Specifically, the resource harvest function states that harvesting mineral resource requires economic resources and efforts in terms of labour. The semi-logarithmic energy-development function (Pasternak, 2000; Steinberger and Roberts, 2010) states: $HDI = a + b \log EU$

of these gases' (Dones et al., 2004). These arguments, in addition to theoretical models on the dirty energy-pollution nexus (Van der Ploeg and Withagen, 2012; Dato, 2017) directly link fossil energy use to environmental pollution. Therefore, we specify CO_2 emissions (in log) as primarily depending on fossil energy use: $\log CO2_{pc} = b_0 + b_1 \log EU_{pc}$. The latter formulation supports the regression model 1.

These theoretical discussions over equations 1 and 2 describe a recursive mechanism linking development level to energy use and afterwards fossil energy use to pollution, supporting our empirical strategy. Moreover, they question existing causality analyses directly linking GHG emissions to economic growth. Finally, they imply two obvious propositions: ($i.$) Efforts of improving living conditions (human development) strengthen primary energy use in SSA and ($ii.$) the higher primary energy use, the larger CO_2 emissions. In addition, given the geographical contiguity of (most) SSA countries, the existence of spatial spillovers in energy and CO_2 emissions across SSA is also postulated. These rationales will guide the recursive analysis on the relationship between GHG emissions, fossil energy consumption and human development.

3.2. Econometric model

Following with the discussions above, we define the regression models for CO_2 emissions and energy as follows:

$$\log CO2_{it} = b_1 \log EU_{it} + x_{1,it}\beta + \varepsilon_{it} + \epsilon_i, \;\; with \;\; \varepsilon_{it}|x_{1,it}, EU_{it} \sim iid(0, \sigma_\varepsilon^2) \tag{1}$$

$$\log EU_{it} = a_1 HDI_{it} + x_{2,it}\alpha + v_{it} + \nu_i, \;\; with \;\; v_{it}|x_{2,it}, EU_{it} \sim iid(0, \sigma_v^2) \tag{2}$$

where the index i refers to country and t to the year. ε_{it} and v_{it} stand for the error terms and ϵ_i and ν_i for individual effects. $\log CO2_{it}$ and $\log EU_{it}$ respectively represent CO_2 emissions and primary energy use per capita, while the matrices x_1 and x_2 stand for additional determinants (control variables) that will be considered.

Regarding control variables, x_1 and x_2, the recent literature mentions as drivers of CO_2 emissions, population dynamics, urbanization, industrial production (Martínez-Zarzoso and Maruotti, 2011), openness to trade and political institution (Halicioglu, 2009; You et al., 2015). In addition, Aldy (2007) and Liddle (2013) mentioned GDP, while Soukiazis et al. (2019) consider education, spending on R&D and development level as driving energy use. Data on most of these variables are available and will be introduced into the regression models.

Primary energies being harvested from natural resources, we intend to address geographical spillovers in energy use, as well as in resulting CO_2 emissions. Indeed, 'everything is related to everything else, but near things are more related than distant things' (Tobler, 1970). Neighbouring SSA countries sharing similar geographical characteristics, likely have comparable endowments in energy resources and could also show correlated intensities in primary energy use and GHG emissions. Let $\omega_{n\times n}$ be a common-border based connectivity matrix, the spatial lag of CO_2 emissions and energy use ($\sum_{j=1}^{n} w_{ij}CO2_{jt}$ and $\sum_{j=1}^{n} w_{ij}EU_{jt}$) will be introduced into the respective models.

3.3. Addressing endogeneity

The feedback hypothesis in the energy and development relationship suggests that not only energy use depends on living condition (as in Eq. 2), but also that access to electricity or energy use reversely drives well-being. Arbex and Perobelli (2010) and Omri (2013) provide some theoretical and empirical discussions on this issue of reverse causality (endogeneity). Additionally, equations 1 and 2 in our case may suffer from omitted variables and measurement errors also leading to endogeneity, which will bias the estimated parameters if not properly addressed.

Addressing endogeneity, we rely on instrumental variables technique, using as instrument for HDI the one year lag of income per capita ($GDP_{pc,t-1}$) and of life expectancy (LE_{t-1}). These variables are highly correlated with HDI and are unlikely to directly drive energy consumption observed in period t. Therefore, they seem good instruments for human development. The regression model becomes the following, where the same included instruments are considered:

$$\log CO2_{it} = \rho_c \sum_{j=1}^{n} w_{ij} CO2_{jt} + b_1 \log EU_{it} + x_{it}\beta + \varepsilon_{it} + \epsilon_i, \quad \varepsilon_{it}|x_{it} \sim iid(0, \sigma_\varepsilon^2) \quad (3)$$

$$\log EU_{it} = \rho_e \sum_{j=1}^{n} w_{ij} EU_{jt} + a_1 HDI_{it} + x_{it}\alpha + v_{it} + \nu_i, \quad v_{it}|x_{it} \sim iid(0, \sigma_v^2) \quad (4)$$

$$HDI_{it} = \varphi_1 GDP_{pc,i,t-1} + \varphi_2 LE_{i,t-1} + x_{it}\delta + u_{it} + \mu_i, \quad u_{it}|x_{it}, GDP, LE \sim iid(0, \sigma_\mu^2) \quad (5)$$

where ρ_c and ρ_e respectively traduce the geographical spillovers in CO_2 emissions and primary energy use, while $\sum_{j=1}^{n} w_{ij} CO2_{jt}$ and $\sum_{j=1}^{n} w_{ij} EU_{jt}$ represent for a country i the average CO_2 emissions and primary energy use in the neighbouring countries.

4. Data and descriptive statistics

Investigating the relationship between CO_2 emissions, fossil energy use and human development, common determinants of GHG emissions and energy use identified in existing studies need to be considered. Thus, we collected data, among others, on primary energy use, CO_2 emissions, HDI, GDP per capita, population dynamics, access to electricity and trade. The final dataset is constituted by 41 SSA countries and is reduced to the period between 1990 and 2013 due to missing values.

- *Carbon dioxide emissions* are used as indicator of GHG emissions in SSA. By definition, it includes carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring WDI (2019).

- *Fossil Energy use:* We consider as proxy for fossil energy use data on total primary energy consumption. Primary energy use refers to the direct use, or supply to users without transformation of energies directly harvested from natural resources and which are dominated by fossil energies (coal, oil and gas) (United Nations, 1997).

- *Human development:* Living conditions or human well-being at country-level is represented by the HDI, which is 'a summary measure of average achievement in key dimensions of human development: a long and healthy life, being knowledgeable and have a decent standard of living' (United Nations Development Programme, UNDP). Contrary to income per capita, the UNDP argues that HDI should be the ultimate criteria for assessing the development of a country. The HDI takes values ranging from 0 to 1 and is a more qualitative measure of living standard.

Table 1. Descriptive statistics

	Units	N	Mean	St. Dev.	Min	Max	Source
log.CO_2 emissions	M. tons per cap.	984	5.469	1.333	2.373	9.197	WDI
log.Primary Energy use	Kj. per capita	984	15.306	1.182	12.616	18.622	EIA
log.GDP per capita	\$, PPP. 2011	984	7.597	0.899	5.508	10.833	WDI
HDI	index	984	0.427	0.099	0.200	0.690	UNDP
log.Consumption expenditures	\$, PPP. 2011	696	6.504	0.815	5.151	8.443	WDI
Agricultural activities	in % of GDP	984	28.659	16.787	0.892	78.655	WDI
Industrial activities	in % of GDP	984	27.528	15.903	3.329	84.283	WDI
Natural resources rents	in % of GDP	984	15.311	14.562	0.374	89.002	WDI
FDI, net inflows	in % of GDP	984	4.226	10.651	−82.892	161.824	WDI
Imports	in % of GDP	984	43.803	36.326	7.066	424.817	WDI
Exports	in % of GDP	984	30.468	19.788	3.335	124.393	WDI
Population growth	in %	984	2.619	1.037	−6.343	7.989	WDI
Urban population growth	in %	984	4.066	1.729	−7.103	17.598	WDI
Temperatures	°C	943	24.646	3.280	12.628	29.541	CCKP
Total Rainfalls	in mm	943	1,044.569	596.912	70.418	3,282.239	CCKP
Political stability	index	984	−0.680	0.897	−2.989	1.183	WDI
Unrest (Riots and protests)	Counts	656	15.848	50.408	0.000	993.000	ACLED
Poverty gap at 1.9\$a day	%, PPP. 2011	622	19.944	12.030	1.800	63.600	WDI
Access to electricity	in %	982	51.450	25.489	0.010	100.000	WDI
Mean years of Education	years	946	3.913	1.921	0.700	10.100	UNDP
Life expectancy	years	984	53.146	5.946	27.610	65.914	UNDP

Notes: $n = 41$ SSA countries observed over 1990-2013, 24 periods. N varies because of missing values. ACLED stands for Armed Conflict Location & Event Data and CCKP for "Climate Change Knowledge Portal".

- *Control variables:* Our dataset also includes data on industry and agriculture in share of GDP, population growth, access to electricity, openness to trade (imports and exports), net inflows foreign direct investments (FDI), as well as indicators of institutional characteristics, social unrest and weather differentials, among others.

Table 1 reports descriptive statistics of the variables involved in our study. By comparing the minimum values to the maximum for HDI, primary energy use and CO_2 emissions, differences are observable, suggesting a relatively heterogeneous sample. Since these descriptive statistics do not provide any understanding of the geographical distribution of energy use and pollutant emissions in SSA allowing between countries comparisons, Figures 2 and 3 are proposed. Observing both maps, in addition to differences between countries, some similarities in the geographical distribution of energy use and CO_2 emissions are quite striking.

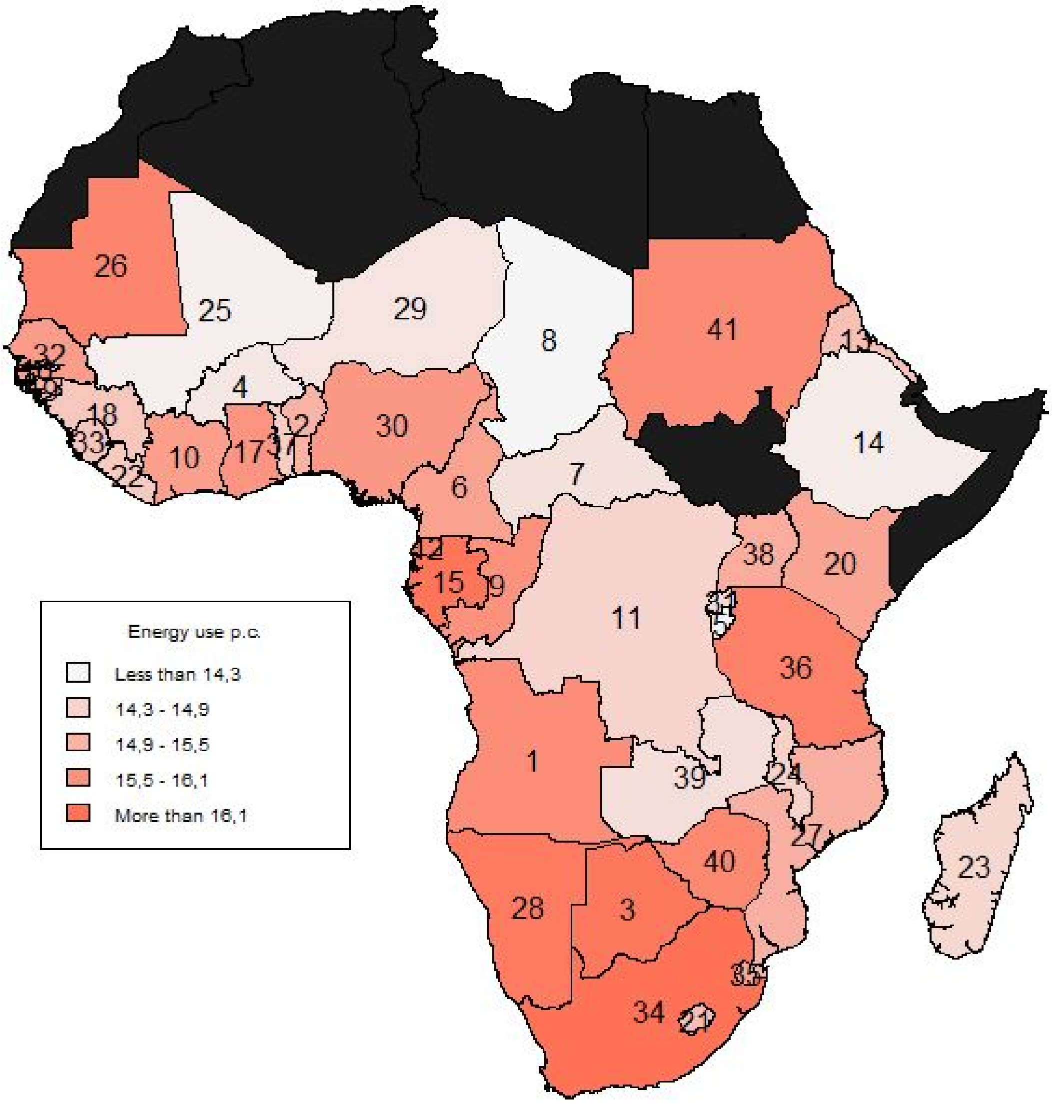

Figure 2. Mean primary energy use in SSA, 1990-2013

List of countries: 1 Angola, 2 Benin, 3 Botswana, 4 Burkina Faso, 5 Burundi, 6 Cameroon, 7 Central African Republic, 8 Chad, 9 Congo,Rep., 10 Cote d'Ivoire, 11 Congo, Dem. Rep., 12 Equatorial Guinea, 13 Eritrea, 14 Ethiopia, 15 Gabon, 16 Gambia, The, 17 Ghana, 18 Guinea, 19 Guinea Bissau, 20 Kenya, 21 Lesotho, 22 Liberia, 23 Madagascar, 24 Malawi, 25 Mali, 26 Mauritania, 27 Mozambique, 28 Namibia, 29 Niger, 30 Nigeria, 31 Rwanda, 312 Senegal, 33 Sierra Leone, 34 South Africa, 35 Swaziland, 36 Tanzania, 37 Togo, 38 Uganda, 39 Zambia, 40 Zimbabwe, 41 Sudan.

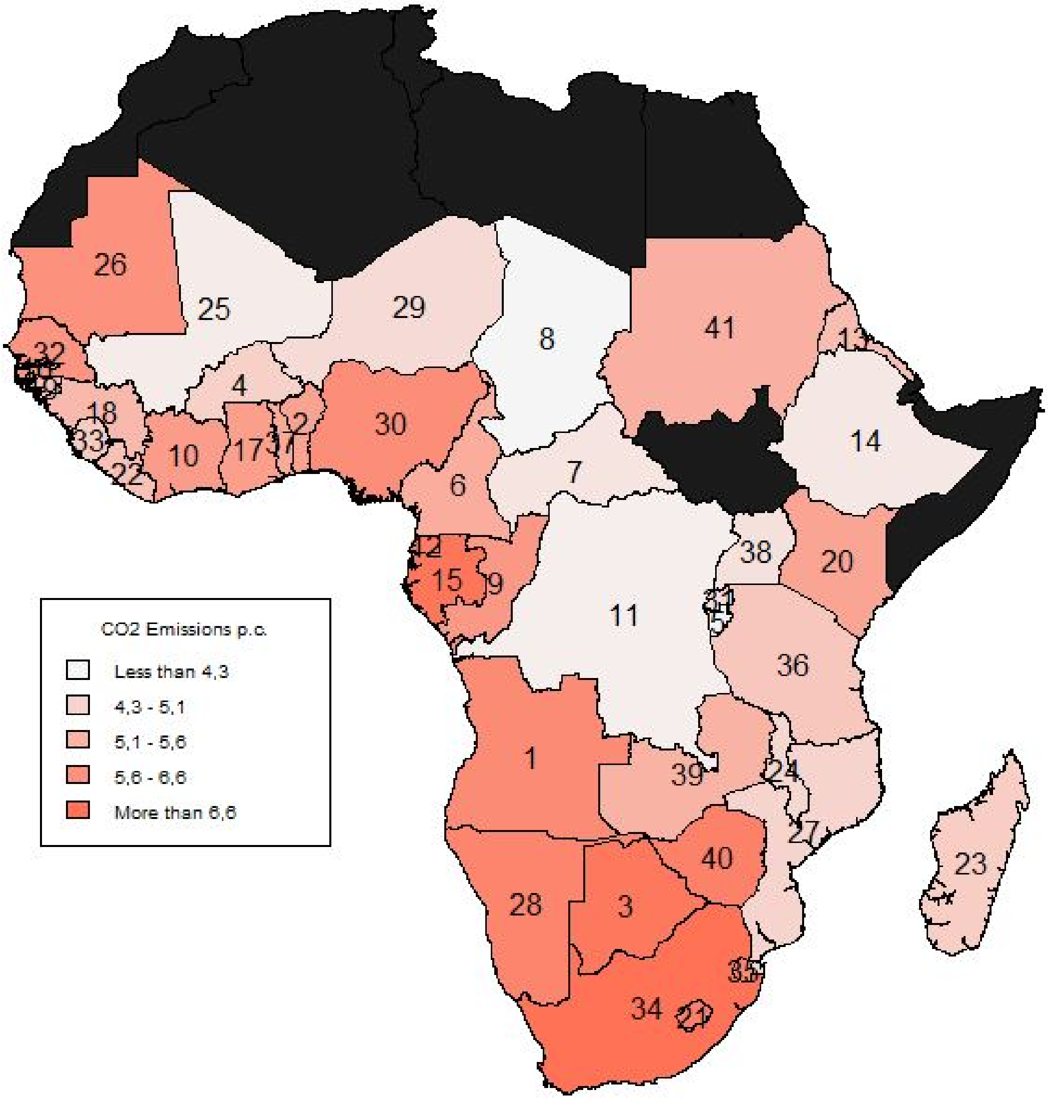

Figure 3. Mean CO_2 emissions in SSA, 1990-2013

List of countries: 1 Angola, 2 Benin, 3 Botswana, 4 Burkina Faso, 5 Burundi, 6 Cameroon, 7 Central African Republic, 8 Chad, 9 Congo,Rep., 10 Cote d'Ivoire, 11 Congo, Dem. Rep., 12 Equatorial Guinea, 13 Eritrea, 14 Ethiopia, 15 Gabon, 16 Gambia, The, 17 Ghana, 18 Guinea, 19 Guinea Bissau, 20 Kenya, 21 Lesotho, 22 Liberia, 23 Madagascar, 24 Malawi, 25 Mali, 26 Mauritania, 27 Mozambique, 28 Namibia, 29 Niger, 30 Nigeria, 31 Rwanda, 312 Senegal, 33 Sierra Leone, 34 South Africa, 35 Swaziland, 36 Tanzania, 37 Togo, 38 Uganda, 39 Zambia, 40 Zimbabwe, 41 Sudan.

Initially, compared to inland countries, coastal located SSA countries mostly and concurrently show higher HDI, energy use and pollutant emissions (see Figure 2, 3 and A.1 in Supplementary Materials for HDI). Analysing the CO_2-energy-HDI nexus in SSA, geographical characteristics such as regional spillovers should be addressed. Moreover, countries showing high level of primary energy use also appear to be characterized by high levels of CO_2 emissions. However, an appropriate regression analysis will be more informative in answering the question whether or not efforts of improving living conditions (HDI) drive primary energy use and indirectly CO_2 emissions.[5]

[5] The data used in this paper are available in csv-file to those who wish to replicate our results

5. Estimation results

5.1. Are there geographical spillovers in primary energy use and CO_2 emissions?

Evidences of geographical spillovers in primary energy use and in CO_2 emissions across SSA are a prerequisite for estimating the parameters of equations 3 and 4. Therefore, we primarily test for the presence of spatial spillovers in each yearly wave of our panel dataset. Our argument being that countries sharing similar geographical characteristics (contiguous countries), likely have comparable endowments in energy resources and also correlated intensities in primary energy use and CO_2 emissions, we exploit the connectivity matrix $\omega_{n\times n}$ (see Table A.3 in Supplementary Materials).[6]

Table 2. Test for spatial dependence in primary energy use and CO_2 emissions

	Primary energy use		CO_2 emissions	
Yearly waves of the panel dataset	Moran I	p-value	Moran I	p-value
Wave 1990	.133	.076	.223	.012
Wave 1991	.116	.099	.409	.000
Wave 1992	.093	.141	.426	.000
Wave 1993	.089	.149	.387	.000
Wave 1994	.083	.163	.378	.000
Wave 1995	.088	.151	.415	.000
Wave 1996	.067	.202	.382	.000
Wave 1997	.072	.188	.465	.000
Wave 1998	.100	.128	.468	.000
Wave 1999	.130	.080	.485	.000
Wave 2000	.168	.039	.474	.000
Wave 2001	.187	.027	.484	.000
Wave 2002	.242	.007	.466	.000
Wave 2003	.241	.008	.492	.000
Wave 2004	.224	.011	.464	.000
Wave 2005	.279	.003	.457	.000
Wave 2006	.276	.003	.455	.000
Wave 2007	.304	.002	.462	.000
Wave 2008	.329	.000	.471	.000
Wave 2009	.326	.001	.472	.000
Wave 2010	.344	.000	.466	.000
Wave 2011	.321	.000	.456	.000
Wave 2012	.318	.001	.456	.000
Wave 2013	.312	.001	.455	.000

Notes: Moran-I test under randomisation using data on primary energy use and CO_2 emissions per capita (in log). H_0 is no spatial dependence. Each yearly wave consists of 41 observations.

The test results (Table 2) in 71% of the case show statistically significant spatial spillovers in primary energy use among SSA countries. This indicates that modelling primary energy use, spatial autocorrelation should be considered as done in equation 4. CO_2 emissions being direct consequences of fossil energy use, spatial autocorrelations are also expected in data on CO_2 emissions. The test results in 100% of the case support the latter perspective by also indicating statistically significant spatial effects. Finally, we perform the Durbin-Wu-Hausman test, the results of which largely support a fixed-effects specification. (see Table A.1 in Supplementary Materials).[7]

[6]The matrix $\omega_{n\times n}$ is based on contiguity principle. See Table A.3 in Supplementary Materials for details.
[7]The Hausman test compares fixed-effects to random-effects specification for panel data models.

5.2. On living conditions or human development in SSA

Our specification introduces the model for human development (Eq. 5) as a first-stage regression, addressing endogeneity issues. Nevertheless, its outcomes remain crucial for the pollution-energy-development analysis intended in the paper. Table 3 reports the results of estimating fixed-effects models for HDI, exploiting the one year lag of GDP per capita ($GDP_{pc,t-1}$) and life expectancy (LE_{t-1}) as excluded instrumental variables.[8] Subsequently, the predicted values of HDI will be used in estimating the parameters of the model for primary energy use in SSA (Eq. 4). The following discussions are essentially based on the model specification FE IV-ii, as the latter shows the highest predictive power (Adj. R-Squared).

Table 3. Standard FE regression model for Human Development Index

	First stage regression				
Covariates / Models	FE I	FE II	FE III	FE IV-i	FE IV-ii
Lag.lnGDP per capita	.026***(.005)	.031***(.006)	.024***(.007)	.032***(.006)	.032***(.006)
Life expectancy	.008***(.002)	.008***(.000)	.008***(.000)	.007***(.002)	.007***(.003)
Agriculture, GDP share	−.010***(.001)	−.009***(.001)	−.007***(.001)	−.013 (.013)	−.013 (.013)
Industry, GDP share	−.004**(.002)	−.005** (.002)	−.004**(.002)	−.001 (.001)	−.001 (.002)
Rents of nat. resources	.005***(.001)	.005***(.001)	.003***(.001)	.004 (.011)	.004 (.011)
FDI, net inflows		.007(.010)	.008 (.011)	−.003**(.001)	−.003**(.001)
Imports, GDP share		.009* (.005)	.007 (.006)	.006 (.004)	.006 (.005)
Exports, GDP share		−.002 (.010)	−.004 (.009)	−.001 (.001)	−.001 (.001)
Population growth			.003**(.001)	.007***(.002)	.007***(.002)
Urban population growth			−.002***(.000)	−.003 (.002)	−.003 (.002)
Average Temperatures			.017***(.002)	.006 (.017)	.006 (.018)
Total rainfalls, yearly			.013***(.004)	−.008 (.043)	−.008 (.040)
Political stability				−.004*(.002)	−.004*(.002)
Riots incidence				−.003 (.002)	−.003 (.002)
Poverty gap, at 1.9$				−.036***(.009)	−.036***(.008)
Access to electricity				.027***(.010)	.027***(.010)
Mean years of education				.015***(.002)	.015***(.002)
Intercept					−.233***(.057)
Origin of the colonial power (categorical, ref. = not colonized):					
Belgian					−.038***(.013)
British					−.056***(.011)
French					−.059***(.016)
Portuguese					−.057***(.008)
Country dummy					✓
Observations	946	946	915	557	557
F-stat (*p*-value)	646.501 (.000)	409.631 (.000)	333.484 (.000)	228.727 (.000)	631.30 (.000)
Adj. R-Squared	.771	.774	.812	.873	.984

Notes: Dependent variable is the Human Development Index. In bracket are bootstrapped standard errors. Lag.lnGDP per capita and Life expectancy are the excluded instrumental variables used in the first stage. '***', '**' and '*' respectively stand for significance level at 1, 5 and 10%.

Observing the results, both our instrumental variables are pertinent predictors of human development across SSA. As GDP per capita and life expectancy are

[8]Though the Hausman test suggests a random-effects specification for FE III (see Table A.1), we estimate a fixed-effects model, since the latter remains consistent. The results discussions are all based on FE IV-ii

involved in computing the HDI, such results are predictable and principally support the statistical relevance of our instrumental variables.

Regarding control variables, mean years of education and access to electricity significantly enhance human development in Sub-Saharan Africa, confirming conclusions by Ouedraogo (2013) and Aglina et al. (2016). Contrary to access to electricity and education, FDI have a negative effect on human development in SSA. FDI in developing countries being very often attracted by resource endowments, oils deposits and even corruption (Melo et al., 2015), their primary goal seems not to be improving living conditions in SSA.

'The colonial origins of comparative development' literature (Acemoglu et al., 2001, 2012) sheds light on how colonisation shapes current institutions and human development in former colonies. Following the latter, we address historical characteristics of SSA by controlling for the origin of the colonial power as proposed by Lawson and Nguyen-Van (2020). The estimated parameters show that compared to not-colonized SSA countries, being a former colony undermines social well-being, independently of the colonial power's origin. Since colonisation has derailed countries from their natural path, former colonies of SSA hold institutions which derive from colonial and extractive institutions and consequently produce relatively poor performances in terms of education, income and standard of living. Thereby, it is to observe that the highest adverse impact for human development appears in former French colonies. Such a result indicates that the evidence regarding the colonial origin of comparative development can also be extended to human well-being. In contrast to the origin of the colonial powers categorical variable, improvement of living conditions (increase in HDI) in SSA can be expected to positively drive fossil energy use in SSA. The HDI-energy nexus is discussed in the next Section.

5.3. On fossil energy use and human development in SSA

Our regression model (Eq. 4) assumes that fossil energy use is promoted by efforts of improving living conditions and, hence, relates primary energy use to the index of human development. Exploiting predicted values of HDI from the first-stage regression (Eq. 5), we perform a second-stage regression for primary energy use per capita accounting for geographical spillovers. This delivers pertinent results regarding the causal link between living conditions and energy use (Table 4). The following discussions are based on model FE IV-ii.

Firstly, the estimated parameter for $\sum_{j=1}^{n} w_{ij} EU_{jt}$ supports the existence of positive geographical spillovers in primary energy use, as suggested by the Moran I-tests for spatial effects (Table 2). Based on the latter, one can argue that neighbouring SSA countries, sharing similar geographical characteristics, likely have comparable endowments in energy resources and actually show co-related intensities in primary energy use. In addition to geographical spillovers, HDI positively drives energy use implying that efforts of improving living conditions increase energy demand and consequently fossil energy use in SSA. A similar positive relationship between HDI and energy consumption has been explored in recent studies, among others, by Niu et al. (2013) and Arto et al. (2016). In contrast to Pîrlogea (2012), Niu et al. (2013) on the reverse hypothesis, Arto et al. (2016) argues that efforts of improving human well-being drive energy use in SSA. Finally, since African countries appear among the most dynamic economies, a collective increase in primary energy use is to expect across SSA.

Table 4. FE Spatial lag model Primary Energy Use

	Second stage regression				
Covariates / Models	FE I	FE II	FE III	FE IV-i	FE IV-ii
Spatial lag of energy use, ρ_e	.227***(.040)	.167***(.037)	.120***(.039)	.179***(.051)	.179***(.052)
Human Development index	1.657***(.220)	1.555***(.201)	1.792***(.208)	.760**(.377)	.760**(.375)
Agriculture, GDP share	.007**(.003)	.005**(.002)	.006**(.002)	.003 (.003)	.003 (.003)
Industry, GDP share	.016***(.002)	.011***(.002)	.011***(.002)	.012***(.003)	.012***(.003)
Rents of nat. resources	−.014***(.003)	−.013***(.002)	−.015***(.002)	−.012***(.003)	−.012***(.003)
FDI, net inflows		−.004(.016)	−.006 (.017)	−.004 (.018)	−.004 (.018)
Imports, GDP share		−.007***(.001)	−.006 (.018)	−.002*(.001)	−.002*(.001)
Exports, GDP share		.012 (.002)	.012*** (.002)	.007***(.002)	.007***(.002)
Population growth			−.040***(.020)	.018 (.030)	.018 (.029)
Urban population growth			−.014(.015)	.004 (.022)	.004 (.021)
Average Temperatures			.020(.024)	.045* (.028)	.045* (.028)
Total rainfalls, yearly			−.006 (.007)	.003 (.007)	.003 (.006)
Political stability				−.009 (.024)	−.009 (.023)
Riots incidence				.003 (.002)	.003 (.002)
Poverty gap, at 1.9$				.004**(.002)	.004**(.002)
Access to electricity				.011***(.002)	.011***(.002)
Mean years of education				−.032 (.031)	−.032 (.032)
Intercept					1.151***(.095)
Origin of the colonial power (categorical, ref. = not colonized):					
Belgian					−1.981***(.013)
British					−.872***(.011)
French					−2.156***(.016)
Portuguese					−.770***(.008)
Country dummy					✓
Observations	946	946	915	557	557
F-stat (p-value)	29.364 (.000)	54.868 (.000)	40.376 (.000)	11.416 (.000)	354.9 (.000)
Adj. R-Squared	.140	.293	.321	.397	.972

Notes: Dependent variable is primary energy use per capita. In brackets are bootstrapped standard errors. '***', '**' and '*' respectively stand for significance level at 1, 5 and 10%.

Socio-economic variables reflecting the structure of economic production, openness to trade, demographic change, weather differentials and social unrest have been introduced into the regression model. Since electricity production in SSA mostly exploits oil, gas and coal sources (approximately 70% of the total, WDI (2019)), electricity supply and access to electricity are potential drivers of primary energy use in SSA. As expected, our empirical results show that access to electricity significantly promotes energy use, similar to industrial production and exports in GDP. These predictable outcomes suggest that increase in population share with access to electricity and economic production in the industry sector intensify energy demand which resolve into fossil energy consumption. Contrary to exports, the GDP share of imports negatively affects energy use and indicates that while SSA countries utilise fossil energies to produce and export goods (mostly raw materials and primary goods), imports of goods and services evidently do not participate in increasing energy demand.

Conclusively, the estimated parameter for FDI shows no significant effect on energy use, disproving the pollution haven hypothesis regarding fossil energy use in SSA.[9] Interestingly, the rents of natural resources show a negative and statistically significant link to primary energy use, i.e. the more SSA economies rely on resource rents, the less fossil energy they utilise. Analysing such an effect, we first observe that the share of resource rents in GDP (resource harvest) does not significantly enhance human well-being in accordance with the resource curse hypothesis.[10] Whether or not the negative link between resource rents and energy use characterises the resource curse paradox is left to future research.

5.4. On fossil energy use and CO_2 emissions in SSA

This paper argues that economic growth is not to blame for GHG emissions and identifies CO_2 emissions as direct consequences of fossil energy consumption. Thus, our regression model 3 relates CO_2 emissions to energy use (values predicted from Eq. 4), accounting for geographical spillovers, access to electricity, openness to trade and further socio-economic variables.

The estimated parameter for $\sum_{j=1}^{n} w_{ij} CO2_{jt}$ is positive and statistically significant. This confirms the existence of spatial effects in CO_2 emissions and implies that SSA countries do not only show co-related intensities of fossil energy consumption, which also reflects into increasing carbon dioxide emissions (see Table 5). Fossil energy use being at the heart of CO_2 emissions, primary energy use and population access to electricity are both expected to significantly enhance CO_2 emissions. The results clearly support such a perspective by showing a positive and significant impact of primary energy use on CO_2 emissions. Similar conclusions advocating for causal effects running from energy to GHG emissions are also observed in the recent contributions by Omri (2013) and Soukiazis et al. (2019), among others. Globally, based on our results, the expected collective increase in primary energy use across SSA countries is also to associate with growing CO_2 emissions and further environmental consequences.

Among control variables, very appealing results appear regarding the role of access to electricity, FDI and natural resources rents. Access to electricity driving energy demand and fossil energy use is positively linked to CO_2 emissions. While natural resource rents are not significant for human development (and negatively affect primary energy use), they are positively related to CO_2 emissions. It is to acknowledge that the latter outcome raises questions on the resource curse hypothesis, on the relationship between resource rents and energy as well as on the resource rents-CO_2 emissions nexus. In fact, as there is a negative link between resource rents and energy, one expects a similar link between resource rents and CO_2 emissions.[11] A profound investigation on the forces behind this outcome is left for future research for not being the aim of this paper. Nevertheless, since non-linearities are possible justifications of such surprising outcomes, the general patterns of each of these nexuses are assessed. A U-shaped curve appears for each of the mentioned relationships, supporting the

[9] The pollution haven hypothesis states that environmental regulations will move polluting activities (of multinationals) for tradeable products to poorer countries (Eskeland and Harrison, 2003).

[10] The resource curse hypothesis refers to the paradox that economies abundant endowment in natural resources tend to show low-level of economic development (Ross, 2015).

[11] We thank an anonymous reviewer for drawing our attention to this specific relationship.

non-linearity postulate (see Figures ??, A.2 and A.3). Hence, a feasible explanation of this unpredictable result is the utilisation of a linear specification for the control variables, also for resource rents. Finally, net inflows FDI show a negative impact on CO_2 emissions, implying that investments made by foreigners into business interests in SSA countries do not systematically increase GHG emissions and environmental degradation. The latter result also disproves the pollution haven hypothesis concerning FDI.

Table 5. FE Spatial lag model of CO_2 Emissions

	Third stage regression				
Covariates / Models	FE I	FE II	FE III	FE IV-i	FE IV-ii
Spatial lag of CO_2, ρ_c	.149***(.045)	.146***(.045)	.195* (.053)	.213***(.075)	.213***(.069)
Primary Energy use	.308***(.042)	.267***(.038)	.327***(.001)	.187***(.027)	.187***(.026)
Agriculture, GDP share	.005** (.002)	.005**(.002)	.006**(.002)	.006* (.003)	.006**(.002)
Industry, GDP share	.001 (.003)	−.003 (.002)	−.004* (.002)	−.001 (.003)	−.001 (.003)
Rents of nat. resources	.006***(.002)	.005**(.002)	.004* (.002)	.007***(.002)	.007***(.002)
FDI, net inflows		−.004(.015)	−.007 (.017)	−.005**(.002)	−.005***(.001)
Imports, GDP share		−.004***(.001)	−.003***(.001)	.001 (.001)	.001 (.001)
Exports, GDP share		.010***(.002)	.009***(.002)	−.002 (.002)	−.002 (.002)
Population growth			−.006 (.012)	.046 (.029)	.046 (.029)
Urban population growth			−.027**(.013)	−.039* (.024)	−.039* (.024)
Average Temperatures			.095***(.025)	.024 (.027)	.024 (.027)
Total rainfalls, yearly			.011 (.007)	.012**(.005)	.012**(.005)
Political stability				.005 (.024)	.005 (.024)
Riots incidence				.001 (.001)	.001 (.001)
Poverty gap, at 1.9$				−.010***(.002)	−.010***(.003)
Access to electricity				.007***(.001)	.007***(.002)
Mean years of education				−.107**(.029)	−.107**(.031)
Intercept					2.014***(.737)
Origin of the colonial power (categorical, ref. = not colonized):					
Belgian					−1.762***(.229)
British					−.289** (.121)
French					−.963***(.267)
Portuguese					−.012 (.178)
Country dummy					✓
Observations	946	946	915	557	557
F-stat (p-value)	32.766 (.000)	33.851 (.000)	35.412 (.000)	11.949 (.000)	473.0 (.000)
Adj. R-Squared	.154	.191	.289	.298	.979

Notes: Dependent variable is CO_2 emissions per capita. Lag.lnGDP per capita and Life expectancy are the excluded instrumental variables used in the first stage. In bracket are bootstrapped standard errors. '***', '**' and '*' respectively stand for significance level at 1, 5 and 10%.

Globally, it is to note that the recursive regression model introduced by this paper to assess the mechanism through which the relationship between human development, energy and CO_2 emissions operates delivers results supporting our hypotheses. Firstly, these results show that efforts of improving human well-being are the direct forces driving fossil energy consumption in SSA. Secondly, CO_2 emissions appear as by-products of primary energy use, implying that economic growth and efforts of improving living condition are not directly to blame for GHG emissions. Finally, our preliminary tests and regression analysis support the existence of geographical spillovers in both primary energy consumption and CO_2 emissions. In the light of these results, a collective increase of primary energy use and pollutant emissions are to expect in a near future in individual SSA countries, where population growth, increasing access to electricity and economic performances are being observed.

6. Robustness check and non-parametric perspectives

6.1. Robustness analysis

This paper argues that causality analyses mostly failed to address the mechanisms through which the CO_2 emissions, energy and development nexus operates, by ignoring its recursive nature, qualitative measures of well-being, as well as geographical spillovers. Moreover, by directly linking income to GHG emissions (e.g. causality analyses), existing studies hold economic growth responsible for GHG emissions, although a direct link between these phenomena remains debatable. Thus, we propose a recursive analysis of the relationship between CO_2 emissions, primary energy use and human development for a sample of SSA countries. Our results mainly support the argument that efforts of improving human development create an energy demand and the higher fossil energy use, the higher GHG emissions. To test these conclusions for robustness, we proceed exactly as primarily, however, considering a different measure of human well-being, household final consumption expenditures.

- *Using an alternative measure of living conditions*

Using data on household expenditures on final consumption as indicator of living conditions shows slight changes in the estimated parameters, though, not in the signs and causal links previously established.[12] Observing the results of the first stage regression or for household final consumption (Table 6), the model shows high predictive power in addition to being globally significant. The one year lag per capita GDP, agricultural production and educational level positively drive household final consumption. As previously established, colonial characteristics of SSA countries reveal that being a former colony negatively affects human development, supporting the literature on the role of history in comparative development (Acemoglu et al., 2001; Nunn, 2009).

Regarding energy use, the results support the existence of geographical spillovers in primary energy use and confirm the role played by efforts of improving living conditions (household final consumption) in enhancing fossil energy consumption. Moreover, common determinants of fossil energy use in SSA such as industrial production, exportations and access to electricity remain statistically significant. Net inflows FDI is insignificant for primary energy use, while the rents of natural resources show, as previously, a negative effect.

Finally, observing the results for CO_2 emissions, the spatial spillovers in GHG emissions remains statistically significant. As previously shown, increasing energy demand, thus fossil energy use and access to electricity (which mainly results from coal sources) enhance GHG emissions in Africa. Among control variables, the level of education and FDI show a negative link, while natural resource rents surprisingly show

[12]The WDI (2019) defines the household final consumption expenditure (private consumption) as ‘the market value of all goods and services, including durable products (such as cars, washing machines, and home computers), purchased by households’.

as previously a positive link to CO_2 emissions per capita. As discussed above (see Figures A.2 and A.3), there seems to be non-linearity in the resource rents-energy use and the resource rent-GHG emissions nexus which explains the conflicting results, when a linear specification is used. Since these specific relationships are not the focal point of this study, a profound assessment of that is left to future research.

Table 6. CO_2 emission, primary energy use and household final consumption

	Dependent variables:		
	Household final consumption	Primary energy use	CO_2 emissions
Lag.lnGDP per capita	.363***(.064)		
Life expectancy	.003 (.003)		
Spatial lag of energy use		.154** (.073)	
H. final consumption exp. p.c.		.204***(.066)	
Spatial lag of CO_2			.396***(.073)
Primary Energy use			.213***(.034)
Agriculture, GDP share	.007***(.002)	.010***(.004)	.008**(.004)
Industry, GDP share	.001 (.002)	.018*** (.003)	−.002 (.003)
Rents of nat. resources	−.001 (.001)	−.013***(.002)	.009***(.002)
FDI, net inflows	−.001 (.001)	.001 (.002)	−.004** (.002)
Imports, GDP share	−.002***(.0005)	−.002** (.001)	.002***(.001)
Exports, GDP share	.002 (.001)	.009*** (.002)	−.004** (.002)
Population growth	.093***(.024)	.037 (.041)	.023 (.037)
Urban population growth	−.062***(.018)	−.001 (.031)	−.022 (.028)
Average Temperatures	.030 (.024)	.096** (.043)	.029 (.038)
Total rainfalls, yearly	−.00004 (.0001)	.0001 (.0001)	.0001 (.0001)
Political stability	.034 (.019)	−.037 (.034)	−.060* (.031)
Riots incidence	−.0003 (.0003)	.0004 (.0005)	.0003 (.0004)
Poverty gap, at 1.9$	−.001 (.001)	.003 (.003)	−.013***(.002)
Access to electricity	.002*(.001)	.014***(.002)	.006***(.002)
Mean years of education	.131***(.025)	−.049 (.045)	−.100** (.041)
Intercept	3.003***(.749)	9.155***(1.500)	.228 (1.051)
Origin of the colonial power (categorical, ref. = not colonized):			
Belgian	−.702***(.157)	−1.744***(.204)	−1.275***(.274)
British	−1.196***(.105)	−.830***(.193)	−.592***(.160)
French	−1.114***(.202)	−2.371***(.359)	−.712** (.333)
Portuguese	−.561***(.112)	−.952***(.204)	.423* (.211)
Country dummy	✓	✓	✓
Observations	416	416	416
F-stat (*p*-value)	374.903 (.000)	274.091 (.000)	456.221 (.000)
Adj. R-Squared	.979	.972	.983

Notes: Lag.lnGDP per capita and Life expectancy are the excluded instrumental variables used in the first stage. In bracket are bootstrapped standard errors. '***', '**' and '*' respectively stand for significance level at 1, 5 and 10%.

- *Using 4 years averaged data*

Although the cross-sectional characteristic of our panel dataset (41 countries) is larger than its time-series dimension (24), motivating standard panel data approach as proposed above, it matters to check our results relying on k-years averages. This process reduces the time span of the data and mitigates concerns that (non-) stationarity of the series involved in the analysis may be affecting the results. Using 4-years averages, our conclusions are reviewed for robustness. The results of the latter procedure globally support our discussions regarding the link between human development, primary energy use and CO_2 emissions as presented above (Table 7).

Table 7. Regression Results using 4 years average data

	Dependent variables:		
	Human Development index	Primary energy use	CO_2 emissions
Lag.lnGDP per capita	.043*** (.010)		
Life expectancy	.007*** (.000)		
Spatial lag of energy use		.172* (.103)	
Human Development index		1.364* (.727)	
Spatial lag of CO_2			.306** (.117)
Primary Energy use			.432*** (.081)
Agriculture, GDP share	−.002 (.004)	−.001 (.006)	.012** (.005)
Industry, GDP share	−.002 (.004)	.009 (.006)	−.004 (.005)
Rents of nat. resources	.002 (.003)	−.011** (.004)	.006 (.004)
FDI, net inflows	−.001* (.000)	−.006 (.005)	−.004 (.005)
Imports, GDP share	.001 (.001)	−.003* (.002)	.003* (.002)
Exports, GDP share	−.005* (.002)	.006* (.004)	−.003 (.003)
Population growth	.002 (.020)	−.056 (.037)	−.010 (.035)
Urban population growth	−.002 (.002)	.011 (.027)	−.011 (.025)
Average Temperatures	.017** (.007)	.061 (.110)	.178* (.103)
Total rainfalls, yearly	.003 (.002)	.001 (.003)	.001** (.000)
Political stability	−.005 (.003)	−.043 (.052)	−.002 (.048)
Riots incidence	−.002 (.004)	.001 (.001)	.0004 (.001)
Poverty gap, at 1.9$	−.001*** (.000)	.005 (.004)	−.012*** (.003)
Access to electricity	.004* (.002)	.012*** (.003)	.005 (.003)
Mean years of education	.011*** (.004)	−.137** (.067)	−.169*** (.061)
Intercept	−.593*** (.167)	11.75*** (3.086)	−5.815** (2.450)
Origin of the colonial power (categorical, ref. = not colonized):			
Belgian	−.043 (.032)	−2.178*** (.438)	−1.461** (.576)
British	−.078*** (.018)	−.637** (.294)	−.076 (.265)
French	−.181*** (.059)	−2.245** (.941)	−1.825* (.928)
Portuguese	−.086*** (.028)	−.675 (.448)	.016 (.459)
Country dummy	✓	✓	✓
Observations	184	184	184
F-stat (p-value)	84.564***	4.809***	7.170***
Adj. R-Squared	0.918 (.000)	0.390 (.000)	0.488 (.000)

Notes: Dependent variable for the first stage is the HDI. Lag.lnGDP per capita and Life expectancy are the excluded instrumental variables used in the first stage. Primary energy use and CO_2 emissions are the dependent variables for the second and third stages. In bracket are bootstrapped standard errors. '***', '**' and '*' respectively stand for significance level at 1, 5 and 10%.

An exhaustive reading of the results of our recursive regression suggests that efforts of human development and of poverty alleviation drive fossil energy use and indirectly CO_2 emissions in SSA. Since the empirical results indicate fossil energy use driving GHG emissions, any environmental policy aiming at reducing GHG emissions and related environmental consequences in SSA should target energy supply and demand.

In conclusion, the robustness analyses relying on an alternative indicator of human development, household final consumption expenditures, and using 4-years averaged data globally supports our primary discussions regarding the link between pollutant emissions, fossil energy use and human development. As the literature largely questions linearity in the CO_2 emissions, energy and development nexus, we propose a non-parametric analysis of the core individual relationships.

6.2. A non-parametric perspective

Assessing general patterns of the core individual relationships we discussed above, it is satisfactory to only focus on primary energy use and to provide insights into its overall behaviour to human development (HDI) and household final consumption expenditures.

For this purpose, we use the local constant or Nadayara-Watson (NW) kernel estimation method, the aim of which is to directly estimate the functions $\mathrm{E}[EU_{it}|HDI_{it}] = m(HDI_{it})$ and $\mathrm{E}[EU_{it}|HFC_{it}] = n(HFC_{it})$, where $m(.)$ and $n(.)$ are non-parametric functions. Using the Nadayara-Watson estimator, we rely on the Silverman's rule-of-thumb bandwidth. Doing so, we obtain results clarifying interrogations concerning linearity in the energy and human development relationship. Figures 4, 5 and 6 below depict the results of the non-parametric regression.

Overall, primary energy use per capita shows an increasing relationship to human development index, implying that the higher the level of development, the larger the demand for energy and consequently fossil energy consumption in SSA. The corresponding (heteroscedasticity-robust) confidence intervals indicate that the observed upward trend is statistically significant. The latter patterns (Figure 4) support the linear specification used throughout this paper, in addition to invalidating the Environmental Kuznets Curve hypothesis for SSA countries. The alternative indicator of living conditions, household final consumption, shows comparable patterns to primary energy use (Figure 5). Globally, our parametric and non-parametric analyses fairly indicate that efforts of improving living conditions mainly drive fossil energy use.

Carbon dioxide emissions primarily resulting from fossil energy consumption, increasing patters in CO_2 emissions are to associate with the growing primary energy use observed in SSA. As expected, the non-parametric result shows an upward trend between primary energy use and GHG emissions (Figure 6). This suggests that as long as the energy demand driven by efforts of improving living conditions is compensated by fossil energies, CO_2 emissions will be increasing in SSA. Therefore, environmental policies aiming at reducing CO_2 emissions in SSA should be promoting less polluting and renewable energies consumption as well as energy efficiency.

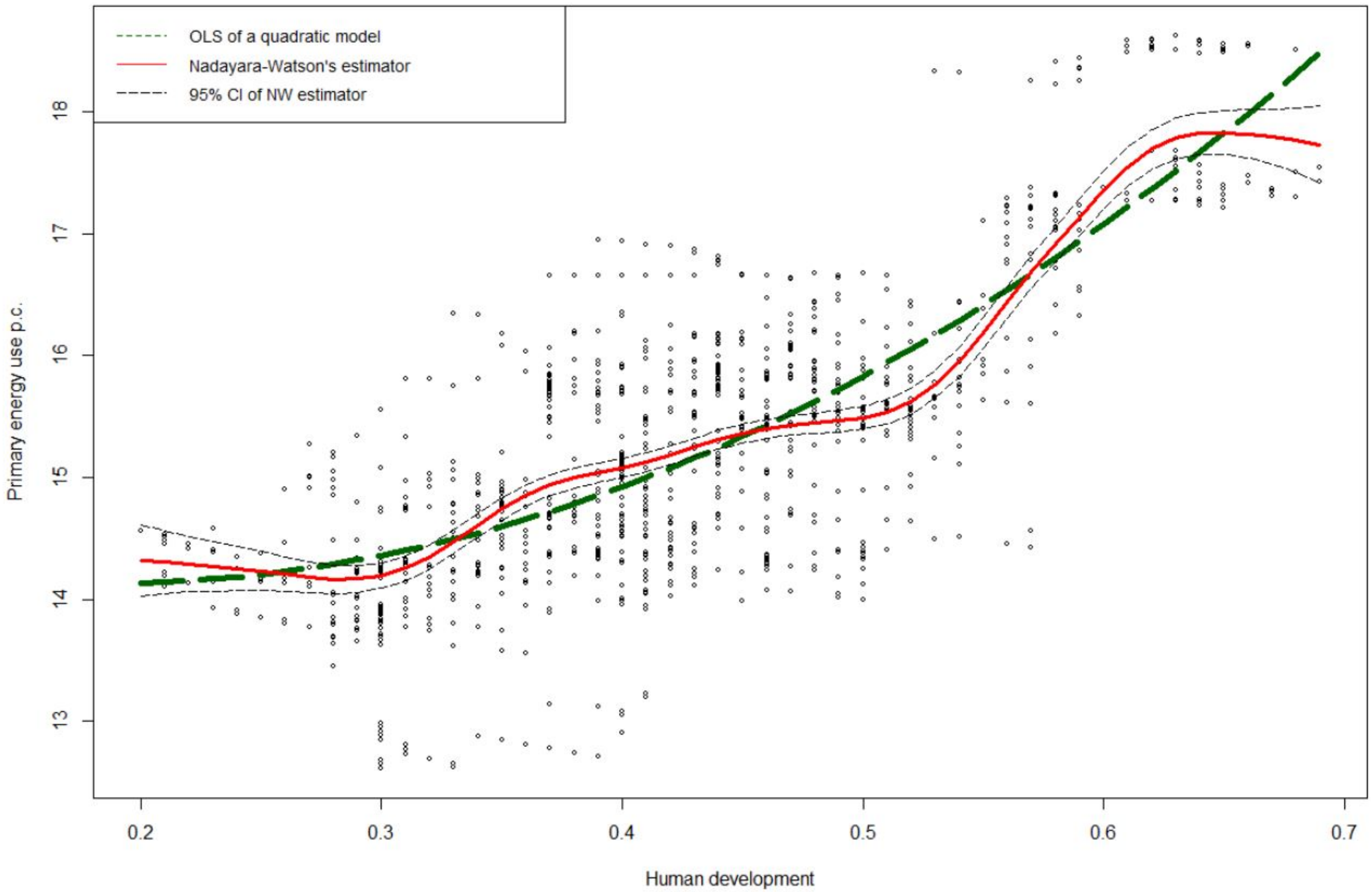

Figure 4. Primary energy use and HDI in SSA countries, 1990-2013

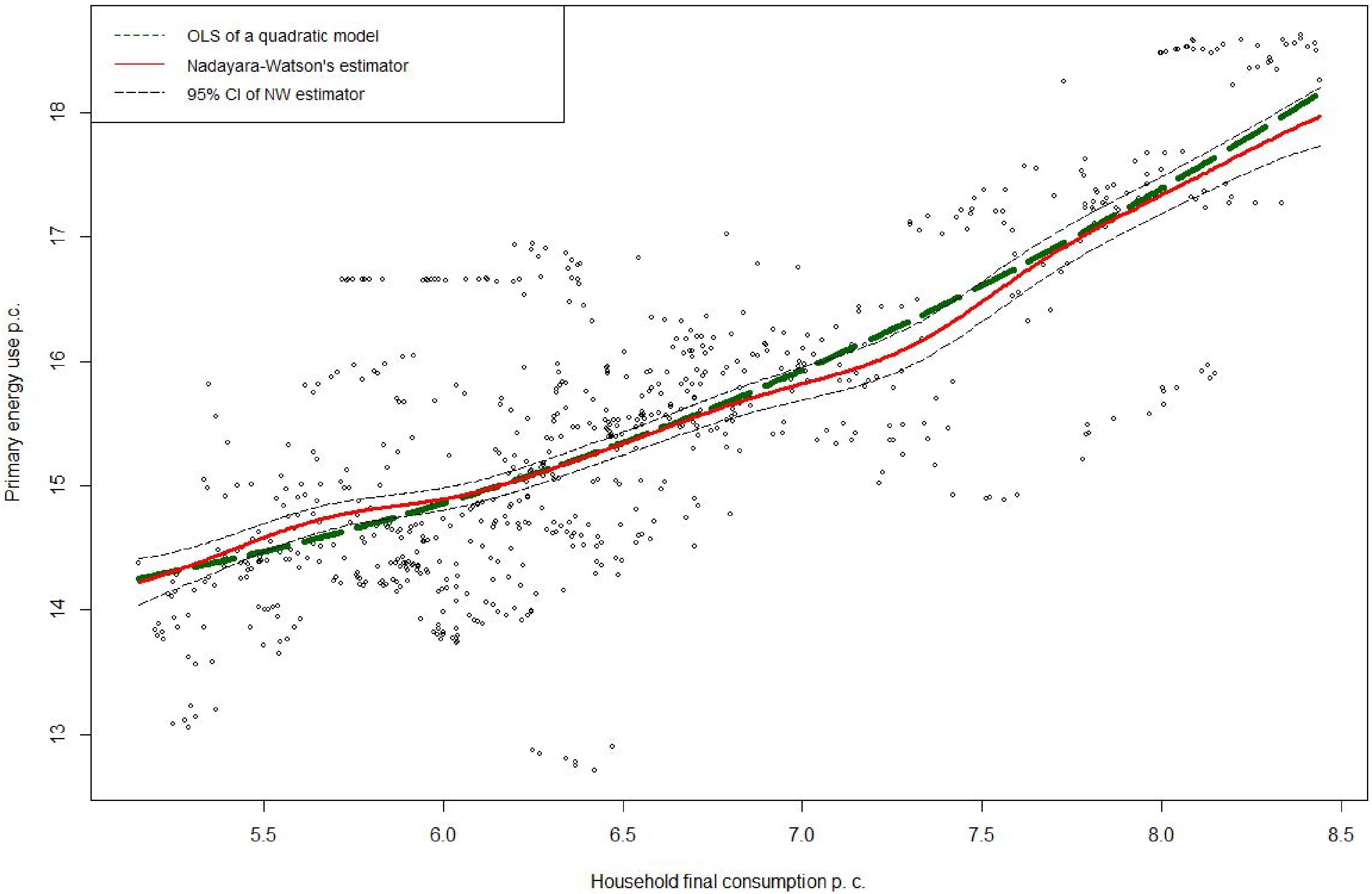

Figure 5. Primary energy use and household final consumption in SSA, 1990-2013

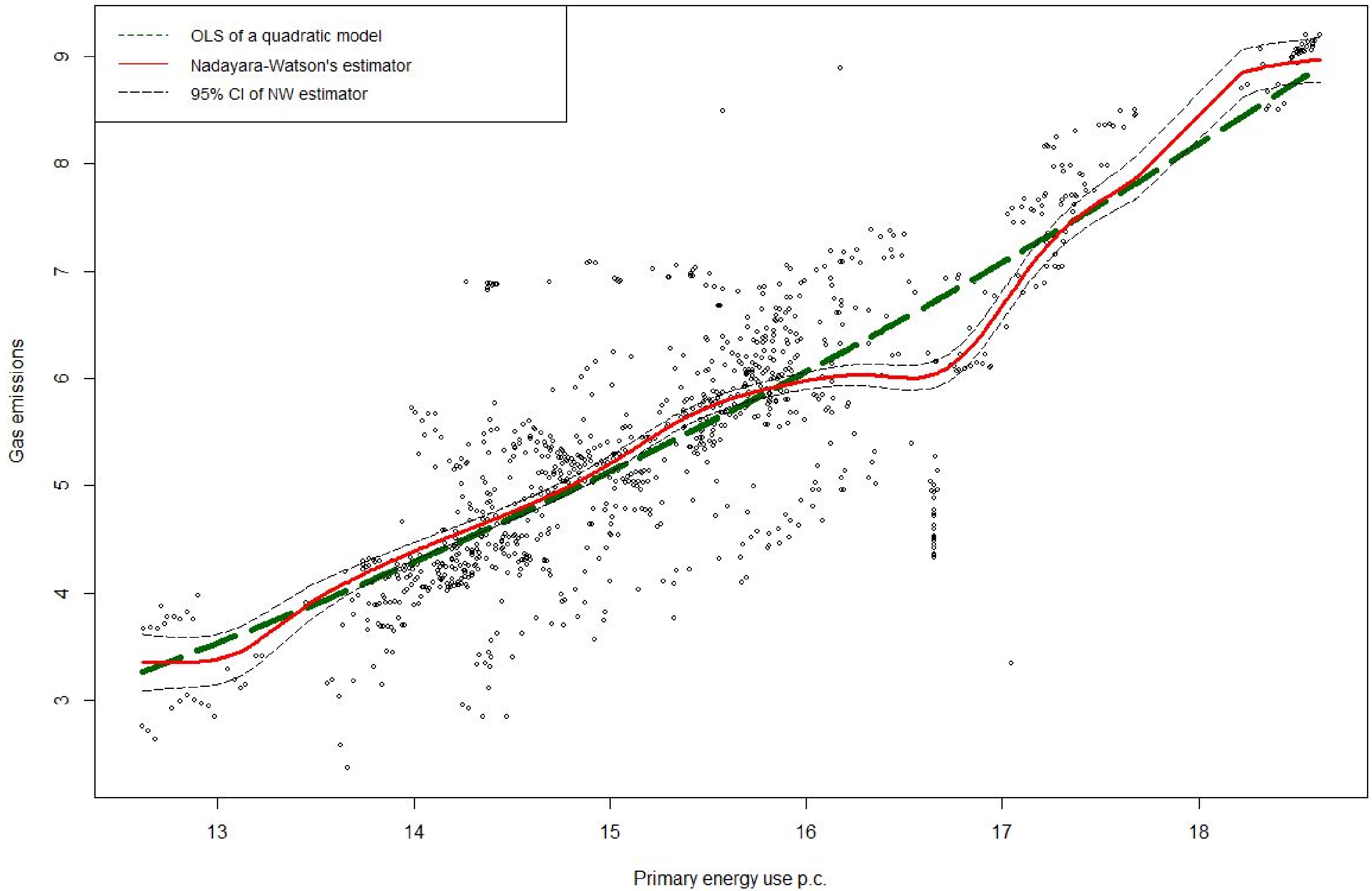

Figure 6. The CO_2 emissions and primary energy use nexus

7. Concluding Remarks

This paper assesses the relationship between carbon dioxide emissions, primary energy use and human well-being in SSA countries, arguing that economic growth does not directly and systematically promote CO_2 emissions, fossil energy consumption does. Hence, contrary to existing studies (EKC and causality analyses) linking GHG emissions to economic growth, our analysis proposes to model CO_2 emissions as directly resulting from primary energy use, the latter being promoted by efforts of improving living conditions. We address further shortcomings of existing studies such as geographical spillovers, qualitative measures of economic development (HDI) and historical considerations.

Using a recursive specification, we derive results of a first stage regression indicating that income level, education, life expectancy and access to electricity improve human development in Africa. In accordance with the comparative development literature, we control for colonial history of SSA countries and find results supporting perspectives on the colonial origins of comparative development. Specifically, our analysis suggests that being a former colony negatively impacts human development in African countries. Since current political institutions in SSA countries mostly derive from colonial and extractive institutions, they produce relatively poor performances in terms of education, life expectancy and standard of living.

Regarding the drivers of energy use, our analysis indicates that efforts of improving human well-being principally lead to primary energy use. Socio-economic characteristics of SSA countries such as population growth and access to electricity are found to promote energy demand, thus primary energy use in SSA. Based on this, we can state that fossil energy consumption notably results from energy demand (due to access to electricity) and efforts of improving living conditions. Concerning GHG emissions, the results support our argument in identifying CO_2 emissions as a direct consequence of fossil energy use in SSA, rather than economic development. As neighbouring SSA countries show similar geographical characteristics and correlated intensities in primary energy use, it is not surprising to observe positive and significant geographical spillovers in GHG emissions across SSA. A comprehensive reading of the outcomes of our recursive analysis consists in concluding that CO_2 emissions in SSA are direct consequences of fossil energy use, the latter being promoted by efforts of improving living conditions. Such a conclusion also applies to post-industrial societies, as long as energy demand resulting from efforts of improving well-being is compensated by fossil energies.

The present paper questions studies analysing causality between economic growth and GHG emissions, holding economic growth responsible for environmental pollution. It rather argues for a recursive mechanism between GHG emissions, energy and human development. Hence, in terms of environmental strategy for Africa, instead of a de-growth, this study suggests reducing fossil energy use. This implies for SSA further effort towards energy efficiency and more largely a transition from traditional and fossil to less polluting and renewable energies. Indeed, improving human well-being is a priority in SSA. Nonetheless, environmental degradation and climate change threaten the future of African societies if not dealt with. Therefore, SSA countries are encouraged to tackle the issue of increasing GHG emissions at its source by fostering private and public initiatives and investments in renewable energies and energy saving technologies.

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Supplementary Materials

Table A.1. Standard Hausman Test

	In models for HDI		In models for Energy use		In models for $Co2$	
Yearly waves	χ^2	p-value	χ^2	p-value	χ^2	p-value
Model I	77.573	.000	121.80	.000	25.975	.000
Model II	2.988	.000	32.437	.000	33.939	.000
Model III	9.272	.319	4.120	.000	37.357	.000
Model IV	15.32	.000	41.068	.000	24.91	.000
Model V	24.497	.010	33.029	.011	101.84	.000

Note: The test evaluates the consistency of the fixed-effects (FE) estimator when compared to a random-effects (RE) specification. Under the null-hypothesis there should be no systematic difference between the two estimators.

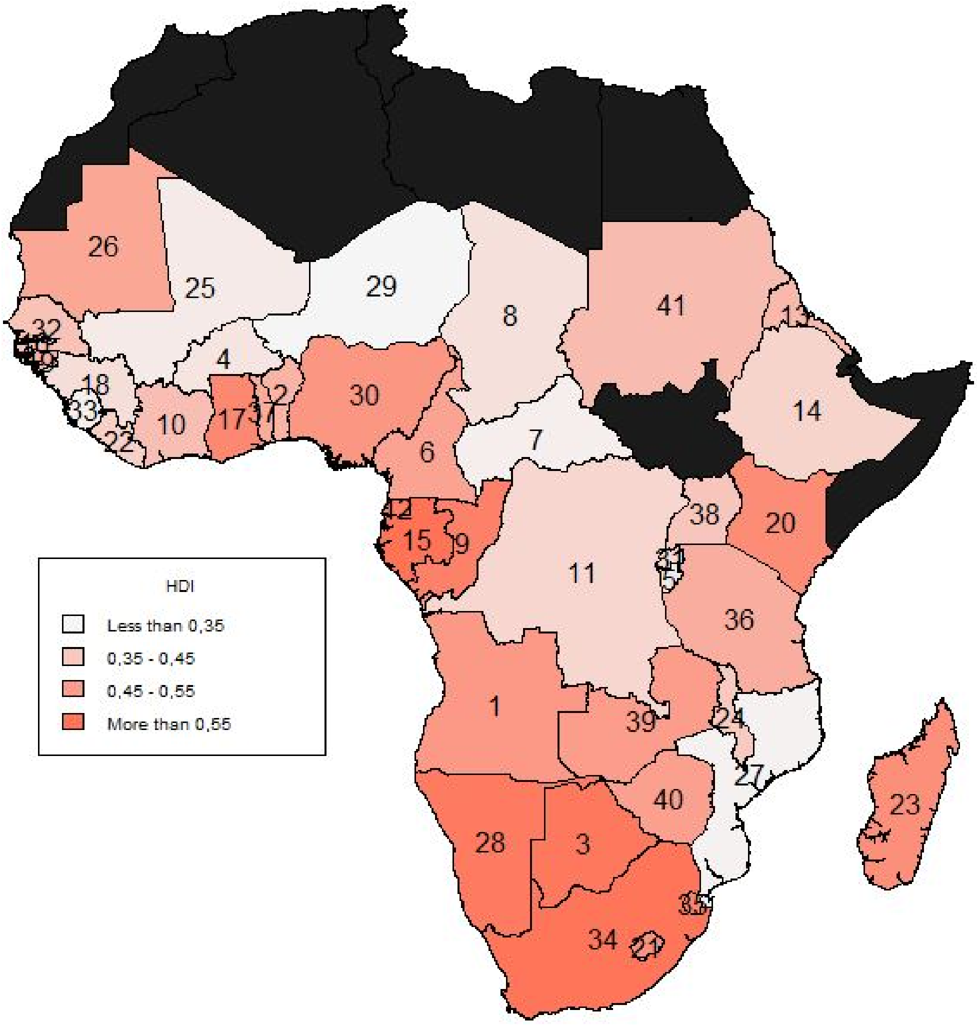

Figure A.1. Human Development Index in SSA

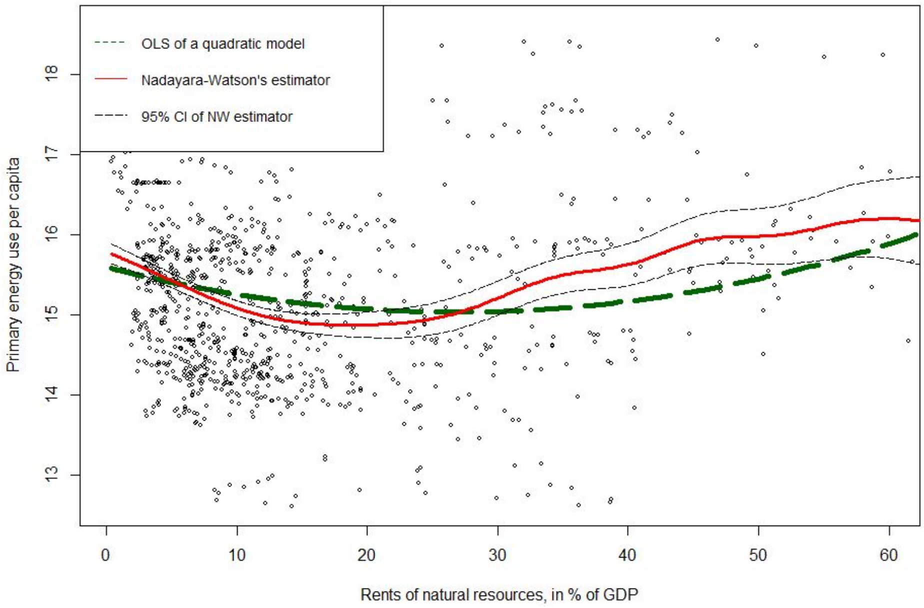

Figure A.2. Primary energy use and natural resources rents in SSA, 1990-2013

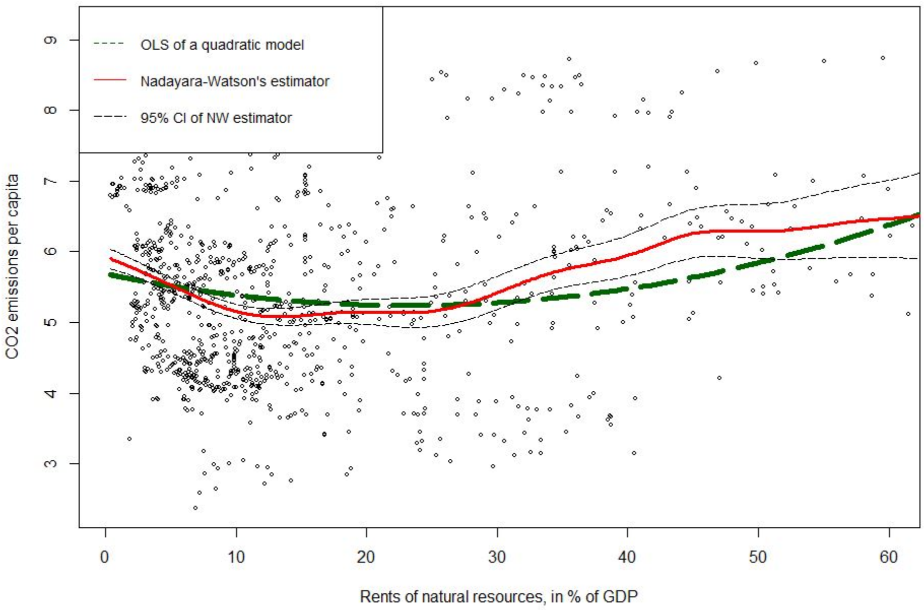

Figure A.3. CO2 emissions and natural resources rents in SSA countries, 1990-2013

Note: Assessing each of these individual relationships, we ignored the very few observations on the right of the natural resource rents i.e. very high values of resource rents in GDP. This explains why the highest value of resource rents in GDP is constrained to 60%.

Table A.2. Summary of existing empirical studies on human development, energy and GHG emissions

Authors, year	Countries/period	Y/X indicators	Model/Method	Results	Shortcoming
Pasternak (2000)	60 countries, 1997	HDI, life expectancy education/Electricity use	Correlation and Reg. analysis	+ Corr betw. Electricity use HDI + Corr betw. access to En. and human dev.	Ignore reverse causality
Martinez and Ebenhack (2008)	120 countries, 2006	HDI/Energy use p.c	Correlation analysis	+ Corr betw. access to En. and human dev.	No inference
Wu et al. (2010)	129 countries, 1998-2007	Inequality in energy use/HDI	Correlation and Reg.	energy use $\mapsto$ Human development Decreasing inequality in en. use	No in-depth inference Ignore reverse causality
Pîrlogea (2012)	6 EU countries, 1997-2008	HDI/En. use (renew. and fossil) HDI/En. intensity, CO2	FE model/GLS	Energy use has mixed effects on HDI Renew. en. use $\mapsto$ Human development	Ignore reverse causality
Niu et al. (2013)	50 countries, 1990-2009	Life exp. at birth, urban. rate/Electricity GDP p.c., Cons. expend./Electricity use	Panel Co-integration Causality analysis	Bidirectional causality HDI $\mapsto$ Electricity cons. $\mapsto$ HDI	
Roy et al. (2015)		HDI/Energy use p.c	Panel co-integration tests Panel data model	Long-run relationship Energy use $\mapsto$ Human development	Ignore reverse causality
Kazar and Kazar (2014)	154 countries, 1980-2010	HDI/Renew. En.	Granger causality tests Fixed-effects model	Various: Develop. $\mapsto$ Renew. En. in long-run Bidirectional causality in short-run	Ignore reverse causality
Satrovic (2018)	Turkey, 1992-2015	HDI/Renew. En. use	Co-integration and Granger causality tests	unidirectional causality Renew. En. $\mapsto$ HDI	Ignore reverse causality
Wang et al. (2018)	Pakistan, 1990-2014	HDI/Renew. En. use	2 SLS	Renew. Ene. use does not improve human dev. $\nearrow$ GDP $\mapsto$ $\searrow$ HDI	Inappropriate methods
Nguyen et al. (2019)	19 countries/1990-2014	HDI-Energy-CO2	System GMM	$\nearrow$ HDI $\mapsto$ $\nearrow$ CO2 No causal link betw. Energy use and human development	
Soukiazis et al. (2019)	28 OECD, 2004-2015	HDI-Renew. En.-CO2	3SLS	$\nearrow$ Renew. En. $\mapsto$ $\nearrow$HDI $\nearrow$ Total En. use $\mapsto$ $\nearrow$CO2	

Notes: Summary Table of studies on the relationship between human development indicators, energy and GHG emissions. We purposely reduced this to studies utilizing qualitative indicators of development. Recent systematic review of studies using GDP per capita are proposed by Ozturk (2010), Tiba and Omri (2017) and Mardani et al. (2019).

Supplementary Materials

Table A.3. The border-based connectivity matrix, $\omega_{n\times n}$

	[,1]	[,2]	[,3]	[,4]	[,5]	[,6]	[,7]	[,8]	[,9]	[,10]	[,11]	[,12]	[,13]	[,14]	[,15]	[,16]	[,17]	[,18]	[,19]	[,20]	[,21]	[,22]	[,23]	[,24]	[,25]	[,26]	[,27]	[,28]	[,29]	[,30]	[,31]	[,32]	[,33]	[,34]	[,35]	[,36]	[,37]	[,38]	[,39]	[,40]	[,41]
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[28,]	.250	.000	.250	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.250	.000	.000	.000	.000	.250	.000	.000
[29,]	.000	.200	.000	.200	.000	.000	.000	.200	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.200	.000	.000	.000	.000	.200	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
[30,]	.000	.250	.000	.000	.000	.250	.000	.250	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.250	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
[31,]	.000	.000	.000	.000	.250	.000	.000	.000	.000	.000	.250	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.250	.000	.250	.000	.000	.000
[32,]	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.200	.000	.200	.200	.000	.000	.000	.000	.000	.200	.200	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
[33,]	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.500	.000	.000	.000	.500	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
[34,]	.000	.000	.167	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.167	.000	.000	.000	.000	.000	.167	.167	.000	.000	.000	.000	.000	.000	.167	.000	.000	.000	.000	.167	.000
[35,]	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.333	.000	.000	.000	.000	.000	.333	.000	.000	.000	.000	.000	.000	.333	.000	.000	.000	.000	.000	.000	.000
[36,]	.000	.000	.000	.000	.125	.000	.000	.000	.000	.000	.125	.000	.000	.000	.000	.000	.000	.000	.000	.125	.000	.000	.000	.125	.000	.000	.125	.000	.000	.000	.125	.000	.000	.000	.000	.000	.000	.125	.125	.000	.000
[37,]	.000	.333	.000	.333	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.333	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
[38,]	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.200	.000	.000	.000	.000	.000	.000	.000	.000	.200	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.200	.000	.000	.000	.000	.200	.000	.000	.000	.000	.200
[39,]	.125	.000	.125	.000	.000	.000	.000	.000	.000	.000	.125	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.125	.000	.000	.125	.125	.000	.000	.000	.000	.000	.000	.000	.125	.000	.000	.000	.125	.000
[40,]	.000	.000	.250	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.250	.000	.000	.000	.000	.000	.250	.000	.000	.000	.000	.250	.000	.000
[41,]	.000	.000	.000	.000	.000	.000	.200	.200	.000	.000	.000	.000	.200	.200	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.200	.000	.000	.000

Notes: This matrix is based on common borders principle and is of dimension 41×41 (number of regions: 41). This is that countries sharing a geographical frontier are defined as neighbours (nearest country for Madagascar). A country i is not its own neighbour (0 elements on the diagonal). Number of non-zero links: 169. Percentage non-zero weights: 1.054. Average number of links: 4.122.

Figure A.4. Access to electricity (% of population) - Sub-Saharan Africa

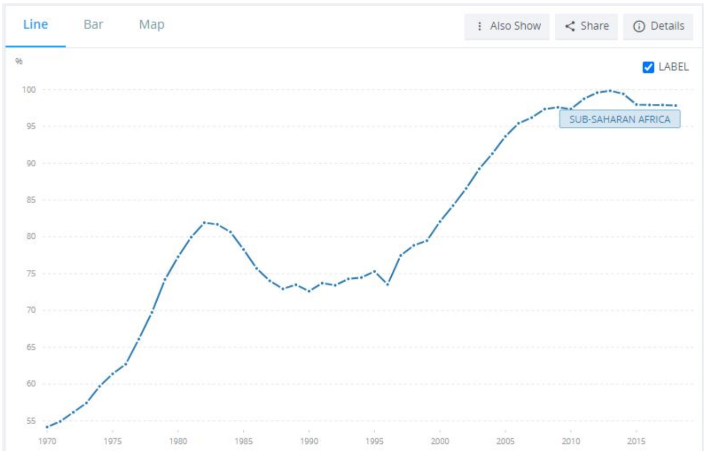

Figure A.5. School enrollment, primary (% gross) - Sub-Saharan Africa

Figure A.6. Life expectancy at birth, total (years) - Sub-Saharan Africa

Source: World Bank Data accessed on 06 June, 2020. See respectively for SM2, SM3 and SM4