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Inequality and Renewable Energy Consumption in Sub-Saharan Africa: Implication for High Income Countries

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Abstract

The study investigates conclusions from the scholarly literature that for low and middle-income countries, higher income inequality is linked with lower carbon dioxide (CO_2) emissions. Using a sample of 39 sub-Saharan countries consisting of lower- and middle-income countries, this study investigates how increasing inequality affects renewable energy consumption. Three income inequality indicators are used, namely: the Gini coefficient, the Palma ratio and Atkinson index. The empirical evidence is based on quadratic Tobit regressions. The investigated assumption is only partially valid because a net positive impact is apparent only in one of the three income inequality variables used in the study. Hence, it is difficult to establish whether the inequality or equality hypothesis underpinning the nexus between income inequality and renewable energy consumption hold for Sub-Saharan Africa. However, based on the significant results in terms of the threshold, the equality hypothesis is valid when the Atkinson index is below a threshold of 0.6180 while the inequality hypothesis becomes valid when the Atkinson index exceeds the threshold of 0.6180. Hence, as the main policy implication, for the equitable redistribution of income to be promoted and, therefore, for policies that favor income inequality for renewable energy consumption not to be encouraged, policy makers should keep the Atkinson index below a threshold of 0.6180. An implication for Europe and/or high income countries is provided, notably, that the equality hypothesis on the nexus between income inequality and CO_2 emissions may not withstand empirical scrutiny but contingent on: (i) the measurements of income inequality and (ii) inequality thresholds when a specific income inequality measurement is retained.

1. Introduction

Understanding how rising income inequality levels affect development outcomes in African countries is particularly relevant because the challenge of income inequality in African countries is critical to achieving progress towards poverty reduction and realization of Sustainable Development Goals (SDGs). Accordingly, despite some achievements in promoting inclusive development in Africa over the past 25 years, most countries in Sub-Saharan Africa (SSA) failed to reach the Millennium Development Goal (MDG) targets due to income inequality (Tchamyou, 2020). Moreover, in the light current projections, unless the concern of income inequality is critically taken on board by the attendant countries, most SDGs targets would not be achieved (Bicaba, Brixiova & Ncube, 2017). Against this background, the focus of this study which is on investigating how growing income inequality in SSA affects renewable energy consumption is premised on three main insights from the scholarly and policy literature, notably: (i) growing inequality in SSA; (ii) the imperative of promoting a green economy using renewable energy consumption in the sub-region and (iii) a hypothesis from the attendant literature that is worth engaging within the context of SSA. The critical foundational elements are substantiated in the same chronology as highlighted.

First, whereas impressive economic growth has characterized most countries in SSA since the 2000s, with many countries registering a double-digit rate of economic growth, the fruits of economic prosperity have not been translated into sustained poverty and inequality reduction (Asongu & Odhiambo, 2020a; Tchamyou, Erreygers, & Cassimon, 2019). Hence, while unequal wealth and income distribution continue to stifle the economic development prospects of the sub-region, the present study is concerned about how increasing inequality can affect renewable energy consumption owing to the documented imperative of promoting a green economy by means of renewable energy consumption in the sub-region (Nathaniel & Iheonu, 2019; Bekun, Emir & Sarkodie, 2019).

Second, both the scholarly and policy literature maintain that in the post-2015 development agenda, the promotion of renewable energy consumption in SSA should be a particularly important priority because, *inter alia*: potential unfavorable consequences of global warming, especially as it pertains to the improvement of livings standards through the adoption of cleaner energy (Niranjan, 2019; Nathaniel & Bekun, 2020). The issue of rising inequality is even more concerning because while Africa emits less than 4% of the global carbon dioxide (CO_2) emissions, its population is projected to double in 30 years, which could considerably justify a rising demand for alternative energy sources such as renewable energy

consumption. This is essentially because existing income inequality levels affect the green economy in terms of CO_2 emissions (Grunewald, Klasen, Martínez-Zarzoso & Muris, 2017).

Third, the positioning of the above inquiry departs from the contemporary literature on the nexus between inequality and environmental degradation which has largely focused on, *inter alia*: the effects of income inequality on CO_2 emissions with evidence from spatial and non-spatial perspectives (Liu, Wang, Zhang, Li & Kong, 2019) and the connection between income inequality and CO_2 emissions within country-specific frameworks (Uzar & Eyubolgu, 2019; Demir, Cergibozan & Gök, 2019). Among studies in the attendant literature, the closest research in the literature to the present study is Grunewald et al. (2017) which has investigated trade-offs between income inequality and CO_2 emissions. This study aims to assess the following conclusion of the underlying study within the specific context of SSA: "*We show that for low and middle-income economies, higher income inequality is associated with lower carbon emissions while in upper middle-income and high-income economies, higher income inequality increases per capita emissions*" (Grunewald et al., 2017, p. 249). SSA mostly consists of low- and middle-income countries because a country like Equatorial Guinea considered as an upper middle-income country in SSA is not involved in the dataset. Our objective is to assess if higher levels of inequality in SSA are associated with more renewable energy consumption which is consistent with less CO_2 emissions in the light of the conclusions of Grunewald et al. (2017). Hence, the research question being examined by this study is the following: are the conclusions of Grunewald et al. (2017) for low- and middle-income countries relevant to SSA within the framework of renewable energy consumption?

Our findings reveal that the conclusions of Grunewald et al. (2017) are only partly valid because measures of the Gini coefficient and Palma ratio do not reveal significant results. Hence, in average terms (i.e. based on the Gini coefficient), the conclusions are not valid whereas when conditional distributions of inequality are considered, the conclusions are only partially valid because the validity is apparent only in one of the two inequality indicators that capture the entire distribution of inequality (i.e. it is valid for the Atkinson index and not for the Palma ratio). However, in the light of the inequality and equality hypotheses connecting income inequality with environmental degradation, from the significant findings, the equality hypothesis is valid when the Atkinson index is below a threshold of 0.6180 while the inequality hypothesis becomes valid when the Atkinson index exceeds the threshold of 0.6180.

The theoretical underpinnings underlying the nexus between renewable energy consumption and inequality are broadly consistent with the theoretical underpinnings

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surrounding the "Environmental Kuznets Curve" (EKC) because it involves two main variables, one which is a policy syndrome (i.e. income inequality) and the other which is a policy variable (i.e. renewable energy consumption). Hence, the connection between the two main variables of interest in this study is consistent with theoretical underpinnings of the Kuznets hypothesis (Kuznets, 1955); the EKC (Selden & Song, 1994; Grossman & Krueger, 1995) and "Carbon Kuznets Curve" (CKC) (Xu & Song, 2011). These theoretical underpinnings are further substantiated in Section 2 in the light of more specific hypotheses underpinning the nexus between income inequality and environmental degradation.

The rest of the study is structured as follows. There is a literature review section after this introduction. The data and methodology are discussed in the next section which is followed by another section on empirical results. The study concludes with a section on the main implication of the study and future research directions.

2. Theoretical and empirical literature

In accordance with Grunewald et al. (2017), there is no consensus in the theoretical literature neither in the direction of causality nor in the signs of effects between inequality and environmental degradation. This is essentially because, *inter alia*, economists have provided a plethora of theoretical arguments to elucidate the underlying nexus. Theoretical arguments for an "equality hypothesis" support a positive nexus in view of the fact that inequality increases environmental degradation. Studies supporting this strand of theoretical literature include Borghesi (2006), Torras and Boyce (1998) and Boyce (1994). Conversely, another strand of the literature on the inequality hypothesis argues for a trade-off between environmental quality and redistributive policies, such that income inequality is negatively linked to environmental degradation (Scruggs, 1998; Ravallion, Heil & Jalan, 2000; Heerink, Mulatu & Bulte, 2001). The two attendant equality (i.e. Hypothesis 1) and inequality (i.e. Hypothesis 2) hypotheses are provided below:

*Hypothesis*1: there is a positive nexus between income inequality and environmental degradation (i.e. the equality hypothesis).

Hypothesis 2: there is a negative linkage between income inequality and environmental degradation (i.e. the inequality hypothesis).

In the light of the outcome variable in this study which is renewable energy consumption, the two underlying hypotheses could be rewritten as follows.

Hypothesis 3: there is a negative nexus between income inequality and renewable energy consumption (i.e. the equality hypothesis).

Hypothesis 4: there is a positive linkage between income inequality and renewable energy consumption (i.e. the inequality hypothesis).

Consistent with Grunewald et al. (2017) on the perspective that the theoretical literature remains ambiguous on the sign linking income inequality to environmental degradation, especially on the premise that the nexus could also be non-monotonous; the modeling in this study is such that quadratic regressions are taken on board to enable the manifestation of both Hypotheses 3-4 within the same regression framework.

Granting that economies with skewed income classes are linked with high levels of income inequality, it is also important to view   Hypotheses 2 and 4 in the perspective of microeconomic studies which support the association between higher income classes and less carbon footprints (Grunewald, Harteisen, Lay, Minx & Renner. 2012; Serino & Klasen, 2015). However, the extant contemporary literature is largely dominated by findings supporting Hypotheses 1 and 3, notably that the income inequality promotes environmental degradation and/or reduces renewable energy consumption. The corresponding empirical studies are discussed as follows.

Uzar (2020) investigates how income inequality affects renewable energy consumption in 43 countries using a panel autoregressive distributed lag approach and concludes that when income distribution is fairer, it has a positive incidence on renewable energy consumption. Hence, given that the trade-off hypotheses (i.e. Hypotheses 2 and 4) are not valid, the author recommends policy makers to simultaneously promote environmental quality and the fair distribution of income.

McGee and Greiner (2019) explore how income inequality at the national level modulates the nexus between CO_2 emissions and renewable energy consumption in 175 countries for the period 1990-2014. They conclude by arguing that policies designed to enhance the consumption of renewable energy should be tailored towards reducing income inequality as well as effectively displacing fossil fuels.

Bai et al. (2020) are concerned with assessing whether income inequality would affect the abatement impact of innovation in renewable energy technology on environmental degradation in terms of CO_2 emissions. They establish a significant threshold impact with

regards to income inequality and recommend that measures designed to reduce inequality in income can further contribute towards reducing CO_2 emissions.

Li, Zhang, Zhang and Ji (2019) examine if gender inequality influences household green energy consumption in China. The study concludes that enhanced inequality engenders less green consumption in households in China. Within the same scope of China, Liu, Wang, Zhang, Li and Kong (2019) have examined the impact of income inequality of CO_2 emissions within spatial and non-spatial frameworks to establish that income inequality, especially the spatial distribution of income that is uneven, promotes CO_2 emissions.

Uzar and Eyuboglu (2020) have focused on the linkage between income inequality and CO_2 emissions in Turkey using an ARDL empirical strategy. They find that CO_2 emissions are positively affected by income inequality in the country. The authors recommend that fairer income distribution should be encouraged in order to promote environmental quality.

In the light of the above theoretical and empirical studies, it is apparent that there is yet no consensus in the literature on the relationship between environmental degradation and income inequality. The present study attempts to merge both strands of the debate by assessing the conclusions of Grunewald et al. (2017) within the framework of quadratic regressions. It follows that if the nexus is non-monotonic with an established threshold of income inequality, both strands of the empirical and theoretical literature can be apparent before or after the attendant threshold.

3. Data and methodology

3.1 Data

To examine the testable conclusion of Grunewald et al.(2017),enunciated in the previous section, the present study engages 39 countries in Sub-Saharan Africa using data for the period 2004-2014[1].It is worth articulating that the adopted sample and periodicity are informed by constraints pertaining to data availability at the time of the study. The variables are sourced from a plethora of databases, *inter alia*: (i) the Global Consumption and Income Project (GCIP); (ii) the World Bank's World Development Indicators (WDI); (iii) the World Bank's World Governance Indicators (WGI) and (iv) the World Bank's Financial

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[1] The 39 sampled countries are: "Angola; Benin; Botswana; Burundi; Cabo Verde; Cameroon; Central African Republic; Chad; Comoros; Congo Democratic Republic; Congo Republic; Cote D'Ivoire; Eswatini; Gabon; Gambia; Ghana; Guinea; Guinea-Bissau; Kenya; Lesotho; Liberia; Madagascar; Malawi; Mali; Mauritius; Mozambique; Namibia; Niger; Nigeria; Rwanda; Sao Tome and Principe; Senegal; Seychelles; Sierra Leone; South Africa; Sudan; Tanzania, Togo and Uganda"

Development and Structure Database (FDSD). In what follows, the attendant variables are discussed.

First, three main inequality variables which are the independent indicators of interest are sourced from the GCIP, notably: the Palma ratio, the Atkinson index and the Gini coefficient. The first-two variables are used to complement the last variable because the last variable does not capture the extreme points of the inequality distribution (Tchamyou, 2020). In other words, it is because the Gini coefficient fails to articulate the richest and the poorest in the inequality distribution that in an effort for robustness, the first-two are brought on board. (i) The Gini coefficient is defined as the distribution of income across the population in a country, with a value of 1 representing a situation in which all the national wealth is distributed to a few wealthy individuals while the value of 0 denotes a situation where citizens have equal incomes. (ii) The Atkinson index reflects the proportion of the total income that a specific society is willing to sacrifice in order to promote the distribution of equal income across the population. (iii) The Palma ratio is the share of national income of the top 10% of households against the bottom 40%. The choice of the Atkinson index and the Palma ratio to complement the Gini coefficient is consistent with contemporary income inequality literature (Naceur & Zhang, 2016; Tchamyou, 2020).

The adopted outcome indicator from WDI which is renewable energy consumption (% of total final energy consumption) is informed by contemporary energy consumption literature, notably, Nathaniel and Iheonu (2019), Asongu et al. (2019) and Akinyemi et al. (2019).

In order to control for variable omission bias, eight control variables are taken on board, two dummy variables and six non-dummy variables. The non-dummy variables are financial access, mobile phone penetration, regulation quality, CO_2 emissions per capita, trade openness and the urban population. The dummy variables are captured by middle-income countries and petroleum-exporting countries. The choice of the control variables is informed by contemporary environmental sustainability literature (Asongu, 2018; Nathaniel & Iheonu, 2019; Akinyemi et al., 2019). It is difficult to establish the expected signs because dummy variables have been taken on board in a quadratic regression estimation exercise. Accordingly, the estimation exercise which is based on quadratic regressions implies that concerns about multicollinearity among the dummy variables, non-dummy variables and quadratic interactions can lead to control variables reflecting the unexpected signs (Beck,

Demirgüç-Kunt & Levine, 2003)[2]. However, in quadratic regressions, the concern of multicollinearity is not an issue because the interacted variables are not interpreted as linear additive models (Brambor, Clark & Golder, 2006). It follows from the underlying that this study only expects significant estimated coefficients between the outcome variable and the independent control variables, while making abstraction to the signs of corresponding estimated coefficients from the independent control variables. The definitions and corresponding sources of the variables are displayed in Appendix 1, the summary statistics is provided in Appendix 2, while Appendix 3 discloses the corresponding correlation matrix. In what follows, the specific literature motivating the choice of control variables is discussed.

First, while financial development has been established to promote environmental quality by decreasing CO_2 emissions (Odhiambo, 2020), in countries where financial access is skewed in favor of the rich and not allocated to the pursuit of investments that are associated with renewable energy consumption, the opposite effect can be anticipated (Abbasi & Riaz, 2016; Acheampong, 2019). Second, the mobile phone has been established to contribute towards promoting environmental sustainability if it enables users to *inter alia*, reduce activities linked to CO_2 emissions and encourage activities that are favorable to renewable energy consumption (Asongu, le Roux & Biekpe, 2017, 2018). Third, while regulation quality which is a dimension of economic governance is expected to enable the respect of measures designed to promote environmental quality, the underlying effect can also be the opposite if regulation quality is negatively skewed (Zhao, Yin & Zhao, 2015). Fourth, from intuition, CO_2 emissions should be negatively related with renewable energy consumption because the latter is theoretically and practically meant to reduce the former. Fifth, consistent with Asongu (2018), trade openness and population growth affect environmental degradation by means of CO_2 emissions. This is essentially because trade activities engender CO_2 emissions and the propensity to emit CO_2 emissions is also contingent on the size of the population. Six, middle-income countries which are largely resource-wealthy countries in SSA can be associated with less CO_2 emission because wealthier countries have more financial resources with which to

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[2] *"The political indicators sometimes enter negatively and significantly, perhaps because the predicted components of the political and adaptability channels are highly correlated. Although we did obtain the same results when we added many additional instrumental variables, we interpret these results cautiously and note that they do not imply that the political channel is unimportant in general"* (Beck et al., 2003, p. 671)."*Our sample comprises 43 countries with British common law, 61 countries with French civil law, six countries with German civil law and five Scandinavian civil law countries. We omit the Scandinavian legal origin from the regressions to avoid multicollinearity*" (Beck et al., 2003, p. 663).

invest in renewable energy consumption. Conversely, the opposite effect can also be apparent if the country is characterized by poor governance standards.

3.2 Methodology

The empirical strategy considered by this study is in accordance with the attendant literature on the need for the adopted empirical strategy to align with the data behavior used in the study (Lashitew, van Tulder & Liasse, 2019). The outcome variable in this study, as apparent in Appendix 1, is renewable energy consumption (% of total final energy consumption). It follows that the corresponding outcome variable is theoretically and practically situated within an interval of 0% and 100%. In the light of the specific interval characterizing the outcome variable, a Tobit estimation approach is adopted for the study because the attendant estimation technique has been documented by both the contemporary literature mentioned above, as well as the non-contemporary Tobit-centric studies which underline the essence that the choice of the Tobit estimation strategy should be motivated by outcome variables for which minimum and maximum values are clearly articulated (Kumbhakar & Lovell, 2000; Koetter & Vins, 2008; Coccorese & Pellecchia, 2010; Ariss, 2010).

In the light of the above clarification of the nature of the renewable energy consumption outcome variable, the relevance of the Tobit model is based on the fact that the outcome variable is censored from 0 to 100. Consequently, a double censored Tobit regression model is used to account for the distributions of the outcome variable at extreme points of the outcome variable. To put this observation into more perspective, it is worth articulating that compared to the double censored Tobit approach, an Ordinary Least Squares (OLS) technique cannot feasibly generate consistent estimated coefficients because the OLS approach is not designed to take on board, the conditional probability of limit observations that characterize the outcome variable. Accordingly, the underlying technique is adapted to address limit observations of 0% renewable energy consumption and 100% renewable energy consumption (Amemiya, 1984). It follows from the above narrative that a double censored empirical strategy adopted in this study takes on board extreme points of the renewable energy consumption distribution.

The standard framework for a Tobit estimation is disclosed in Equations (1) and (2) below (Tobin, 1958; Carson & Sun, 2007).

$$y_{i,t}^{*} = \alpha_0 + \beta X_{i,t} + \varepsilon_{i,t}, \qquad\qquad (1)$$

where $y_{i,t}^{*}$ is a latent response variable, $X_{i,t}$ is an observed $1 \times k$ vector of explanatory variables and $\varepsilon_{i,t} \approx$ i.i.d. N(0, σ²) and is independent of $X_{i,t}$. As opposed to observing $y_{i,t}^{*}$, we observe $y_{i,t}$:

$$y_{i,t} = \begin{cases} y_{i,t}^{*}, & \text{if } y_{i,t}^{*} > \gamma \\ 0, & \text{if } y_{i,t}^{*} \leq \gamma, \end{cases} \qquad (2)$$

where γ is a non-stochastic constant. It follows that, the value of $y_{i,t}^{*}$ is missing when it is less than or equal to γ.

In line with the corresponding Tobit-centric literature (Lashitew et al., 2019), the following assumptions are typically consistent with a Tobit model: (i) the residuals are characterized by a normal distribution and (ii) unbounded latent dependent variables reflect a linear function of the predicting indicators (Amemiya, 1984). The corresponding predictors display two effects, notably: one that represents the marginal effect of the underlying predictors on the latent, unobserved rate of renewable energy consumption and the other that shows the observed, censored adoption rateof renewable energy consumption. Contrary to Lashitew et al. (2019) which only discloses one of the two effects, in the results that are presented in section 4 below, the two impacts on renewable energy consumption are disclosed for robustness purposes.

4. Empirical results

The empirical results are disclosed in this section in Table 1, which is divided into seven main columns: the first column provides the definitions of variables and corresponding information criteria while the last-six disclose three main sets of specifications, each corresponding to one of the three engaged inequality variables. In essence, the specifications from the left-hand to the right-hand side focus on the Gini coefficient, the Atkinson index and the Palma ratio.

Table 1: Inequality and renewable energy consumption (Tobit regressions)

	Gini Coefficient		Atkinson Index		Palma Ratio	
	Coefficient	dy/dx	Coefficient	dy/dx	Coefficient	dy/dx
Constant	-18.515 (0.880)	---	**535.434*** (0.000)**	---	**47.332** (0.019)**	---
Gini Coefficient (Gini)	240.246 (0.492)	215.115 (0.492)	---	---	---	---
Atkinson Index (Atkinson)	---	---	**-1479.169*** (0.000)**	**-1324.825*** (0.000)**	---	---
Palma Ratio (Palma)	---	---	---	---	6.902 (0.131)	6.183 (0.130)
Gini × Gini	-102.982 (0.669)	-92.21 (0.669)	---	---	---	---
Atkinson × Atkinson	---	---	**1196.712*** (0.000)**	**1071.841*** (0.000)**	---	---
Palma × Palma	---	---	---	---	-0.093 (0.700)	-0.083 (0.700)
Financial Access	-0.538 (0.000)	**-0.482*** (0.000)**	**-0.512*** (0.000)**	**-0.458*** (0.000)**	**-0.525*** (0.000)**	**-0.471*** (0.000)**
Mobile Phone	0.004 (0.926)	0.004 (0.926)	0.015 (0.742)	0.014 (0.742)	0.025 (0.601)	0.023 (0.601)
Regulation Quality	2.887 (0.520)	2.585 (0.519)	2.607 (0.514)	2.335 (0.513)	2.959 (0.499)	2.651 (0.498)
CO2 emissions per capita	-0.661 (0.503)	-0.592 (0.503)	**-3.298*** (0.0009)**	**-2.954*** (0.008)**	**-2.303** (0.030)**	**-2.063** (0.028)**
Trade Openness	**-0.129*** (0.002)**	**-0.115*** (0.002)**	**-0.140*** (0.001)**	**-0.125*** (0.001)**	**-0.123*** (0.004)**	**-0.110*** (0.003)**
Urban Population	0.222 (0.218)	0.199 (0.215)	0.263 (0.116)	0.236 (0.113)	0.195 (0.256)	0.175 (0.253)
Middle Income Countries	**-7.801*** (0.009)**	**-6.985*** (0.008)**	**-7.950*** (0.003)**	**-7.120*** (0.002)**	**-6.788** (0.015)**	**-6.081** (0.014)**
Petroleum Exporting Countries	-2.527 (0.554)	-2.262 (0.553)	**-6.833* (0.064)**	**-6.120* (0.062)**	-2.152 (0.560)	-1.928 (0.560)
Net Effects	na	na	205.801	184.327	na	na
Thresholds	na	na	0.6180	0.6180	na	na
Fisher	**129.21***		**105.70***		**125.86***	
Observations	245	245	245	245	245	245

***,**,*: significance levels at 1%, 5% and 10% respectively.dy/dx: average marginal effects. na: not applicable because at least estimated coefficient needed for the computation of the net effects and thresholds is not significant. The average value of the Atkinson index is 0.704.

The following findings are apparent from the table. First, while findings from specifications pertaining to the Gini coefficient and Palma ratio do not lead to significant results, those related to the Atkinson index reflect significant estimates. However, in order to avoid the pitfalls documented in Brambor et al. (2006) for interactive and quadratic regressions, the net effects of growing inequality are computed. The computation is informed by contemporary literature based on quadratic estimations (Asongu & Odhiambo, 2020b). For instance, in the fourth column of Table 1, the net effect of increasing the Atkinson index on renewable energy consumption is 205.801 (2×[1196.712× 0.704] + [-1479.169]).In the underlying calculation, -1479.169 is the unconditional effect of the Atkinson index on renewable energy consumption, 0.704 is the average value of the Atkinson index, 1196.712 is the marginal effect of the Atkinson index while the leading 2 corresponds to the quadratic derivation. The Atkinson index threshold corresponding to the underlying net effect is 0.6180=1479.169/ (2×1196.712). In the same vein, in the fifth column of Table 1, the net

marginal effect on renewable energy consumption is 184.327 (2×[1071.841× 0.704] + [-1324.825]) while the corresponding thresholds or cut off point is 0.6180=1324.825/ (2×1071.841). The computed thresholds are critical masses at which the effect of the Atkinson index on renewable energy consumption changes from negative to positive. Most of the significant control variables have the expected signs. Even when the control variables are not significant, most of the corresponding signs are consistent with the narrative in the data section as it pertains to their anticipated signs.

In the light of the above, the conclusions of Grunewald et al. (2017) motivating this study, (as clearly articulated in the introduction) are only partially valid because: (i) they are exclusively relevant to one of the three income inequality variables used in this study and (ii) higher levels of the Atkinson index are associated with the green economy in terms of higher levels of renewable energy consumption when the Atkinson index has reached a threshold of 0.6180.

The established findings in terms of net effect with respect to the Atkinson index are contrary to a strand of the literature on the equality hypothesis that posits a positive nexus between income inequality and CO_2 emissions, *inter alia*: Lui et al. (2019) who have concluded that income inequality, especially within the framework of the spatial distribution of incomes, increases CO_2 emissions, and Uzar and Eyubolgu (2019) who have established that income inequality positively affects CO_2 emissions. While this study has partially confirmed the findings of Grunewald et al. (2017), it is also worthwhile to note that these unexpected findings are not particularly unexpected because two decades ago, Ravallion, Heil and Jalan (2000) also found that with higher income inequality both within and between countries inequality dynamics are linked to lower CO_2 emissions. More recently, Demir et al. (2019) have concluded that income inequality decreases environmental degradation.

If we make abstraction to the net effects and the significant findings are now observed from the prism of the establish Atkinson index thresholds, it becomes apparent that in the light of the formulated hypotheses in Section 2 pertaining to renewable energy consumption, both Hypothesis 3 and Hypothesis 4 are valid. This is essentially because the equality hypothesis is valid when the Atkinson index is below a threshold of 0.6180, while the inequality hypothesis becomes valid when the Atkinson index exceeds the threshold of 0.6180. Accordingly, there is a negative relationship between income inequality and renewable energy consumption because the unconditional effect of the Atkinson index on renewable energy consumption is negative. However, owing to the positive marginal effect of the Atkinson index on renewable energy consumption, the unconditional negative effect is

nullified when the Atkinson is 0.6180 and above the critical mass, the overall effect of the Atkinson index on the renewable energy consumption becomes positive, thus supporting the trade-off or inequality hypothesis (or Hypothesis 4).

The above non-monotonic perspective in the findings supports the stance that the adopted quadratic modeling approach gives room for policy implications that are not blanket, not least, because the examined nexuses are contingent on a critical mass or threshold of income inequality. Hence, countries promoting income inequality and by extension, the equality hypothesis underpinning the linkage between income inequality and environmental degradation should not allow the Atkinson index to exceed the established threshold of 0.6180. This policy perspective is supported by a growing strand of contemporary studies maintaining the equality hypothesis covered in Section 2 notably: Uzar and Eyuboglu (2020), Liu et al. (2019) on the linkage between CO_2 emissions and income inequality; Li et al. (2019) on the detrimental role of gender inequality in promoting household green consumption and studies on the nexus between renewable energy consumption and income inequality which maintain that fair redistribution of income promotes renewable energy consumption (McGee & Greiner, 2019; Bai et al., 2020; Uzar, 2020).

5. Concluding implications and future research directions

The study investigates conclusions from the scholarly literature that for low and middle-income countries, higher income inequality is linked with lower carbon dioxide (CO_2) emissions. Using a sample of 39 Sub-Saharan countries (SSA) consisting of lower- and middle-income countries, this study investigates how increasing inequality affects renewable energy consumption. Within this framework, the purpose of this study is to assess the following conclusion "*We show that for low and middle-income economies, higher income inequality is associated with lower carbon emissions while in upper middle-income and high-income economies, higher income inequality increases per capita emissions*" (Grunewald et al., 2017, p. 249). The objective is to assess if higher levels of inequality in SSA are associated with more renewable energy consumption. Three income inequality indicators are used, namely: the Gini coefficient, the Palma ratio and Atkinson index. The empirical evidence is based on quadratic Tobit regressions.

The investigated conclusion of Grunewald et al. (2017) is only partially valid because a net positive impact is exclusively relevant to one of the three income inequality variables used in the study. Accordingly, when the Atkinson index has reached a threshold of 0.6180, higher levels of the Atkinson index are linked with a green economy in terms of higher levels

of renewable energy consumption. This examined conclusion is only partly valid because measures of the Gini coefficient and Palma ratio do not reveal significant results. Hence, in average terms (i.e. based on the Gini coefficient), the hypothesis is not valid because when conditional distributions of inequality are considered, the hypothesis is only partially valid given that the validity is apparent only in one of the two inequality indicators that capture the entire distribution of inequality.

The research which is focused on extending the findings of Grunewald et al. (2017) within the context of SSA has contributed to the empirical literature on the nexus between CO_2 emissions and income inequality because compared to the underlying study (i.e. Grunewald et al., 2017), this study has: (i) been restricted to SSA countries where the concerns of inequality and consequences of environmental degradation are very worrisome (compared to 158 countries used in the study being extended); (ii) used three income inequality indicators (compared to the underlying study which has focused exclusively on the Gini coefficient); (iii) focused on renewable energy consumption as the outcome variable instead of CO_2 emissions and (iv) employed Tobit regressions that account for some fixed effects in the light of the behavior of the outcome variable, instead of a fixed effects estimator as in the underlying study. Moreover, in order to better inform policy makers, this study has provided a specific threshold or critical mass at which the inequality hypothesis (i.e. on the nexus between income inequality and environmental degradation) formulated in Section 2 is valid.

Considering the findings in the light of the theoretical literature, it is worthwhile to note that from a perspective of net effects, the findings are consistent with the attendant theoretical studies (Ravallion et al., 2000; Heerink, Mulatu, & Bulte,2001) on the importance of income inequality in CO_2 emissions in developing countries because, in the corresponding countries, an already existing wealthy proportion of the population may be associated with lower likelihoods to emit CO_2 emissions, relative to poor fractions of the population which cannot afford the initial costs associated with renewable energy consumption and hence, is constrained to continue relying on traditional sources of energy or fossil fuels for a livelihood.

However, if we make abstraction to the net effects and the significant findings are now observed from the prism of the established Atkinson index threshold, it becomes apparent that in the light of the formulated hypotheses in Section 2 pertaining to renewable energy consumption, both Hypothesis 3 and Hypothesis 4 are valid. This is mainly because the equality hypothesis is valid when the Atkinson index is below a threshold of 0.6180, while the

inequality hypothesis becomes valid when the Atkinson index exceeds the threshold of 0.6180.

Two main policy implications can be drawn from the findings. First, for income equality and equitable redistribution of income to be promoted and therefore for policies that favor income inequality for renewable energy consumption not to be encouraged, policy makers should keep the Atkinson index below a threshold of 0.6180. Second, the hypothesis of Grunewald et al. (2017) investigated in this study is relevant to low, middle and high income economies. While this study has focused on low and middle income economies to establish that the conclusions Grunewald et al. (2017) applying to the said countries are only partially valid contingent on inequality thresholds, an obvious implication for high income economies such as Europeans countries may be that, the corresponding conclusions on the equality hypothesis (i.e. on the nexus between income inequality and CO_2 emissions) applying to wealthy countries also withstand empirical scrutiny contingent on: (i) the measurements of income inequality and (ii) inequality thresholds when a specific income inequality measurement is retained.

Future research can investigate if the established findings withstand empirical scrutiny for the sampled countries within country-specific frameworks. Such country-specific orientations which are worthwhile for country-specific policy implications should also build on the relevant empirical strategies that are more robust for country-specific studies. Moreover, extending the analysis to high income regions such as Europe to investigate the implications of this study as they pertain to the conclusions of Grunewald et al. (2017) is worthwhile.

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Appendices

Appendix 1: Definitions of Variables

Variables		Definitions of variables (Measurements)	Sources
Income inequality proxies	Gini Coefficient	*"The Gini coefficient is a measurement of the income distribution of a country's residents"*.	GCIP
	Atkinson Index	*"The Atkinson index measures inequality by determining which end of the distribution contributed most to the observed inequality"*.	GCIP
	Palma Ratio	*"The Palma ratio is defined as the ratio of the richest 10% of the population's share of gross national income divided by the poorest 40%'s share"*.	GCIP
Renewable energy (Renenc)		Renewable energy consumption (% of total final energy consumption)	WDI
Financial access (Pcrdof)		Private domestic credit from deposit banks and other financial institutions (% of GDP)	FDSD
Mobile phones (Mobile)		Mobile cellular subscriptions (per 100 people)	WDI
Regulation quality (RQ)		"Regulation quality (estimate): measured as the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development"	WGI
CO_2 emissions per capita (CO_2)		CO_2 emissions (metric tons per capita)	WDI
Trade openness (Trade)		Imports plus Exports of Goods and Services (% of GDP)	WDI
Urban population (Upop)		Urban Population (% of Total Population)	WDI
Middle income (MI)		"There are four main World Bank income groups: (i) high income, $12,276 or more; (ii) upper middle income,$3,976-$12,275; (iii) lower middle income, $1,006-$3,975 and (iv) low income, $1,005 or less".	WDI, Asongu, Nwachukwu and Pyke (2019)
Petroleum exporting countries (Oil)		"Stratification by natural resource-wealth is exclusively based on petroleum exports which represent at least 30 percent of the country's GDP for a minimum of one decade of the study period"	WDI, Asongu, Nwachukwu and Pyke (2019)

WDI: World Bank Development Indicators of the World Bank
(https://databank.worldbank.org/source/worlddevelopment-indicators).
FDSD: Financial Development and Structure Database of the World Bank
(https://www.worldbank.org/en/publication/gfdr/data/financial-structure-database).
GCIP: Global Consumption and Income Project (http://gcip.info/).
WGI: World Governance Indicators of the World Bank (https://info.worldbank.org/governance/wgi/).

Appendix 2: Summary statistics (2004-2014)

	Mean	SD	Minimum	Maximum	Observations
Gini Coefficient	0.586	0.034	0.488	0.851	428
Atkinson Index	0.704	0.057	0.509	0.834	428
Palma Ratio	6.454	1.477	3.015	14.434	428
Renewable energy	66.216	25.810	0.354	97.882	406
Financial Access	21.055	25.319	0.873	150.209	414
Mobile Phones	47.148	37.672	1.272	171.375	425
Regulation quality	-0.601	0.544	-1.879	1.123	429
CO_2 emissions per capita	0.934	1.823	0.020	9.979	429
Trade Openness	76.756	41.186	19.458	311.354	415
Urban Population	16.792	11.034	4.595	59.915	264
Middle Income Countries	0.410	0.492	0.000	1.000	429
Petroleum Exporting Countries	0.179	0.384	0.000	1.000	429

S.D: Standard Deviation. CO_2: Carbon Dioxide.

Appendix 3: Correlation matrix (uniform sample size: 245)

	Renenc	Gini	Atkinson	Palma	Finance	Mobile	RQ	CO_2	Trade	Upop	MI	Oil
Renenc	1.000											
Gini	0.217	1.000										
Atkinson	0.264	0.800	1.000									
Palma	0.264	0.969	0.868	1.000								
Finance	-0.493	-0.104	-0.194	-0.133	1.000							
Mobile	-0.021	0.181	0.037	0.186	0.079	1.000						
RQ	0.139	0.421	0.159	0.418	0.031	0.295	1.000					
CO_2	0.116	0.734	0.493	0.771	-0.078	0.444	0.496	1.000				
Trade	-0.087	-0.055	0.095	-0.044	-0.099	-0.004	-0.370	-0.049	1.000			
Upop	0.010	0.223	0.245	0.239	-0.106	0.359	-0.264	0.334	0.560	1.000		
MI	-0.071	0.124	0.087	0.156	-0.054	0.291	0.008	0.403	-0.180	0.200	1.000	
Oil	-0.080	-0.273	-0.099	-0.201	-0.126	0.018	-0.478	-0.047	0.088	0.274	0.330	1.000

Renenc: Renewable Energy Consumption. Gini :the Gini Coefficient. Atkinson: the Atkinson Index. Palma: the Palma Ratio. Finance:
Financial Access. Mobile: Mobile Phones Penetration. RQ: Regulation Quality. CO_2: Carbon dioxide emissions. Trade: Trade Openness.
Upop: Urban Population. MI: Middle Income. Oil: Petroleum-Exporting Countries.