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The Conditional Relationship between Renewable Energy and Environmental Quality in Sub-Saharan Africa [1]

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Simplice A. Asongu
African Governance and Development Institute,
P. O. Box 8413, Yaoundé, Cameroon
E-mails: asongusimplice@yahoo.com / asongus@afridev.org

Chimere O. Iheonu
Department of Economics,
University of Nigeria, Nsukka.
E-mail: iheonuchimere@yahoo.com

Kingsley O. Odo
Department of Economics,
University of Nigeria, Nsukka
E-mail: obinnakingsley35@yahoo.com

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The Conditional Relationship between Renewable Energy and Environmental Quality in Sub-Saharan Africa

Simplice A. Asongu, Chimere O. Iheonu & Kingsley O. Odo

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Abstract

This paper complements existing literature by assessing the conditional relationship between renewable energy and environmental quality in a sample of 40 African countries for the period 2002 to 2017. The empirical evidence is based on fixed effects regressions and quantile fixed effects regressions. The findings from both estimation techniques show that renewable energy consistently decreases carbon dioxide (CO_2) emissions. Moreover, the negative effect is a decreasing function of CO_2 emissions or the negative effect of renewable energy on CO_2 emissions decreases with increasing levels of CO_2 emissions. In other words, countries with higher levels of CO_2 emissions consistently experience a less negative effect compared to their counterparts with lower levels of CO_2 emissions. Policy implications are discussed.

JEL Classification: Q32; Q40; Q45; O55

Keywords: Panel econometrics; Renewable energy; Carbon emissions; Africa

1. Introduction

Countries in Sub-Saharan Africa (SSA) in particular and Africa in general are in the position of adopting innovative and sustainable technologies which, if properly leveraged, could put the region and the continent into the global spotlight of playing a leading role in shaping a sustainable energy future, due to abundant and substantial renewable energy sources (IRENA, 2019). Renewable energy and associated technologies provide a major benefit in lowering CO_2 emissions and other Greenhouse Gases (GHGs) compared to fossil-fuel based sources. Renewable energy is that energy derived from renewable resources and is naturally restocked on a human timescale such as tide, wind, hydro, sunlight, ocean thermal, biomass, geothermal and waves (IEA, 2013; Ellabban et al., 2014; Asongu et al., 2017, 2018; Shahbaz and Sinha, 2019; Shahbaz et al., 2019a, 2019b; Zafar et al., 2019; Bekun and Agboola, 2019; Bekun and Akadiri, 2019).

The driving forces propelling the shift from fossil fuel to renewable energy for electricity generation and other usages are their environmental impacts. It is known that GHG emissions in which CO_2 emission is an element, are one of the major contributors to global warming (Baek, 2016; Liu and Xiao, 2018; Nathaniel and Iheonu, 2019; Opeyemi et al., 2019; Balsalobre-Lorente et al., 2018; Alola et al., 2019a, 2019b ; Saint Akadiri et al., 2019; Emir and Bekun, 2019). The Earth System Research Laboratory, ESRL (2017) revealed that globally, the average atmospheric CO_2 concentration in 2016 was 404.7 ppm. According to Hansen et al. (2017), global temperature has risen to 1.26˚C. These are some of the reasons studies have reiterated the need to improve the quality of the environment by way of reducing CO_2 emissions (Green and Stern, 2017; Balogh and Jambor, 2017; Bekun et al., 2019a, 2019b; Balcilar et al., 2019). The World Energy Council (2018) notes that the region of SSA is both a shaper and taker of new global trends and unruly developments from climate change. Nathaniel and Iheonu (2019) have revealed that while SSA may not be among the highest emitters of CO_2, the region is significantly being affected by the negative consequences. According to Niang et al. (2014) and Asongu (2018), Africa has been identified as one of the continent in the world that is most vulnerable to the impact of climate change, and deteriorating environmental quality.

Many countries in SSA have made some commitment through the signing of international agreements (e.g. Paris Climate Agreement) to lower CO_2 emissions and adopt efficient production procedures that minimize environmental risks and improve the environment. As at 2015, about 146 countries globally had initiated renewable energy policies with the aim of improving the environment. The energy from this source is important in four areas: electricity generation, transportation, air and water cooling/heating and rural energy services (REN21, 2010). Renewable energy potential is vast as it can in principle be leverage to meet global energy demands while also reducing environmental degradation. According to Akella, Saini and Sharma (2009), small hydropower, wind, solar, biomass and geothermal can deliver significant energy services established on the use of normally available, native resources. Globally, more than two-thirds of all new electricity capacity installed as at 2019 was renewable energy (IRENA, 2019).

The adoption and development of renewable energy technologies that make use of renewable energy sources is central to addressing worries about climate change and some environmental problems. Nevertheless, the use of renewable energy sources will not eradicate all environmental concerns of the system because the life-cycle analysis does not only consider the emissions during generation, but also at the manufacturing, disposal and waste management stage (Yadoo & Cruickshank, 2012). However, renewable energy significantly contributes to the reduction in GHG emissions. According to Aliyu et al. (2018) and Asongu and Odhiambo (2019a), African countries are very rich in renewable energy sources. However, the utilization of these energy sources is low. For instance, solar energy production is low, even when the region experiences about 320 days of sunlight out of 365 days in a year. Wind potential as well is estimated to be around 1300GW with an installed capacity of only 190MW (IEA, 2014).

While fossil fuels substantially cause harm to the environment, and even pose a threat to human health, as well as produce residuals which are generally non-biodegradable, renewable energy can substantially reduce the environmental implications of energy generation. Like other sources of power production, renewable energy can have environmental impacts but these depends on the location, technology and size of the facility with some examples like soil erosion, forest clearing, disturbance and/or loss of wildlife, air/water/noise pollution, damage to public health, land use and damage of attractive views among others. Given the forms of renewables, one can say that all energy sources have some impact on the environment. However, the use of non-renewable energy does significant damage compared to renewable energy.

This study seeks to evaluate the conditional relationship between renewable energy and environmental quality in sub-Saharan Africa applying the fixed effects model to account for individual country characteristics and the quantile fixed effects regression with in a bid to estimate the parameters throughout the conditional distribution of the dependent variable. The study utilizes data from 40 sub Saharan African countries from 2002 to 2017. The application of the quantile fixed effects model is based on articulating lower, intermediate and higher levels of environmental quality.

The closest paper to this study is Nathaniel and Iheonu (2019) which has explored the importance of renewable energy consumption on CO_2 emissions in a panel of 19 African countries for the period 1990-2014 using an Augmented Mean Group (AMG) estimation strategy. The study concludes that whereas non-renewable (renewable) energy positively (negatively) affects CO_2 emissions in the sampled countries. This present study departs from Nathaniel and Iheonu (2019) by: using a more updated dataset (1990 to 2014 versus 2002 to 2017), expanding the dataset to more African countries (40 versus 19 countries) and adopting an estimation technique that accounts for the underlying incidence of renewable energy on CO_2 emissions throughout the conditional distribution of CO_2 emissions.

The rest of the study is structured as follows. Section 2 covers a review of the literature which the data and methodology are discussed in Section 3. The empirical results are provided in Section 4 while Section 5 concludes with implications and future research directions.

2. Review of Related Literature

The development of environmental problems resulting from technological progress and human activities has continued to deteriorate biodiversity. However, the utilisation of renewable energy has been acknowledged to improve biodiversity and the environment. Studies across various countries and regions have supported this claim. One of such studies is that of López-Menéndez, Pérez and Moreno (2014) on a panel data of 27 European Union countries running from 1996-2010, with empirical results revealing that renewable energy reduces the volume of CO_2 emissions. Boluk and Mert (2014) also observed using a panel fixed effects model that renewable energy contributes about 0.5 less per unit of GHG emissions in European Union countries as compared to non-renewable energy. The result of their study suggests that a change in energy consumption combination to renewable energy technologies reduces GHG emissions.

Apergis and Payne (2015) examined the correlation among renewable energy, output, CO_2 emissions and oil prices using a panel of 11 South America N countries from 1980-2010. The result from the panel error correction model indicates a feedback relationship among the variables employed in the study. Further results show that renewable energy is significant for both the growth of output and the control of CO_2 emissions in the countries, thereby improving environmental quality. Sulaiman, Azman and Saboori (2013) in their study also show that renewable energy can guarantee sustainability of electricity supply and likewise reduce CO_2 emissions in Malaysia. Shafiei and Salim (2014) surveyed the link between non-renewable and renewable energy and CO_2 emissions for the Organisation of Economic Co-operation and Development (OECD) countries employing the Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT) model on data from 1980-2011. The outcome from the empirical analysis shows that renewable energy decreases CO_2 emissions. Bilgili, Kocak and Bulut (2016) assessed 17 OECD countries from 1977 to 2010 employing the panel fully modified ordinary least squares and showed that renewable energy reduces CO_2 emissions.

Jebli, Youssef and Ozturk (2015) assessed the short and long run relationship between CO_2 emissions, gross domestic product, renewable energy consumption and international trade for 24 sub Saharan Africa countries over the period 1980 to 2010. The result shows an indirect short run causality running from CO_2 emissions to renewable energy and an indirect short run causality running from GDP to renewable energy. Long run estimates also suggest the existence of an inverted U-shaped environmental Kuznets curve.

Bento and Moutinho (2016) analysed the varying causal link between CO_2 emissions, conventional and non-conventional electricity production, economic growth, and global trade in Italy from 1960-2011. The study used the autoregressive and distributed lag bounds testing method and revealed that per capita renewable electricity production reduces CO_2 emissions per capita. Hence, the use of renewable electricity production is a basic answer in decreasing contaminant emissions over time. Employing a similar estimation method, Al-Mulali, Solarin and Ozturk (2016) analyzed the influences of real income, conventional and non-conventional energy, trade, financial development and urbanization for Kenya from 1980-2012. The result indicated that renewable energy reduces air pollution.

Dogan and Seker (2016) investigated the impact of real output, conventional and non-conventional energy, trade and financial development on CO_2 secretions in the highest renewable energy nations. Applying Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) techniques revealed that increases in renewable energy, trade openness and financial development decrease CO_2 emissions.

Bildirici and Gökmenoğlu (2017) assessed the link between environmental pollution, hydropower energy and economic growth among the Great Seven (G7) nations in the different business cycle regimes from 1961 to 2013. The Markov Switching-Vector Autoregressive and MS-Granger Causality techniques were adopted. The findings reveal that from the first to the third regimes, CO_2 emissions Granger cause hydropower energy. Nevertheless, hydropower energy Granger causes CO_2 secretions for a number of G7 nations.

Inglesi-Lotz and Dogan (2018) assessed the impact of renewable and non-renewable energy on CO_2 emission among the 10 largest electricity generators in SSA from 1980-2011. A panel evaluation method robust to cross sectional dependence was employed. Empirically, result reveals that a rise in renewable energy usage decreases the level pollution in SSA. Furthermore, the causality analysis indicated a unidirectional causality running from emissions, income, trade and non-renewable energies towards renewable energies.

Karasoy and Akçay (2018) examined the impacts of renewable energy and trade on environmental pollution in Turkey from 1965-2016 using ARDL and VECM techniques for estimation. The aftermath of the empirical study showed that increase in the consumption of renewable energy reduces environmental pollution from CO_2 emissions.

Employing a panel error correction model on a group of nineteen developed and developing countries, Apergis et al. (2010) examined the underlying changes between emissions, nuclear energy, renewable energy, and economic growth during the period 1984-2007. The finding from the long-run assessments displays a significant positive relationship between emissions and renewable energy. However, the panel Granger causality test outcome suggests that in the short-run renewable energy does not contribute to emission reduction which could be linked to adequate storage technology.

Farhani and Shahbaz (2014) examined the underlying link between conventional and non-conventional energy, output and CO_2 emissions for 10 MENA countries between 1980-2009. Employing the Pedroni cointegration test as well as the FMOLS and DOLS techniques, the findings show that conventional and non-conventional energy enhances CO_2 emissions. Also, the long-run granger causality test appears to have a bidirectional causality between conventional and non-conventional and CO_2 emissions.

Bölük and Mert (2015) studied the connection between renewable energy, growth and environmental Kuznets curve in Turkey from 1961 to 2010 employing ARDL techniques. Results revealed that renewable energy (hydropower source excluded) have a negative and substantial long-run influence on CO_2 emission. However, the reverse exists in the short-run.

This section is completed with a strand of literature that has focused on nexuses between inclusive development and environmental degradation. Asongu and Odhiambo (2019b) have investigated how increasing CO_2 emissions influence inclusive human development in Sub-Saharan Africa while Asongu and Odhiambo (2019c, 2019b) have been concerned with nexuses between governance, CO_2 emissions and inclusive human development. The strand of literature is consistent on the position that CO_2 emissions are negatively associated with inclusive human development.

3. Data and Methodology

3.1 Data

The study focuses on a panel of 40 African countries for the period 2002 to 2017. The study employs the natural logarithm of CO_2 emissions (metric tons per capita), the natural logarithm of Gross Domestic Product (constant US$), Renewable Energy Consumption (% of total final energy consumption), Domestic Credit to the Private Sector (% of GDP) to proxy financial development and capture the level of financial resources provided to the financial sector by financial corporations and Trade (% of GDP) to capture Trade Openness. The study also captures governance quality in the model by employing government effectiveness and regulatory quality. While government effectiveness entails the perception of the quality of policy formulation as well as implementation, and government credibility to such policies, regulatory quality reflects the perception of government's ability in formulating and implementing good policies and regulations necessary for private sector development.

Table 1: Summary Statistics of the Variables

Variables	Mean	Minimum	Maximum	Standard Deviation	Observations	Source
Log of CO_2	-1.3124	-3.9837	2.3049	1.3982	516	WDI(2019)
Log of GDP	6.8523	-0.9786	9.9200	1.2429	587	WDI(2019)
Renewable Energy	67.7438	0.3540	139.6574	28.0689	522	WDI(2019)
Financial Development	19.4487	0.4914	160.1248	23.2276	617	WDI(2019)
Trade	80.0083	19.1008	311.3553	43.3593	576	WDI(2019)
Government Effectiveness	-0.7767	-1.8673	0.7272	0.5734	640	WGI(2019)
Regulatory Quality	-0.6842	-2.2437	0.7915	0.5496	640	WGI(2019)

List of Countries

Angola, Benin, Botswana, Burkina Faso, Burundi, Cabo Verde, Cameroon, Central African Republic, Chad, Comoros, Congo Democratic Republic, Congo Republic, Cote d'Ivoire, Equatorial Guinea, Eritrea, Ethiopia, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Liberia, Madagascar, Malawi, Mali, Mauritania, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Seychelles, Sierra Leone, South Africa, Sudan, Swaziland, Togo, Uganda, Zambia.

Source: Authors' computation

Notes: WDI (2019) is World Development Indicators (2019). WGI (2019) is World Governance Indicators (2019).

From Table 1, it is apparent that CO_2 emission which is in its natural logarithm has a mean value of -1.312, a minimum value of -3.984 and a maximum value of 2.305. This disparity in the minimum and maximum values entails the disparity in the level of CO_2 emissions across time and countries employed in the study. This can also be seen in the minimum and maximum values of the natural logarithm of GDP, renewable energy, financial development and trade.

Table 1 also reveals that the natural logarithm of GDP has an average value of 6.85. Renewable energy, financial development and trade also have an average value of 67.71, 19.45 and 80.01, respectively. The table further shows that the indicators of governance employed in the study, which include government effectiveness and regulatory quality have mean values of -0.77 and -0.068, respectively, indicating that on the average, the quality of governance is low in sub Saharan Africa.

3.2 Methodology

In line with the motivation of the study which is to assess the relationship between renewable energy and CO_2 emissions throughout the conditional distributions of CO_2 emissions, this study adopts the quantile regression strategy. As discussed in the introduction, previous assessments of the underlying nexus such as the by Nathaniel and Iheonu (2019), have been based on mean values of the CO_2 emissions. As documented by Asongu and Odhiambo (2019e), the policy importance of modeling an independent variable with an outcome variable based on mean values of these underlying variables is that estimations based on average values of the variables of interest could produce blanket policy implications that can be ineffective unless such policies are based on various levels of CO_2 emissions. It follows that when countries with low, intermediate and high levels of CO_2 emissions are articulated in the estimation exercise, policy implications can be more effective because they are tailored to be consistent with initial levels of CO_2 emissions.

In the light of the above, this study builds on the attendant quantile regressions (QR) literature (Koenker & Bassett, 1978; Tchamyou & Asongu, 2018) which has been documented to be appropriate in articulating initial levels of the outcome variables (Okada & Samreth, 2012; Asongu, 2013). Furthermore, as argued by Koenker (2005) and Hao and Naiman (2007), the QR technique is distinct from linear estimations from a multitude of standpoints, *inter alia*, it: (i) predicts conditional quantiles (compared to conditional mean); is relevant when sufficient data is used (against a baseline Ordinary Least Squares technique which can be contingent on small values of n); is consistent with an agnostic distribution (contrary to normal distribution assumption); is robust to outliers in the outcome variable (contrary to outlier sensitivity) and is computationally intensive (contrary to a computationally less intensive linear approach).

The θ^{th} quantile estimator of CO_2 emissions is derived by engaging the following optimization problem that is disclosed in Eq. (1) without subscripts for purposes of readability and simplicity.

$$\min_{\beta \in R^k} \left[\sum_{i \in \{i: y_i \geq x_i' \beta\}} \theta \left| y_i - x_i' \beta \right| + \sum_{i \in \{i: y_i < x_i' \beta\}} (1-\theta) \left| y_i - x_i' \beta \right| \right], \quad (1)$$

where $\theta \in (0,1)$. Contrary to mainstream linear regressions techniques (i.e. Ordinary Least Squares which is largely based on the minimization of the sum of squared residuals), with the QR techniques, it is the weighted sum of absolute deviations that is minimized. For instance, the 75th and 90th quantiles (with respectively, θ=0.75 or 0.90) are assessed by weighing approximately the residuals. In essence, the conditional quantile of CO_2 emissions or y_i given x_i is:

$$Q_y(\theta / x_i) = x_i' \beta_\theta \,, \quad (2)$$

where unique slope parameters are modeled for each θ^{th} specific quantile. This formulation is analogous to $E(y/x) = x_i' \beta$ in the Ordinary Least Squares slope where parameters are estimated only at the conditional mean of CO_2 emissions. For Eq. (2), the dependent variable y_i is a CO_2 emission whereas x_i contains: a constant term, renewable energy, GDP, financial development, government effectiveness, regulatory quality and trade.

Given the above, equations of regressions for the QR and Fixed Effects estimations are as follow.

$CO_{i,t} = \sigma_0 + \sigma_1 X_{i,t} + \eta_i + \varepsilon_{i,t}$ (3)

$CO_{i,t} = \sigma_0^{(p)} + \sigma_1^{(p)} \sigma_1 X_{i,t} + \eta_i + \varepsilon_{i,t}^{(p)}$ (4)

The Fixed Effects estimations that account for individual country peculiarities (Iheonu, 2019; Iheonu et al. 2019) and QR which are presented respectively in Equation (3) and Equation (4) focus on the incidence of renewable energy on CO_2 emissions, where, $CO_{i,t}$ is Carbon dioxide emissions in country i at period t, σ_0 is a constant, X entails renewable energy and other control variables (GDP, financial development, government effectiveness, regulatory quality and trade), $\varepsilon_{i,t}$ denotes country-specific effects and $\varepsilon_{i,t}$ is the error term.

4. Empirical results

The empirical results are disclosed in this section. While Table 2 shows the findings with government effectiveness in the conditioning information set, Table 3 shows the corresponding findings with regulatory quality in the conditioning information set. The first specifications (i.e. in the second column) of each table reveal estimates from Fixed Effects regressions while the remaining output in each of the respective tables correspond to QR. In the interpretation of QR estimates, it is worthwhile to note that existing levels of CO_2 emissions increase from the left hand-side to the right hand-side. In other words, CO_2 emissions are higher in the right hand-side compared to the left hand-side.

Table 2: Fixed Effects and Quantile Fixed Effects Regressions (1)

	Fixed Effects	Q.10	Q.25	Q.50	Q.75	Q.90
Log of GDP	0.2191**	0.3240***	0.2796***	0.2166***	0.1609*	0.1110
	(0.025)	(0.008)	(0.002)	(0.001)	(0.056)	(0.355)
Renewable Energy	-0.0160**	**-0.0176*****	**-0.0169*****	**-0.0159*****	**-0.0151*****	**-0.0143*****
	(0.016)	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.002)**
Financial Development	0.0096***	0.0093***	0.0095***	0.0097***	0.0099***	0.0101***
	(0.010)	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)
Trade	0.0022**	0.0017*	0.0019***	0.0022***	0.0024***	0.0027***
	(0.014)	(0.055)	(0.003)	(0.000)	(0.000)	(0.002)
Government Effectiveness	-0.0167	-0.0421	-0.0313	-0.0161	-0.0026	0.0094
	(0.834)	(0.601)	(0.594)	(0.708)	(0.962)	(0.904)
Constant	-2.0897**					
	(0.025)					
R- squared Overall	0.6494					
F-Statistics	8.96***					
	(0.000)					
Number of Groups	39					
Number of Observations	492	492	492	492	492	492

Source: Author's computation.
Note: ***, ** and * represents statistical significance at 1%, 5% and 10% respectively. Fixed Effects estimates computed with robust standard errors to account for heteroskedasticity.

Table 3: Fixed Effects and Quantile Fixed Effects Regressions (2)

	Fixed Effects	Q.10	Q.25	Q.50	Q.75	Q.90
Log of GDP	0.2356**	0.3535**	0.3049***	0.2341***	0.1724*	0.1183
	(0.019)	(0.017)	(0.005)	(0.002)	(0.060)	(0.365)
Renewable Energy	-0.0162**	**-0.0179*****	**-0.0172*****	**-0.0162*****	**-0.0152*****	**-0.0144*****
	(0.018)	**(0.001)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.003)**
Financial Development	0.0099**	0.0097***	0.0098***	0.0099***	0.0101***	0.0102***
	(0.011)	(0.005)	(0.000)	(0.000)	(0.000)	(0.001)
Trade	0.0021**	0.0016	0.0018**	0.0022***	0.0025***	0.0028***
	(0.018)	(0.123)	(0.016)	(0.000)	(0.000)	(0.003)
Regulatory Quality	-0.1032	-0.1916*	-0.1552*	-0.1021*	-0.0558	-0.0152
	(0.260)	(0.099)	(0.069)	(0.084)	(0.438)	(0.882)
Constant	-2.2535**					
	(0.016)					
R- squared Overall	0.6463					
F-Statistics	9.34***					
	(0.000)					
Number of Groups	39					
Number of Observations	492	492	492	492	492	492

Source: Author's computation.
Note: ***, ** and * represents statistical significance at 1%, 5% and 10% respectively. Fixed Effect estimates computed with robust standard errors to account for heteroskedasticity.

The following findings can be established. First, findings from both estimation techniques show that renewable energy consistently decreases carbon dioxide (CO_2) emissions. Second, the negative effect is a decreasing function of CO_2 emissions. In other words, countries with higher levels of CO_2 emissions consistently experience a less negative effect compared to their counterparts with lower levels of CO_2 emissions. Third, the control variables largely have the expected signs. Accordingly, economic prosperity, financial development and trade are positively correlated with CO_2 emissions while economic governance in terms of government effectiveness and regulatory quality are negatively correlated with CO_2 emissions. However, while government effectiveness insignificantly reduces CO_2 an emission, regulatory quality significantly reduces CO_2 emissions.

5. Concluding implications and future research directions

This paper has complemented existing literature by assessing the conditional relationship between renewable energy and environmental quality in a sample of 40 African countries for the period 2002 to 2017. The empirical evidence is based on fixed effects regressions and quantile fixed effects regressions. The findings from both estimation techniques show that renewable energy consistently decreases carbon dioxide (CO_2) emissions. Moreover, the negative effect is a decreasing function of CO_2 emissions. In other words, countries with higher levels of CO_2 emissions consistently experience a less negative effect compared to their counterparts with lower levels of CO_2 emissions. In what follows attendant policy implications are discussed.

First, the fact that renewable decreases CO_2 emissions is an indication that in order to mitigate CO_2 emissions in Africa in the light of sustainable development goals pertaining to energy, sampled policies will need to tailor policies that favor the replacement of non-renewable resources of energy with renewable sources. Some policies that can be implemented in this direction include: making environmental conscious political decisions aimed at encouraging the use of green energy sources such as solar and wind power for electricity generation. Adopting green energy sources in the industry also reduces CO_2 emissions as the industry is one of the leading contributors of CO_2 emissions not just in sub Saharan Africa but also in the rest of the world. Governments should also study the feasibility of the use of electric cars in the region and a possible adoption of such cars in order for CO_2 emissions to be reduced.

Second, the fact that the negative effect of renewable energy on CO_2 emissions decreases with increasing levels of CO_2 emissions is an indication that complementary policies are needed in countries experiencing higher levels of CO_2 emissions in order to exert comparable effects in magnitude relative to countries experiencing lower levels of CO_2 emissions. Some policies that can be implemented in this direction include: the employment of carbon budget and carbon limits in countries with lower negative impact of renewable energy consumption on CO_2 emissions. This controls the amount of CO_2 emissions and hence the incidence of renewable energy on CO_2 emissions because the alternative renewable energy sources are not associated with such limits.

Various stakeholders should be aware that the success of the underlying complementary policies would entail three key dimensions, notably: environmental effectiveness, economic efficiency and limited effect on competitiveness. First, on environmental effectiveness, the policies should lead to real CO_2 emission reductions in a sustainable manner. In order words, the policies should not just be designed to help countries achieve short term emission reduction goals. Second, as far as economic efficiency is concerned, policies that cost least would also enable some flexibility on how and where to reduce emissions so that the corresponding investment in abatement flows are channeled to the cheapest alternatives. Third, looking at the reduced effect on competitiveness, it is worthwhile to first of all assess existing measures that have been put in place to reduce CO_2 emissions so that effects of newly implemented policies do not overlap with measures already in place. Moreover, the engaged policies should be feasibly implementable and adequately forward-looking in order for incentives to be provided to boost technological innovation in the long term as well as investment in options of low carbon intensity, as time unfolds.

Future studies can use the relevant estimation techniques to assess to assess how policy variables that can be captured by the relevant proxies can be used to improve the negative effect of renewable energy on CO_2 emissions. Interactive and quadratic regressions can be used for the suggested directions.

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