Resources Policy 69 (2020) 101840

Contents lists available at ScienceDirect

Resources Policy

journal homepage: www.elsevier.com/locate/resourpol

How do output, trade, renewable energy and non-renewable energy impact carbon emissions in selected Sub-Saharan African Countries?

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ARTICLE INFO

Keywords:
Carbon emissions
Output
Renewable Energy
Non-Renewable Energy
Trade
Sub-Saharan Africa

ABSTRACT

Harmful effects of fossil fuels on environment and probability of extinction of these reserves cause to search alternative energy resources. Renewable energy use appears as the leading applicable solution in preventing climate change and global warming. The objective of this study is to quantify the relationship between output, renewable energy, non-renewable energy, trade and carbon dioxide (CO_2) emissions for eight Sub-Saharan African countries during the 1980–2014 period with second generation panel cointegration methods. Cointegration between the analyzed variables is established by Pedroni test and Westerlund (2007) error correction based panel test. The long run empirical findings reveal that, non renewable energy and trade have important role in increasing carbon emissions while renewable energy mitigates CO_2 emissions. Environmental Kuznets Curve (EKC) hypothesis is supported for the selected countries and the time span. The policy implications of the results are also discussed.

1. Introduction

Global warming and climate change remain as hot topics on the global agenda. Since fossil fuel (e.g., oil, natural gas, coal) combustion releases high amount of green house gases (GHGs), especially carbon dioxide, to the environment, they cause environmental problems. Climate change results in severe drought, natural disasters like floods and health risks. WHO (2018) COP24 report points out the strong link between climate change, air pollution and health. According to the report, carbon emissions from burning fossils fuels result in climate change and are the major contributor to health damaging air pollution. Every year, over seven million people die due to the exposure of air pollution inside and outside their home (WHO, 2017).

The detrimental effects of emission of green house gases (GHGs), especially carbon dioxide on climate change and global warming are gained quite attention in recent years. The importance of decreasing environmental pollution and carbon dioxide emissions has been getting more crucial issue. The target GHGs emissions are identified by Kyoto Protocol which was signed in 1997. The fundamental purpose of this agreement is to hold the global warming below the 2 °C by declining green house gases. After the Kyoto Protocol countries have started to adopt more environmentally friendly energy sources. The implementation of this protocol was argued further in 2015 Paris Conference on climate change (the 21st Conference of the Parties (COP21)) that was obtained very strong global support and signed by 195 countries. The crucial target of the Paris Agreement is to maintain the global temperature rise below 2 °C above pre-industrial levels and to investigate the necessary actions to limit the temperature increase even further to 1.5 °C. In addition, the agreement aims to enable countries to combat with the climate change more effectively. Make use of renewable energy resources as much as possible instead of fossil fuels is one of the prominent action. Gielen et al. (2019) point out that two thirds of total energy demand in the world will be met by renewable energy resources until 2050. This will reduce green house gas emissions significantly.

The seminal study of Kuznets (1955) provides the environmental Kuznets curve (EKC) hypothesis. According to EKC model there is an inverted U-shaped link between economic growth and environmental pollution. Increases in gross domestic product increases carbon emissions until a certain level and then decreases the emissions. The validity of EKC hypothesis has been examined in many studies but the results are still inconclusive. The energy consumption and growth nexus has been studied extensively after the pioneering study of Kraft and Kraft (1978). However, most of the studies are focused on developed countries or on both of the developed and the developing country groups. Developing countries and least developed countries are less investigated. The main purpose of this paper is to investigate the relationship between renewable energy, non-renewable energy, carbon emissions, trade and income for a balanced panel of the eight Sub Saharan African countries during the 1980–2014 period. The country group includes Gabon, Ghana, Kenya, Nigeria, Madagascar, South

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https://doi.org/10.1016/j.resourpol.2020.101840
Received 7 May 2020; Received in revised form 9 August 2020; Accepted 20 August 2020
Available online 29 August 2020

Africa, Sudan and Zimbabwe which are not being examined as a subgroup. The countries are chosen according to data availability. Even though Africa pollutes less than other continents, it suffered much more than other continents from climate change and global warming (Zoundi, 2017). Analyzing the drivers of carbon emissions is important so that the authorities can develop appropriate policies do deal with the environmental problems. Additionally, most of the studies employ aggregate energy consumption. In this paper, rather than using aggregate energy use, both renewable and non-renewable energy are taken into consideration.

The remainder of the article is organized as follows: The next section provides a brief literature review, Section 3 includes data and model. Section 4 presents methodology, Section 5 has the empirical results. Section 6 concludes.

2. A brief literature review

Payne (2010) provides an extensive literature survey of the energy growth nexus. Shahbaz and Sinha (2019) present a very detailed literature review of the studies on environmental Kuznets curve model during 1991–2017 period.

There exist some prominent examples of the studies focusing on developed countries and total energy consumption : Soytas et al. (2007) analyzed EKC model for USA; Ang (2007) analyzed the model for France; Ajmi et al. (2015) for G7 countries; Kasman and Duman (2015) for European Union Countries; Baek (2015) for Canada, Denmark, Iceland, Finland,Norway, Sweden, USA; and Atici (2009) for Central and Eastern Europe.

Some studies focusing on developing countries and total energy consumption are as follows: Halicioglu (2009) for Turkey; Pao and Tsai (2011) for BRIC countries; Nasir and Rehman (2011) for Pakistan; Chandran and Tang (2013) for ASEAN 5 country; Shahbaz et al. (2014) for Tunisia; Shahbaz et al. (2013) for Malaysia; Apergis and Payne (2009) for six Central American Countries; Jalil and Feridun (2011) for China; Heidari et al. (2015) for five ASEAN countries; Halicioglu and Ketenci (2016) for transition countries.

On the other hand some studies focusing on developed countries and disaggregate energy consumption are inclusive of Sadorsky (2009) for G7 countries and renewable electricity consumption; Iwata et al. (2010) for France and nuclear energy; Menyah and Wolde-Rufael (2010) for USA and nuclear and renewable energy consumption; Bengochea and Faet (2012) for EU countries and renewable electricity consumption; Boluk and Mert (2014) for EU countries and renewable and non-renewable energy consumption; Lopez-Menendez et al. (2014) for EU countries and renewable energy consumption; Al-Mulali et al. (2015a) for EU countries and renewable electricity consumption.

Studies of Farhani and Shahbaz (2014) for MENA countries and renewable and nonrenewable energy consumption; Apergis et al. (2010) for panel of developed and developing countries, and nuclear and renewable electricity consumption; Shafiei and Salim (2014) for OECD countries and renewable and nonrenewable energy consumption; Al-Mulali et al. (2015b) for Vietnam and renewable and nonrenewable electricity consumption; Jebli and Youssef (2015) for North Africa and combustible renewables and waste; Bilgili et al. (2016) for OECD countries and renewable energy consumption, Hu et al. (2018) for 25 developing countries and renewable energy, Inglesi-Lotz and Dogan (2018) for top 10 electricity generators in Sub Saharan Africa and renewable and non-renewable energy, Ali et al. (2019) for Nigeria and total energy consumption, Wu et al. (2020) for China and total energy consumption are also worth to mention. Table 1 presents a summary of some selected studies.

3. Data and model

Following the recent studies (Apergis and Payne, 2009; Boluk and Mert, 2014) and Farhani and Shahbaz (2014) and following Halicioglu (2009) and including trade openness to the framework this study applies the baseline model in Eq. (1) and examines the effects of GDP per capita, renewable energy, non-renewable energy and trade openness on carbon dioxide emissions.

$$co2_{it} = \beta_0 + \beta_1 gdppc_{it} + \beta_2 gdppc_{it}^2 + \beta_3 rec_{it} + \beta_4 nrec_{it} + \beta_5 tr_{it} + e_{it} \tag{1}$$

Where i and t represent country and time respectively. e_{it} is normally distributed error term. The data belong to the 1980–2014 period. The eight Sub-Saharan African countries, Gabon, Ghana, Kenya, Nigeria, Madagascar, South Africa, Sudan, Zimbabwe are selected according to data availability. The variables are in natural logarithm. co_2 is carbon dioxide emissions in metric tons per capita $gdppc$ is the gross domestic product per capita constant 2010 US \$. rec is per capita electricity generation from renewable sources (wind, solar, biomass,waste, hydro and geothermal) measured in kilowatt-hours; $nrec$ is per capita electricity generation from non-renewable sources (oil, natural gas, coal) measured in kilowatt-hours; tr is trade openness measured as the total trade as a share of gross domestic product. The data for co_2, $gdppc$, tr and population data are taken from World Bank World Development Indicators. The data for rec and $nrec$ come from U.S. Energy Information Administration . Table 2 presents summary statistics. In order to support the EKC hypothesis the expected sign of the coefficient β_1 is positive and the expected sign of the β_2 is negative. Since renewable energy is supposed to decrease the CO_2 emissions, the expected sign of the coefficient β_3 is negative, while the nonrenewable energy increases the CO_2 emissions the expected sign of the coefficient β_4 is positive. The expected sign of the coefficient β_5 can be positive or negative. The expected sign of β_5 is positive for the developing countries since they tend to have environmentally unfriendly industries but the expected sign is negative for the developed countries since they prefer to import pollution intensive goods rather than produce themselves (Grossman and Krueger, 1995).

4. Methodology

This section presents a brief explanation of panel estimation methods that are employed in this study.

Cross sectional dependency in panel data is the correlation that appears from common shocks with heterogeneous effects across countries. Failure to detection of cross sectional dependency may cause serious problems, for example forecasting errors, loss of estimator efficiency and invalid test statistics. The existence of cross sectional dependence is tested by using Pesaran's CD-test (Pesaran, 2004).

Pesaran (2004) provides the following test to determine cross sectional dependence:

$$CD = \sqrt{\frac{2T}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij} \right) \tag{2}$$

Where T denotes panel's time dimension N denotes the panel's cross-sectional dimension, $\hat{\rho}_{ij}$ represents the sample estimate of the pairwise correlation of the residuals.

Panel unit root tests are defined as first generation and second generation. First generation unit root tests assume cross sectional independence in the panels but second generation panel unit root tests are robust to cross sectional dependency. The First generation unit roots tests (Im–Pesaran–Shin unit root test (IPS), Levin–Lin–Chu unit root test (LLC) etc.) are extensions of augmented Dickey–Fuller (ADF) unit root test with cross sectional independency assumption. Second generation unit root tests relax this assumption and account for cross sectional dependency. Therefore, cross sectionally augmented Dickey–Fuller (CADF) and cross-sectionally Im–Pesaran–Shin (CIPS) panel unit root tests by Pesaran (2007) are employed.

Table 1
Selected literature.

Study	Region	Period	Methods	Results	
				EKC	Long run results
Soytas et al. (2007)	USA	1960–2004	VAR Granger Causality	No	EC increases CO_2
Ang (2007)	France	1960–2000	ARDL VECM Causality	Yes	EC increases CO_2
Kasman and Duman (2015)	EU Countries	1992–2010	FMOLS Granger Causality	Yes	EC and TR increase CO_2
Baek (2015)	Canada,Denmark Iceland,Finland Norway,Sweden,USA	1990–2011	DFGLS,ARDL	Yes for Iceland	EC increases CO_2
Atici (2009)	Central and Eastern Europe	1980–2002	OLS with FE and RE	Yes	EC increases CO_2
Halicioglu (2009)	Turkey	1960–2005	ARDL	No	EC and TR increase CO_2
Pao and Tsai (2011)	BRIC	1992–2007	OLS	Yes	EC and FDI increase CO_2
Nasir and Rehman (2011)	Pakistan	1972–2008	VECM Causality	Yes	EC and TR increase CO_2
Shahbaz et al. (2014)	Tunisia	1971–2010	ARDL	Yes	EC and TR increase CO_2
Shahbaz et al. (2013)	Malaysia	1971–2011	ARDL	Not Investigated	EC increases CO_2
Apergis and Payne (2009)	Central American Countries	1971–2004	FMOLS	Yes	EC increases CO_2
Jalil and Feridun (2011)	China	1953–2006	ARDL	Yes	EC and TR increase CO_2
Heidari et al. (2015)	ASEAN	1980–2008	PSTR Model	Yes	EC increases CO_2
Halicioglu and Ketenci (2016)	15 Transition Countries	1991–2013	ARDL,GMM	Yes for Turkmenistan Estonia Uzbekistan	Mixed
Sadorsky (2009)	G7 countries	1980–2005	FMOLS,DOLS	Not Investigated	GDP and CO_2 major determinants of RELC
Iwata et al. (2010)	France	1960–2003	ARDL	Yes	Nuclear decreases CO_2
Bengochea and Faet (2012)	EU countries	1990–2004	OLS with FE and RE DFGLS	Not Investigated	GDP and CO_2 increase RELC
Boluk and Mert (2014)	EU countries	1990–2008	OLS with FE	No	REC and NREC increase CO_2
Lopez-Menendez et al. (2014)	EU countries	1996–2010	OLS with FE and RE	No	REC decreases CO_2
Al-Mulali et al. (2015a)	European Countries	1990–2013	FMOLS	Not Investigated	RELC and TR decrease CO_2
Farhani and Shahbaz (2014)	MENA countries	1980–2009	FMOLS,DOLS	Yes	RELC and NRELC increase CO_2
Apergis et al. (2010)	panel of developed and developing countries	1984–2007	VECM Causality	Not Investigated	Nuclear decreases CO_2 RELC increases CO_2
Shafiei and Salim (2014)	OECD countries	1980–2011	GMM	Yes	REC decreases CO_2 NREC increases CO_2

(continued on next page)

Table 1 (*continued*).

Study	Region	Period	Methods	Results	
				EKC	Long run results
Al-Mulali et al. (2015b)	Vietnam	1982 –2011	ARDL	No	NRELC increases CO_2
Jebli and Youssef (2015)	North Africa	1971 –2008	FMOLS,DOLS	Not Investigated	CO_2 and Combustible waste contribute to GDP
Bilgili et al. (2016)	OECD countries	1977 –2010	FMOLS,DOLS	Yes	REC decreases CO_2
Jebli et al. (2015)	24 Sub Saharan African Countries	1980 –2010	Panel Cointegration	No	Mixed
Zoundi (2017)	25 Sub Saharan African Countries	1980 –2012	DOLS	No	REC decreases CO_2
Dogan and Seker (2016a)	European Union	1980 –2012	DOLS	Yes	REC and TR decrease CO_2
Hu et al. (2018)	25 developing countries	1996 –2012	DOLS,FMOLS	Yes	Share of REC decreases CO_2
Inglesi-Lotz and Dogan (2018)	Top 10 Electricity Generators in SSA	1980 –2011	DOLS	No	GDP, REN, TR decrease NREN increases CO_2
Ali et al. (2019)	Nigeria	1971 –2010	ARDL, VECM	Not Investigated	EC, GDP, FD increases CO_2 TR decreases CO_2
Wu et al. (2020)	China	2006 –2015	GMM	Yes	EC increases CO_2

Note: EC (total energy (electricity) consumption), REC (renewable energy consumption), NREC (non-renewable energy consumption), RELC (renewable electricity consumption), TR(trade, trade openness), FDI(foreign direct investment), FD (financial development), PSTR (panel smooth transition regression), VECM (vector error correction mechanism) causality, FE (fixed effects), RE (random effects), GMM (generalized method of moments), ARDL (autoregressive distributed lag model), DOLS(dynamic ordinary least squares), FMOLS(fully modified ordinary least squares), DFGLS (Dickey–Fuller test in generalized least square),AMG (Augmented Mean Group Estimator), BRIC (Brazil, Russia, India, China), SSA (Sub Saharan Africa).

Pesaran (2007) provides a panel unit root test which is the CADF. In Eq. (3) the appropriate lag length p is selected by employing Schwarz Information Criterion (SIC).

$$\Delta y_{it} = \alpha_i + \beta_i y_{i,t-1} + \gamma_i \bar{y}_{t-1} + \sum_{j=0}^{p} \eta_{ij} \Delta \bar{y}_{t-j} + \sum_{j=1}^{p} \delta_{ij} \Delta y_{i,t-j} + \epsilon_{it} \tag{3}$$

Where $\bar{y} = N^{-1} \sum_{j=1}^{N} y_{jt}$. The CIPS statistic is the mean value of the t-statistics that are obtained from estimating the CADF regression for each cross section:

$$CIPS = \frac{1}{N} \sum_{i=1}^{N} CADF_i \tag{4}$$

Pedroni Test (Pedroni, 1999, 2004) is a commonly used test for cointegration in the literature but the test assumes cross sectional independence.

Pedroni cointegration Test (Pedroni, 1999, 2004) employs the regression in Eq. (5) and calculates Panel v-statistic, panel rho-statistic, panel PP-statistic, panel ADF-statistic, group rho-statistic, group PP-statistic and group ADF-statistic:

$$y_{it} = \alpha_i + \delta_i t + \sum_{j=1}^{M} \beta_{ij} x_{ji,t} + \epsilon_{it} \tag{5}$$

Westerlund (2007) error correction based panel cointegration test is robust in the presence of cross sectional dependency. The test investigates whether the cointegration exists or not by detecting the existence of error correction. The test employs bootstrap method.

The error-correction test by Westerlund (2007) assumes the following data-generating process:

$$\Delta y_{it} = \delta_i' d_t + \alpha_i (y_{i,t-1} - \beta_i' x_{i,t-1}) + \sum_{j=1}^{p_i} \alpha_{ij} \Delta y_{i,t-j} + \sum_{j=-q_i}^{p_i} \gamma_{ij} \Delta x_{i,t-j} + \epsilon_{it} \tag{6}$$

where t denotes the time, i denotes the cross sectional units, and d_t includes the deterministic components, for which there are three cases. If $d_t = 0$ then Equation (6) has no deterministic terms; If $d_t = 0$ then Δy_{it} is generated with a constant, and in the third case if $d_t = (1, t)$ then Δy_{it} is generated with a constant and trend. Any dependence across i is handled by bootstrapping that is given in Eq. (7):

$$\Delta y_{it} = \delta_i' d_t + \alpha_i y_{i,t-1} + \lambda_i' x_{i,t-1} + \sum_{j=1}^{p_i} \alpha_{ij} \Delta y_{i,t-j} + \sum_{j=-q_i}^{p_i} \gamma_{ij} \Delta x_{i,t-j} + \epsilon_{it} \tag{7}$$

where $\lambda_i' = -\alpha_i \beta_i'$. The parameter α_i determines the speed at which the system corrects back to the equilibrium relationship $y_{i,t-1} - \beta_i' x_{i,t-1}$ after a sudden shock. If $\alpha_i < 0$ then there is error correction, y_{it} and x_{it} are cointegrated. If $\alpha_i = 0$ then there is no error correction and no cointegration. Therefore the null hypothesis of no cointegration can be stated as; $H_0 : \alpha_i = 0$ for all i. The alternative hypothesis depends on the homogeneity of α_i. The group-mean tests do not require the α_is to be equal then H_0 is tested versus the alternative hypothesis, $H_1^G : \alpha_i < 0$ for at least one i. For the panel tests H_0 is tested versus $H_1^P : \alpha_i = \alpha < 0$ for all i. Westerlund (2007) and Persyn and Westerlund (2008) suggest four panel cointegration statistics, $G_\tau, G_\alpha, P_\tau, P_\alpha$.

The fully modified ordinary least squares (FMOLS) and the dynamic ordinary least squares (DOLS) are widely used in empirical studies. DOLS and FMOLS are successful in removing endogeneity and serial correlations problems. FMOLS estimator employs non-parametric

Table 2
Descriptive statistics.

Country	Statistics	CO_2	rec	nrec	gdppc	tr
Gabon	Mean	1.46	6.46	5.89	9.26	4.50
	Std. Dev.	0.36	0.18	0.38	0.12	0.10
	Min	0.99	5.87	5.32	9.04	4.30
	Max	2.21	6.68	6.50	9.45	4.79
Ghana	Mean	−1.13	5.72	2.71	6.89	3.96
	Std. Dev.	0.24	0.29	1.77	0.23	0.72
	Min	−1.56	4.98	0.07	6.55	1.84
	Max	−0.59	6.19	5.11	7.41	4.75
Nigeria	Mean	−0.54	3.75	4.49	7.36	3.90
	Std. Dev.	0.33	0.25	0.20	0.25	0.34
	Min	−1.12	3.15	4.03	7.05	3.16
	Max	−0.07	4.15	4.89	7.85	4.40
South Africa	Mean	2.17	3.48	8.29	8.75	3.94
	Std. Dev.	0.07	0.59	0.08	0.10	0.16
	Min	2.03	1.29	8.04	8.60	3.62
	Max	2.29	4.48	8.45	8.93	4.29
Sudan	Mean	−1.59	9.17	7.79	6.93	3.18
	Std. Dev.	0.33	3.65	5.31	0.29	0.43
	Min	−2.24	3.53	2.62	6.56	2.41
	Max	−1.06	14.01	16.26	7.52	3.86
Kenya	Mean	−1.33	4.74	3.11	6.79	4.03
	Std. Dev.	0.18	0.20	0.81	0.07	0.11
	Min	−1.65	4.18	1.51	6.71	3.87
	Max	−0.95	5.10	4.26	6.99	4.29
Madagascar	Mean	−2.28	3.39	3.08	6.11	3.92
	Std. Dev.	0.20	0.19	0.19	0.11	0.33
	Min	−2.68	2.82	2.72	5.93	3.32
	Max	−1.69	3.62	3.44	6.43	4.42
Zimbabwe	Mean	0.06	5.76	5.57	6.98	4.15
	Std. Dev.	0.38	0.37	0.66	0.23	0.30
	Min	−0.90	4.99	3.99	6.39	3.58
	Max	0.52	6.32	6.33	7.21	4.70
Full Sample	Mean	−0.40	5.31	5.12	7.38	3.95
	Std. Dev.	1.47	2.24	2.84	1.02	0.50
	Min	−2.68	1.29	0.07	5.93	1.84
	Max	2.29	14.01	16.26	9.45	4.79

methodology to deal with endogeneity and autocorrelations. On the other hand, DOLS estimator deals with these problems by using parametric methodology and lags and leads of the independent variables. The DOLS method was suggested by Saikkonen (1991) for the times series and then developed by Kao and Chiang (2000) and Mark and Sul (2003) for panel data. Kao and Chiang (2000) compared the performances of OLS, FMOLS and DOLS by employing Monte Carlo simulations. According to their analysis DOLS estimator outperforms OLS and FMOLS. They discuss the roles of leads and lags to decrease the bias of the estimation.

The regression equation of DOLS is given in Eq. (8), where $y_{i,t}$ is the dependent variable, $x_{i,t}$ is the independent variable, $\epsilon_{i,t}$ is the error term, $-K_i$ and K_i are the lead and lag of the difference, Δ is the difference operator.

$$y_{i,t} = \alpha_i + \beta_i x_{i,t} + \sum_{k=-K_i}^{K_i} \gamma_{i,k} \Delta x_{i,t-k} + \epsilon_{i,t} \tag{8}$$

5. Empirical results

This section presents the empirical results of the panel estimation techniques that are discussed in the methodology section. Table 3 shows Pesaran's CD-test (Pesaran, 2004) results. According to the reported p-values the null hypothesis of cross-sectional independence is rejected for GDP per capita (square of GDP per capita), non-renewable energy consumption and trade variables.

Table 4 reports CADF and CIPS panel unit root test results. Test results suggest that co_2, $gdppc$, $gdppc^2$, rec, $nrec$, tr become stationary at their first differences.

Since co_2, $gdppc$, $gdppc^2$, rec, $nrec$, tr contain unit roots at their levels, long run relationship among the analyzed variables are investigated by the Pedroni cointegration Test (Pedroni, 1999, 2004; Westerlund, 2007) panel cointegration tests. Table 5 shows Pedroni cointegration Test ((Pedroni, 1999) results. Two out of four panel statistics and two out of three group statistics suggests cointegration relationships between the variables.

Table 6 shows Westerlund (2007) panel cointegration test results. G_α statistics rejects the null hypothesis of no cointegration.

After getting cointegration relationship between the variables, the Dynamic Ordinary Least Square estimator (DOLS) is used as the long run estimator. Table 7 provides the findings of panel DOLS estimation.

Table 3
Pesaran‘s cross sectional independence test results.

	CO_2	$gdppc(gdppc^2)$	rec	$nrec$	tr
CD-test	−0.763	2.49**	0.191	12.477*	6.025*
P-value	0.446	0.013	0.849	0.000	0.000

Note: *, **, denote significance at 1% and 5% level respectively. The CD test performs the null hypothesis of cross sectional independence.

Table 4
Panel unit root test results.

	CADF		CIPS	
	Level	$\triangle$	Level	$\triangle$
CO_2	−2.001	−3.355*	−1.943	−5.702*
$gdppc(gdppc^2)$	−1.668	−2.923*	−1.703	−4.418*
rec	−0.947	−4.123*	−0.892	−5.617*
$nrec$	−1.221	−3.577*	−0.879	−5.661*
tr	−2.634	−3.312*	−2.647	−5.768*

* denotes significance at 1%.

Table 5
Pedroni cointegration test results.

	Statistics
$Panel-v$	0.1187
$Panel-rho$	0.1743
$Panel-PP$	−2.913*
$Panel-ADF$	−2.87**
$Group-rho$	1.007
$Group-PP$	−3.11*
$Group-ADF$	−2.841**

* and ** denote significance at 1% and 5% respectively.

Table 6
Error-Correction panel cointegration (Panel Bootstrap Cointegration) test results.

Statistic	Value	Z-value	P-value	Bootstrapped P-value
G_T	−2.982	−2.179	0.015	0.168
G_a	−9.507	0.817	0.793	0.090
P_T	−6.481	−0.949	0.171	0.688
P_a	−8.647	−0.219	0.413	0.563

xtwest Stata module by Persyn and Westerlund (2008) is used to test cointegration. The Akaike Information Criterion (Akaike 1973) is used to get optimal lags and leads in the error correction test with the Bartlett kernel window width set according to $4(T/100)^{2/9} \approx 3$. The null hypothesis is no cointegration. The p-values are based on a one sided normal distribution. Bootstrapped p-values are robust in the presence of cross sectional dependence. The number of bootstrap replications is set to 400.

Table 7
Panel DOLS estimation results.

Independent variables	Coefficient	t-statistics	p-value
$gdppc$	4.90*	3.17	0.002
$gdppc^2$	−0.24**	−2.22	0.027
rec	−0.15*	−8.91	0.000
$nrec$	0.09*	7.23	0.000
tr	0.19*	2.99	0.003

*** and ** denote significance at 1%, 5% respectively.

The coefficients are significant at 1% and 5%. Since the variables are in natural logarithm the estimated coefficients give the elasticity of co_2 with respect to GDP per capita, square of GDP per capita, renewable energy, non-renewable energy and trade. A 1% increase in GDP per capita increases co_2 emission by 4.90% however a 1% increase in square of GDP per capita decreases co_2 emission by 0.24%. Therefore the EKC hypothesis is supported for the selected Sub Saharan African countries. However, EKC hypothesis is not supported by Zoundi (2017) for 25 Sub Saharan African countries, by Inglesi-Lotz and Dogan (2018) for top 10 electricity generator countries in Sub-Saharan Africa and Jebli et al. (2015) for 24 Sub Saharan African countries. A 1% increase in renewable energy decreases co_2 emission by 0.15%. On the other hand, a 1% increase in non-renewable energy gives a 0.09% increase in co_2 emission. Renewable energy use decreases environmental pollution but the non-renewable energy use increases the pollution for the selected Sub-Saharan African countries. A 1% increase in trade openness is found to increase co_2 emission by 0.19%. Trade has three types of effects, namely composition, scale and technique effects on the environment (Farhani et al., 2014). Scale effect means that increases in trade may result in higher income, energy consumption and pollution. Composition effect means that a country specializes according to comparative advantage if the country produces energy intensive goods then trade can cause higher pollution otherwise trade can lead to lower pollution. Technique effect means technology spillover through trade flows brings environmentally friendly technologies and can cause improvements in the environment. Trade can affect the environment positively or negatively depending on the net effect. The estimated coefficient on trade openness implies that the scale effect dominates composition and technique effect. Since the countries in estimations are Sub-Saharan African countries, this result is plausible in the sense that dirty industries usually move to less developed countries due to low environmental regulations and standards (pollution haven hypothesis). The elasticity estimates of co_2 with respect to renewable energy and non-renewable energy are obtained as −0.17 and 0.34 respectively by Inglesi-Lotz and Dogan (2018). The same coefficients are estimated as −0.03 and 0.44 for European Union countries and −0.03 and 0.23 for top renewable energy generator countries by Dogan and Seker (2016a) and Dogan and Seker (2016b) respectively. Jebli et al. (2015) get the elasticity estimate with respect to renewable energy consumption as 1.38 by FMOLS estimation. The elasticity estimates of co_2 with respect to renewable energy and primary energy consumption are found to be −0.13 and 0.86 by Zoundi (2017). The signs and magnitudes of the estimated coefficients of the renewable energy and nonrenewable energy are in line with the mentioned studies. The positive coefficient estimate of trade is not in line with Dogan and Seker (2016a,b) and Inglesi-Lotz and Dogan (2018). However, the coefficient estimate of trade is in line with the study of Jebli et al. (2015). They obtain elasticity estimate of CO_2 with respect to export as 0.19 for 24 Sub Saharan African countries. The empirical results change according to analyzed variables, methodology and time periods.

6. Conclusion

In this study renewable energy, non-renewable energy, economic growth and trade are examined as the determinants of carbon emissions. Although the effects of some variables on carbon emissions are extensively explored for many country groups, developing and least developed country groups are less studied and limited studies are focused on Sub-Saharan African countries. Second generation panel data techniques are employed to explore the relationship between the analyzed variables for the selected eight Sub-Saharan African countries. After establishing cointegration among the variables, long run relationships between the variables are investigated. Income per capita is found to increase pollution, on the other hand square of income per capita is found to diminish pollution therefore the results confirmed the existence of the EKC hypothesis for the selected time period and the countries in question. This suggests that at the earlier stage of development, environment is sacrificed to attain economic growth in the analyzed countries and the countries will have better environmental conditions after a certain income per capita level. For that reason, Sub Saharan African countries should develop sustainable economic growth policies to reach a certain development level so that they can protect the environment. The findings reveal that renewable energy decreases carbon emissions. On the other hand, non-renewable energy is found to boost carbon emissions. Sub Saharan African countries should increase the renewable energy investment and decrease the amount of non-renewable energy in the total energy mix in order to have lower CO_2 emissions level. In addition, the demand for energy has been gradually growing in African countries due to high economic growth and population growth. Therefore, in order to mitigate carbon emissions and to meet the increasing demand of energy, the policy makers in Sub-Saharan African countries should support investments in renewable energy, by giving some incentives and subsidies. Universities and entrepreneurs can play active role in developing and implementing renewable energy technologies. Although non-renewable energy usage costs less, the effects of non-renewable energy on the environment are detrimental and unfortunately the Sub-Saharan African countries suffer from these harmful effects more than any other country in the world. In the Paris conference, to deal with global warming and climate change, developing countries and the countries that are most affected by climate change are decided to be supported financially. Sub-Saharan African countries should get financial support as suggested by the conference. If the environmental costs of the fossil fuels are taken into account the payoff from renewable energy resources will exceed the payoff of the fossil fuels in the long run. Except Nigeria, the rest of the analyzed countries (Gabon, Ghana, Sudan, Madagascar, Zimbabwe, South Africa, Kenya) do not have significant amount of oil reserves and the economies of these countries heavily depend on the imported energy. Therefore these countries will benefit the advantages of renewable energy both economically and environmentally.

Trade is found to increase the environmental degradation, therefore the sample Sub-Saharan African countries should form and implement strict trade rules that prevent importing environmentally harmful products and limit carbon emissions that embedded in the imported products.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

The author is grateful to Prof. Ferda Halicioglu for the encouragement, very constructive comments and suggestions. The author thanks an anonymous referee for very helpful suggestions and comments.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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