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RESEARCH ARTICLE

Access to clean technologies, energy, finance, and food: environmental sustainability agenda and its implications on Sub-Saharan African countries

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Abstract
The Sub-Saharan Africa (SSA) is far lag behind the sustainable targets that set out in the United Nation's Sustainable Development Goals (SDGs), which is highly needed to embark the priorities by their member countries to devise sustainable policies for accessing clean technologies, energy demand, finance, and food production to mitigate high-mass carbon emissions and conserve environmental agenda in the national policy agenda. The study evaluated United Nation's SDGs for environmental conservation and emission reduction in the panel of 35 selected SSA countries, during a period of 1995–2016. The study further analyzed the variable's relationship in inter-temporal forecasting framework for the next 10 years' time period, i.e., 2017–2026. The parameter estimates for the two models, i.e., CO_2 model and $PM_{2.5}$ models are analyzed by Generalized Method of Moment (GMM) estimator that handle possible endogeneity issue from the given models. The results rejected the inverted U-shaped Environmental Kuznets Curve (EKC) for CO_2 emissions, while it supported for $PM_{2.5}$ emissions with a turning point of US$5540 GDP per capita in constant 2010 US$. The results supported the "pollution haven hypothesis" for CO_2 emissions, while this hypothesis is not verified for $PM_{2.5}$ emissions. The major detrimental factors are technologies, FDI inflows, and food deficit that largely increase carbon emissions in a panel of SSA countries. The IPAT hypothesis is not verified in both the emissions; however, population density will largely influenced CO_2 emissions in the next 10 years' time period. The $PM_{2.5}$ emissions will largely be influenced by high per capita income, followed by trade openness, and technologies, over a time horizon. Thus, the United Nation's sustainable development agenda is highly influenced by socio-economic and environmental factors that need sound action plans by their member countries to coordinate and collaborate with each other and work for Africa's green growth agenda.

Keywords Sustainable development · Clean technologies · Energy demand · CO_2 emissions · PM2.5 · GMM estimator · SSA countries

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Introduction

The United Nation's Sustainable Development Goals (SDGs) is another milestone to the member states to respond 17 goals for global unification to transform the world with free from poverty and hunger, education and health for all, reduce income inequality and disparity among the gender in every walk of life, sustainable water-energy-food resources, sustainable production and promotion of employment, safe cities and mitigate climate change risks, restore marine and natural resources, and promote trade and peaceful environment across the globe (United Nation 2015). Africa is no exception that far behind the sustainable development goals and strive hard to combat poverty, child mortality, water and sanitation issues, women inequality issues, etc. The success rate is still deprived as nearly 70% of the population lack sanitation facilities, more than 40% of the population live below the poverty line of US$1.25 a day, 33 million children out-of-school from primary schooling, etc. These crucial facts exhibit low reforms across African countries that need sustained policy action plans through coordinated efforts of the member countries and from the developed countries to come out the Africa from the crisis (Zaman et al. 2017; Silvestri et al. 2018; Efevbera et al. 2019.

The United Nation's SDG goals largely focused on high rising temperature and its consequences on economic health, water supply, natural resources, industry, trade, and food security challenges, which affect the African rural-urban poor that have a survival on subsistence farming and nomadic communities. The urban crisis is severally affect the Africa's sustainable development projects and human security, as high urbanization substantially decline the pace of country's economic growth due to massive demand of water, food, health, energy, and employment, which a country fails to provide basic necessities that raise serious issues of human security (Hove et al. 2013). Davidson et al. (2003) further continue this debate under the convention of United Nation's sustainable development for resource and environmental conservation and emphasized the need to combat climatic variations through the support of collaborative efforts of the developed and developing countries to sustained Africa through meeting the need of energy and food security. Musa et al. (2005) emphasized the need to adopt sustainable technologies in SSA countries as it reduces socioeconomic issues, including corruption, natural disasters, militarization, education, health, and infrastructure developmental issues, which is imperative for inclusive growth. Bräutigam and Knack (2004) identified three main factors that largely influenced Africa's economic stability, including the issues of good governance, as weaker governance led to increase many social issues that cumbersome the process of humanization, while poor institutional quality and low foreign aid further enlarge the poverty gap that weaken resource stability across Africa. Gowing and Palmer (2008) discussed the possible solution of poverty and hunger through vitalizing the process of agricultural reforms in the form of mechanized transformation in SSA countries. The sustainable agriculture yield reduces food security issues all across Africa; thus, it required land reforms that devoted for agricultural cultivation by high inducement of technology for fruitful gains. Montgomery et al. (2009) emphasized the need of functioning water sustainability and sanitation facility in rural SSA to prevent it from diseases, which will largely impact on community development and economic gains across African countries. Hilson (2009) concluded that small-scale mining provides greater job opportunities in Africa to support the poor that culminates the poverty and makes a step forward towards development. Al-Mulali and Binti Che Sab (2012) considered a panel of 30 SSA countries to evaluate the impact of energy demand and carbon emissions on country's economic development for a period of 1980–2008. The results confirm the strong viability of energy demand in country's economic objectives by increasing financial development; however, this rapid transformation exerts a high emission intensity that affect the country's sustainability agenda. The energy conservation policies may support country's mission and vision towards achievement of environmental sustainability agenda that could be achieved by sound financial sector in countries.

Iiyama et al. (2014)discussed the wide accessibility of wood fuel as an energy source in SSA countries, as it accounts of more than 80% of total energy supply in a region. The urbanization pressure and unsustainable production in the form of by using charcoal intensive demand lead to increase number of socioeconomic and environmental concerns that largely affect the Africa's vision of sustainable development. The sustainable option is by adoption of agro-forestry with improved kilns, and stoves may significantly reduce wood harvest pressures in forests that make environmental friendly atmosphere to reduce environmental issues across Africa. Conceição et al. (2016) discussed the food security issues in SSA countries and concluded that agriculture is the optimized solution to feed up the growing population of Africa; however, due to low level of agricultural yield and low mechanization process, it leads to decrease the potential of agriculture food across Africa. The importance of agriculture sector still has a distinct place in SSA reforms; thus, its realizing concern led to increase agricultural yield by adopting scientific base approach that integrates gender and sustainability in human development concentrated action plans to improve farms inputs and technology. Zou et al. (2016) considered the aggregate data for low-income countries to evaluate the impact of different environmental factors on country's health and economic well-being by using a dataset for 1975–2013. The results derive that air pollution and environmental indicators largely influenced country's health and wealth agenda that need re-corrective measures by using sustainable instruments to mitigate high-mass carbon emissions for healthy economic output. Zaman et al. (2016) evaluated the impact of different environmental factors on health expenditures by using a panel of 7 SSA countries for a period of 1995–2013 and found that high-mass carbon emission and inadequate water sanitation facilities both escalate healthcare expenditures, while fossil fuel energy increases external healthcare resources; thus, it confirmed that environmental factors compromised health gains for economic gains, which is unhealthy for healthy living. Zaman and Moemen (2017) collected a large data set from low-, middle-, and high-income countries to evaluate the long-run relationship between energy demand, CO_2 emissions, and country's economic growth for a period of 1975–2015. The results supported the inverted U-shaped EKC hypothesis for CO_2 emissions, energy associated emissions, and sectoral emissions in different regions across the globe; however, the intensity and magnitude vary from region to region. The intensity of high emissions damages the process of sustainable development all across the globe, which need serious policy plans to achieve United Nations SDGs for broad-based growth. Dos Santos et al. (2017) discussed the economic vulnerability of SSA countries in terms of high urbanization pressure that put a pressure on safe drinking water and sanitation facilities. The urban management committee is largely responsible to ensure safe water resources to prevent the population from notable diseases. The alternative arrangement for reduction of urbanization and provision of safe drinking water is crucial challenge for SSA to revitalize economic action plans for sustained growth. Tumushabe (2018) largely provoked that SSA countries faced three main challenges, including food security issues, climate changes, and sustainable development. All three challenges are interrelated and without solving any one of them; not all three issues would be resolved; thus, the food security challenges would be minimized by sustainable agriculture yield, while climate change is mitigated by sustainable production and consumption, and sustainable development could be achieved by zero carbon emissions. Thus, the United Nation's SDGs for Africa fell short the desired threshold values that need strong policy plans to achieve it. Wazed et al. (2018) emphasized the need to include renewable energy sources in an existing energy mix of SSA countries, and sustainable solar irrigation systems is the optimized solution to reduce water scarcity issues, which helpful to achieve sustainable water development agenda across countries.

The study primarily analyzed the sustainable efforts of SSA countries towards green development by mitigating carbon emissions and PM2.5 emissions through green financing, financial and trade liberalization policies, and meeting energy demand and food challenges. The real motivation of the study is to access different challenges that SSA countries faced in terms of using clean fuel and technologies, finance, renewable energy projects, food challenges, and environmental concerns. The study extensively surveyed on last two decade data and found the number of factors through which sustainability can be achieved, for instance, cooking fuels and stove combustion replaced with green fuels, fossil fuel energy replaced with renewable energy, financial development replaced with green financing, food challenges meet with mechanized and green farming, financial and trade liberalization polices replaced with ISO environmental certification and tight environmental regulations, etc. These crucial factors are helpful to develop sound environmental infrastructure that is imperative for sustainable development.

The above significant discussions stress the need to explore this area in more refined form in the context of SSA countries, which derives out by using number of socio-economic and environmental factors to evaluate United Nation's SDGs for resource conservation and emissions reduction in a panel of 35 selected SSA countries, during a period of 1995–2016. The more specific objectives are follows:

i) To examine the impact of clean fuels and technologies on carbon emissions and $PM_{2.5}$ emissions in a current time period and over a time horizon.
ii) To analyze the energy-based emissions through electricity production and the role of renewable energy consumption on carbon-$PM_{2.5}$ mitigating efforts across countries.
iii) To investigate the role of financial development on country's sustainable agenda in the form of reduction of CO_2 emissions and $PM_{2.5}$ emissions in a panel of countries.
iv) To verify the EKC relationship for CO_2 emissions and $PM_{2.5}$ emissions in a given time period, and
v) To explore the "pollution haven hypothesis (PHH)" and IPAT hypothesis across countries.

These objectives are highly desirable to achieve and evaluate countries efforts towards achievement of SDGs that is imperative for African region.

Data source and methodological framework

The study used the following variables to access the environmental sustainability agenda in a panel of 35 SSA countries, i.e., CO_2 emissions (metric tons per capita), $PM_{2.5}$ air pollution, mean annual exposure (micrograms per cubic meter), access to clean fuels and technologies for cooking (% of population), access to electricity (% of population), domestic credit to private sector (% of GDP), foreign direct investment, net (BoP, current US$), renewable energy consumption (% of total final energy consumption), GDP per capita (constant 2010 US$), trade (% of GDP), depth of the food deficit (kilocalories per person per day), and population density (people per sq. km of land area). The data of the variables collected from World Bank (2017). The missing values filled by the respective variable's succeeding and preceding values, where required. The time period from 1995 to 2016 is selected due to two main reasons, i.e., the two decade data would helpful to analyze the trend movement of the variables towards environmental sustainability agenda, which is desirable for formulating policy implications; while due to rapid economic and environmental transformation been defined by United Nation for developing countries and more particularly for SSA countries, it gives an initiative to study the last two decades scenario for conclusive findings. Table 1 shows the list of variables and their measurement.

Table 1 List of variables and their measurement

Factors	Variables	Symbol	Measurement
Dependent variable			
Environmental factors	Carbon dioxide emissions	CO_2	Metric tons per capita
	Particulate matter 2.5 emissions	$PM_{2.5}$	Micrograms per cubic meter
Independent variables			
Technology	Access to clean fuel and technologies for cooking	ACFT	% of population
Energy	Access to electricity	AELEC	% of population
	Renewable energy consumption	REC	% of total final energy consumption
Finance	Access to finance—domestic credit to private sector	AFIN	% of GDP
Food	Access to food—depth of food deficit	AFOOD	Kilocalories per person per day
Financial liberalization	Foreign direct investment inflows	FDI	Current US$
Economic growth	GDP per capita	GDPpc	Constant 2010 US$
Trade liberalization	Trade openness	TOP	% of GDP
Population	Population density	PD	People per sq. km of land area

Source: World Bank (2017)

The study extended the scholarly work of Qureshi et al. (2017) and evaluated the environmental sustainability agenda under five alternative and plausible hypothesis in a panel of SSA countries, i.e.:

i) Inverted U-shaped EKC hypothesis for CO_2 emissions and $PM_{2.5}$ emissions,
ii) Pollution haven hypothesis for CO_2 emissions and $PM_{2.5}$ emissions,
iii) IPAT hypothesis for CO_2 emissions and $PM_{2.5}$ emissions,
iv) Energy-associated emissions for $CO_2$and $PM_{2.5}$, and
v) Finance led emissions for CO_2 and $PM_{2.5}$.

The first hypothesis is achieved by including per capita income and its second order factor in carbon emissions and $PM_{2.5}$ equations, i.e.:

$$\mathrm{CO2}_{\mathrm{i},t} = \alpha_0 + \alpha_1(GDPpc)_{\mathrm{i},t} + \alpha_2(GDPpc)^2{}_{\mathrm{i},t} + \varepsilon_{\mathrm{i},t} \tag{i}$$

$$\mathrm{PM2.5}_{\mathrm{i},t} = \alpha_0 + \alpha_1(GDPpc)_{\mathrm{i},t} + \alpha_2(GDPpc)^2{}_{\mathrm{i},t} + \varepsilon_{\mathrm{i},t} \tag{ii}$$

where CO_2 shows the carbon dioxide emissions; GDPpc shows the per capita GDP; "i" shows the cross-section countries; and "t" shows the time period.

The expected relationship of Eqs. (i) and (ii) may vary with three different signs that discussed in the previous literatures (see Dinda 2004; Stern 2004), i.e., (i) $\alpha_1 > 0$ and $\alpha_2 < 0$: supported inverted *U*-shaped Kuznets curve for air pollutants that need to be checked its turning point with the following formula, i.e., $-\beta_1/2\beta_2$, (ii) $\alpha_1 < 0$ and $\alpha_2 > 0$: supported *U*-shaped EKC curve for different air pollutants, and (iii) $\alpha_1 = 0$ and $\alpha 2 = 0$: flat/no relationship found between emissions and income across countries.

The second hypothesis is related with PHH, which confirmed that dirty polluting industries operates in a country via the channel of ease of environmental regulations; hence, we checked the environmental performance by FDI inflows and trade liberalization policies in a given context, i.e.:

$$\mathrm{CO2}_{\mathrm{i},t} = \alpha_0 + \alpha_3(FDI)_{\mathrm{i},t} + \alpha_4(TOP)_{\mathrm{i},t} + \varepsilon_{\mathrm{i},t} \tag{iii}$$

$$PM2.5_{\mathrm{i},t} = \alpha_0 + \alpha_3(FDI)_{\mathrm{i},t} + \alpha_4(TOP)_{\mathrm{i},t} + \varepsilon_{\mathrm{i},t} \tag{iv}$$

where FDI shows the FDI inflows and TOP shows the trade openness.

The expected relationship of FDI and trade openness is positive with carbon emissions and PM2.5 emissions, as SSA countries largely influenced by unsustainable production and consumption that sabotage the process of environmental sustainability agenda across countries (see Solarin et al. 2017).

The third hypothesis is related with IPAT hypothesis where population, economic growth, and technology influenced country's environmental sustainability agenda in the form of high-mass emissions in a country; thus, the study took initiate to include population, affluence, and technology as a major factor in emission growth model, i.e.:

$$\mathrm{CO2}_{\mathrm{i},t} = \alpha_0 + \alpha_1(GDPpc)_{\mathrm{i},t} + \alpha_5(PD)_{\mathrm{i},t} + \alpha_6(ACFT)_{\mathrm{i},t} + \varepsilon_{\mathrm{i},t} \tag{v}$$

$$PM2,5_{\mathrm{i},t} = \alpha_0 + \alpha_1(GDPpc)_{\mathrm{i},t} + \alpha_5(PD)_{\mathrm{i},t} + \alpha_6(ACFT)_{\mathrm{i},t} + \varepsilon_{\mathrm{i},t} \tag{vi}$$

where PD shows the population density and ACFT shows the access to clean fuels and technologies.

The expected relationship of per capita income, population growth, and technologies (if not clean technologies) is positive, which implies that these factors increase high-mass emissions level across countries.

The rest of the hypothesis, which related with access to energy, finance, and food, includes as a control variable in conjunction with EKC, PHH, and IPAT hypothesis that confined their impact on country's emissions level. The equations are as follows:

$$\mathrm{CO2}_{\mathrm{i},t} = \alpha_0 + \alpha_7(AELC)_{\mathrm{i},t} + \alpha_8(REC)_{\mathrm{i},t} + \alpha_9(AFIN)_{\mathrm{i},t} + \alpha_{10}(AFOOD) + \varepsilon_{\mathrm{i},t} \quad \text{(vii)}$$

$$\mathrm{PM2.5}_{\mathrm{i},t} = \alpha_0 + \alpha_7(AELC)_{\mathrm{i},t} + \alpha_8(REC)_{\mathrm{i},t} + \alpha_9(AFIN)_{\mathrm{i},t} + \alpha_{10}(AFOOD) + \varepsilon_{\mathrm{i},t} \quad \text{(viii)}$$

where AELC shows the access to electricity; REC shows the renewable energy consumption; AFIN shows the access to finance; and AFOOD shows the access to food.

Figure 1 shows the research framework of the study for ready reference.

Figure 1 shows the clear connections between cleaner technologies, energy demand, financial development, food deficit, and environmental pollutions in SSA countries. The African countries lag behind the United Nation's environmental sustainability goals, which largely influenced by unsustainable production and consumption that increases human costs in the form of food shortages, high unemployment level, and increase poverty. These factors negatively influenced country's economic growth, which further translated in to natural resource depletion that caused deprive performance towards achievement of environmental sustainability across countries. Further, lack of clean technologies, energy crisis, low financial development, and meager agriculture yield sabotage the process of sustainable development in the form of high-mass carbon emissions that need re-corrective measures by tight regulatory mechanism, adoption of cleaner

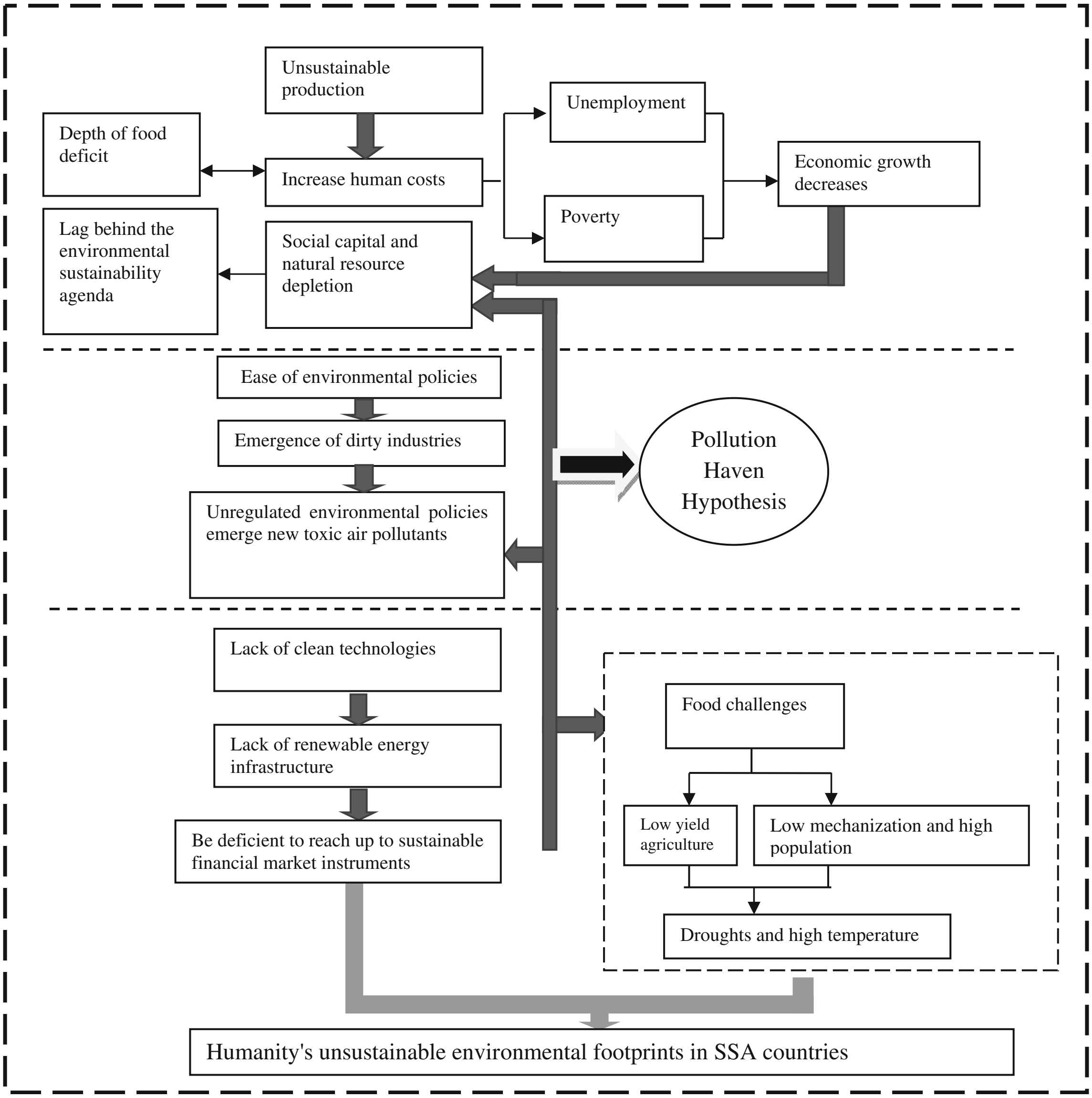


Fig. 1 Research framework of the study

technologies, renewable energy infrastructure, easiness to reach financial market, and high agriculture yield, which mitigate environmental issues and achieve the goals of sustainability in African economies.

Equations (i), (iii), (v), and (vii) combined together to form an estimated equation for a panel of SSA countries for carbon emissions model, while the remaining equations, i.e., Eqs. (ii), (iv), (vi), and (viii) combined for PM2.5 model, i.e.:

$$\begin{aligned}\mathrm{CO2}_{\mathrm{i},t} = {} & \alpha_0 + \alpha_1(GDPpc)_{\mathrm{i},t} + \alpha_2(GDPpc)^2{}_{\mathrm{i},t} + \alpha_3(FDI)_{\mathrm{i},t} \\ & + \alpha_4(TOP)_{\mathrm{i},t} + \alpha_5(PD) + \alpha_6(ACFT)_{\mathrm{i},t} \\ & + \alpha_7(AELC)_{\mathrm{i},t} + \alpha_8(REC)_{\mathrm{i},t} + \alpha_9(AFIN)_{\mathrm{i},t} \\ & + \alpha_{10}(AFOOD)_{\mathrm{i},t} + \varepsilon_{\mathrm{i},t}\end{aligned} \tag{1}$$

$$\begin{aligned}PM2.5_{\mathrm{i},t} = {} & \alpha_0 + \alpha_1(GDPpc)_{\mathrm{i},t} + \alpha_2(GDPpc)^2{}_{\mathrm{i},t} \\ & + \alpha_3(FDI)_{\mathrm{i},t} + \alpha_4(TOP)_{\mathrm{i},t} + \alpha_5(PD) \\ & + \alpha_6(ACFT)_{\mathrm{i},t} \\ & + \alpha_7(AELC)_{\mathrm{i},t} + \alpha_8(REC)_{\mathrm{i},t} + \alpha_9(AFIN)_{\mathrm{i},t} \\ & + \alpha_{10}(AFOOD)_{\mathrm{i},t} + \varepsilon_{\mathrm{i},t}\end{aligned} \tag{2}$$

Equations (1) and (2) are estimated by generalized method of moments (GMM) estimator due to the possible endogeneity issues in the given equations; thus, the significant value of difference in *J*-statistics will confirm the plausible issues in the systematic equations. The instrumental rank and *J*-statistics computed by GMM estimator would be helpful to analyze the suitability of instrumental variables for Eqs. (1) and (2). The diagnostic statistics for AR(1) and AR(2) for serial correlation find out with differenced GMM estimator. The instrumental variables enlisted lagged dependent variable and lagged explanatory factors except square of GDP per capita. The significant lagged dependent variable indicates the system dynamics towards the equilibrium in the long run. Equations (1) and (2) are further modified by GMM estimation, i.e.:

$$\begin{aligned}\mathrm{CO2}_{i,t} = {} & \alpha_0 + \alpha(\mathrm{CO2})_{\mathrm{i},t-1} + \alpha_1(GDPpc)_{\mathrm{i},t} \\ & + \alpha_2(GDPpc)^2{}_{\mathrm{i},t} + \alpha_3(FDI)_{\mathrm{i},t} + \alpha_4(TOP)_{\mathrm{i},t} \\ & + \alpha_5(PD) + \alpha_6(ACFT)_{\mathrm{i},t} + \alpha_7(AELC)_{\mathrm{i},t} \\ & + \alpha_8(REC)_{\mathrm{i},t} + \alpha_9(AFIN)_{\mathrm{i},t} + \alpha_{10}(AFOOD)_{\mathrm{i},t} \\ & + \lambda + \varepsilon_{\mathrm{i},t}\end{aligned} \tag{1.1}$$

$$\begin{aligned}PM2.5_{\mathrm{i},t} = {} & \alpha_0 + \alpha(PM2.5)_{\mathrm{i},t-1} + \alpha_1(GDPpc)_{\mathrm{i},t} + \alpha_2(GDPpc)^2{}_{\mathrm{i},t} \\ & + \alpha_3(FDI)_{\mathrm{i},t} + \alpha_4(TOP)_{\mathrm{i},t} + \alpha_5(PD) + \alpha_6(ACFT)_{\mathrm{i},t} \\ & + \alpha_7(AELC)_{\mathrm{i},t} + \alpha_8(REC)_{\mathrm{i},t} + \alpha_9(AFIN)_{\mathrm{i},t} \\ & + \alpha_{10}(AFOOD)_{\mathrm{i},t} + \lambda + \varepsilon_{\mathrm{i},t}\end{aligned} \tag{2.1}$$

where "$t-1$" shows the lagged dependent variable and λ shows the instrumental variables.

The rationale to used GMM technique for parameter estimates is as follows:

(i) The GMM estimator is involved in the dynamic adjustment process where the lagged regressand is used as a regressor, which helpful to overcome the small sample bias issue for hypothesis testing.

(ii) The linear regression models are powerless to switch endogeneity issues; thus, the coefficient estimates violate the BLUE property, even though the use of fixed and random estimators. The standard practice to handle endogenous covariates with instrumental variables through GMM estimator that gives consistent estimates for large cross-sectional at certain time intervals.

(iii) GMM estimator is a powerful technique that gives asymptotically efficient inference with relatively less set of statistical assumptions.

(iv) One of the limitations with the GMM estimator is raised with weak instruments, which are highly persistent in the simple first lagged autoregressive model where the coefficient is close to unity. By imposing linear restrictions it would improve the efficiency of GMM estimator.

(v) The violation of zero conditional mean assumption is due to the regressand that may arise with omission bias and error in the regressors. Thus, the instrumental estimators address the issue to give robust inferences.

(vi) The persistence of weak instruments is not even the cause of the loss of precision, while it affects the BLUE property of classical linear regression model. Thus, the GMM estimator with lagged explanatory variables should be improved with high precision instruments to control possible endogeneity.

(vii) The major advantage of GMM estimator is to determine the short- and long-run coefficient that helpful to find the potential regressors that would have an ability to serve as endogenous.

(viii) The GMM provides micro-foundation for aggregate data analysis to deal heterogeneity issues.

(ix) The simulation procedure is fairly easy for individual outcomes by pooling the data, and

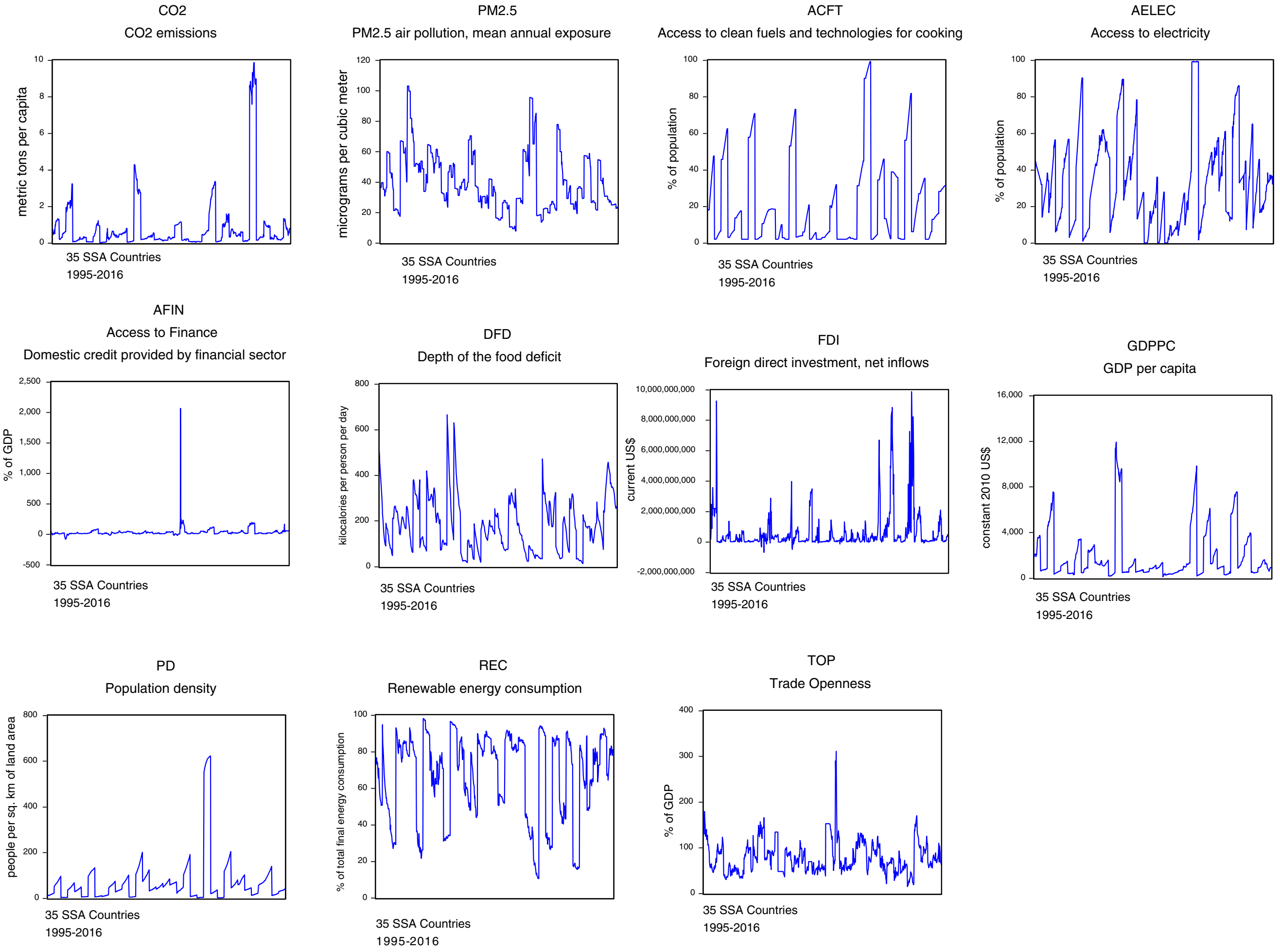
(x) GMM is more efficient estimator to handle endogenous regressors.

Table 2 Descriptive statistics

Statistics	CO_2	PM2.5	ACFT	AELEC	AFIN	AFOOD	FDI	GDPPC	PD	REC	TOP
Mean	0.839	39.890	20.485	33.775	34.485	183.396	6.05E+08	1902.817	67.682	66.766	79.349
Median	0.328	35.794	10.555	31.695	21.094	173.500	1.39E+08	989.712	43.413	76.359	71.224
Maximum	9.870	103.096	99.276	99.400	2066.184	666	9.89E+09	11,925.78	622.400	98.138	311.355
Minimum	0.015	7.851	2	0.015	− 79.092	13	− 6.76E+08	115.794	2.010	10.640	14.772
Std. Dev.	1.568	19.014	23.481	24.295	83.224	117.095	1.30E+09	2266.124	101.249	23.289	35.319
Skewness	3.985	0.939	1.447	0.817	19.162	0.828	3.949	2.124	4.161	− 0.733	1.515
Kurtosis	20.0186	3.743	4.408	3.169	462.948	3.728	21.053	7.064	22.070	2.301	8.343

Note: CO_2 shows carbon dioxide emissions; PM2.5 shows particulate matter 2.5 emissions; ACFT shows access to clean fuels and technologies; AELEC shows access to electricity; AFIN shows access to finance—domestic credit provided by foreign sector; DFD shows department of food deficit; FDI shows FDI inflows; GDPpc shows per capita GDP; PD shows population density; REC shows renewable energy consumption; and TOP shows trade openness

The study further evaluated Eqs. (1.1) and (2.1) in intertemporal forecasting procedure, where shocks on dependent variables are examined by the set of regressors for the next 10-year time period. The study used impulse response function (IRF) and variance decomposition analysis (VDA) to serve this purpose. The IRF is set in the vector autoregressive system that determine the time path of the regressand that influenced by the shocks of the regressors. The system stability is determined by zero shocks, if and only if, the system equations is stable, while unstable system would produce volatility



Source: (Bank, 2017)

Fig. 2 Level data plots

Table 3 Correlation matrix

Correlation (prob. value)	CO_2	PM25	ACFT	AELEC	AFIN	AFOOD	FDI	GDPPC	PD	REC	TOP
CO_2	1										
	–										
PM25	−0.171	1									
	0.000	–									
ACFT	0.673	−0.197	1								
	0.000	0.000	–								
AELEC	0.572	−0.060	0.764	1							
	0.000	0.095	0.000	–							
AFIN	0.244	−0.162	0.155	0.116	1						
	0.000	0.000	0.000	0.001	–						
AFOOD	−0.350	−0.139	−0.401	−0.472	−0.018	1					
	0.000	0.000	0.000	0.000	0.613	–					
FDI	0.365	−0.017	0.131	0.262	0.086	−0.206	1				
	0.000	0.618	0.000	0.000	0.016	0.000	–				
GDPPC	0.742	−0.205	0.824	0.716	0.094	−0.346	0.202	1			
	0.000	0.000	0.000	0.000	0.008	0.000	0.000	–			
PD	0.121	−0.202	0.415	0.463	0.108	−0.328	0.016	0.236	1		
	0.000	0.000	0.000	0.000	0.002	0.000	0.653	0.000	–		
REC	−0.552	0.082	−0.730	−0.634	−0.135	0.367	−0.093	−0.527	−0.314	1	
	0.000	0.021	0.000	0.000	0.000	0.000	0.009	0.000	0.000	–	
TOP	0.077	−0.263	0.304	0.175	0.044	−0.043	−0.045	0.246	0.123	−0.348	1
	0.031	0.000	0.000	0.000	0.216	0.229	0.204	0.000	0.000	0.000	–

Note: CO_2 shows carbon dioxide emissions; PM2.5 shows particulate matter 2.5 emissions; ACFT shows access to clean fuels and technologies; AELEC shows access to electricity; AFIN shows access to finance—domestic credit provided by foreign sector; DFD shows department of food deficit; FDI shows FDI inflows; GDPpc shows per capita GDP; PD shows population density; REC shows renewable energy consumption; and TOP shows trade openness

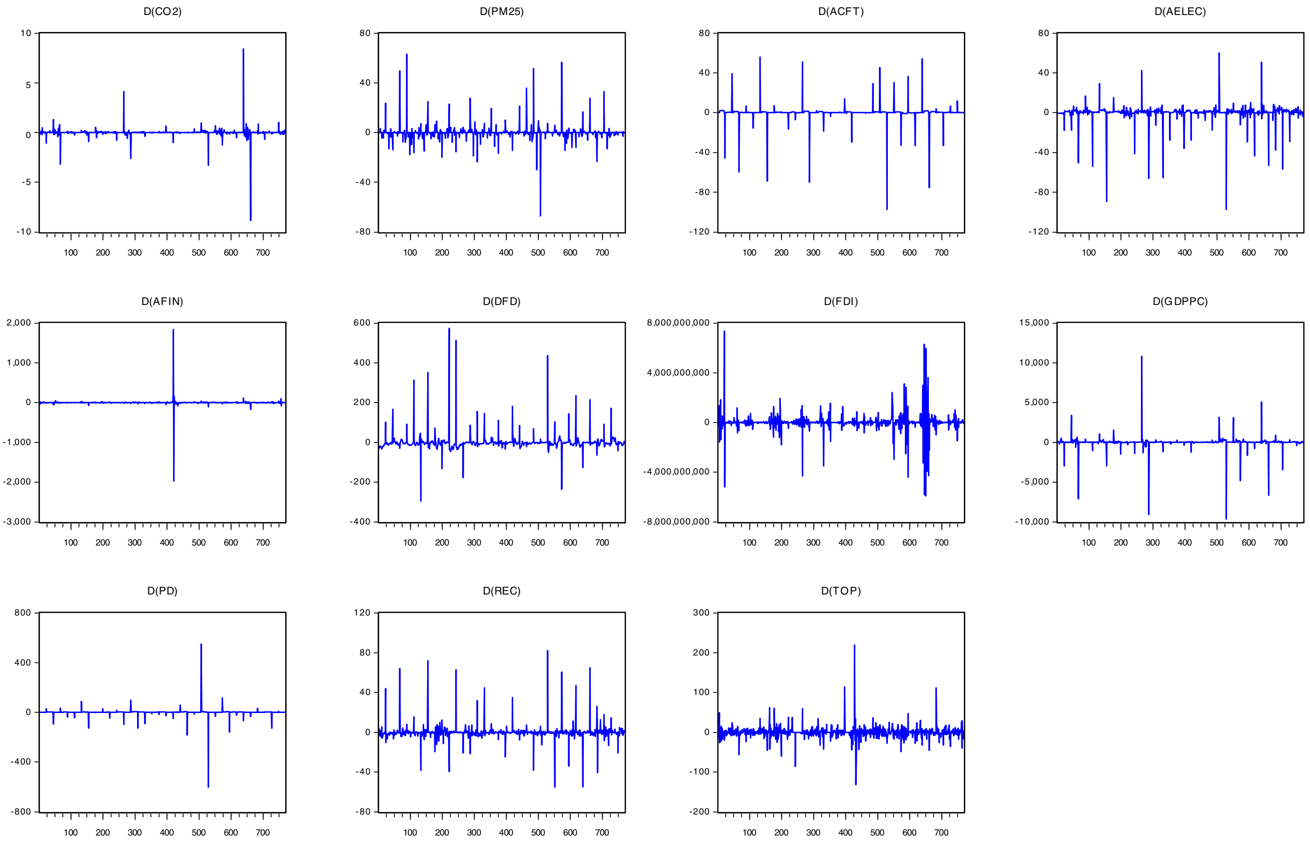
in the time dynamics. The VDA approach is the other way around to estimate inter-temporal forecasting between the studied variables and examined the shocks effects to the regressand. This approach facilitates to determine the forecast error variance in the given system that is explained by regressors, over a series of time horizons. Usually, the regressand has its own innovation shocks that explained most of the error variance, although the system absorbs some more shocks by their regressors. Thus, the viability of the system dynamics determined the error structure of the model that determines the variance error shocks over a time horizon.

Results and discussions

Table 2 shows the descriptive statistics of the variables. The mean value of carbon emissions and PM2.5 emission is about 0.839 metric tons per capita and 39.890 mg/m^3 with positively skewed distribution and high kurtosis value. The access to clean technologies and access to electricity has a mean value of 20.485% of population and 33.775% of population, respectively, while the minimum value is 2 and 0.015% of population, respectively, that shows low reforms towards access of clean technologies and electricity in some parts of SSA countries. The financial factor and trade openness have a mean value of 34.485% of GDP and 79.349% of GDP with a minimum value of − 79.092% of GDP and 14.772% of GDP, respectively. The FDI inflows have a positive mean value, while negative minimum value in some parts of SSA countries shows a deprived financial performance across countries. The per capita income has a minimum value of US$115.794 and maximum value of US$11925.78 with an average value of US$1902.817. The mean value of renewable energy consumption, access to food, and population density has a mean value of 66.766% of total energy consumption, 183.396 kcal per person per day, and 67.682 people per km^2 of land area, respectively.

Figure 2 shows the plots of level data for ready reference.

Table 3 shows the correlation matrix of the candidate variables. The results show that access to clean fuels and technology, electricity demand, access to finance, and per capita income has a positive correlation with the carbon emissions with



Source: (Bank, 2017). 'D' shows first difference. Note: CO2 shows carbon dioxide emissions, PM2.5 shows particulate matter 2.5 emissions, ACFT shows access to clean fuels and technologies, AELEC shows access to electricity, AFIN shows access to finance – domestic credit provided by foreign sector, DFD shows dept of food deficit, FDI shows FDI inflows, GDPpc shows per capita GDP, PD shows population density, REC shows renewable energy consumption, and TOP shows trade openness.

Fig. 3 Plots of differenced data

correlation coefficient values of 0.673, $p < 0.000$; 0.572, $p < 0.000$; 0.244, $p < 0.000$; and 0.742, $p < 0.000$, respectively. The results confirmed the technology associated emissions, energy associated emissions, finance associated emissions, and income-emissions nexus, which need sustainable instruments to re-correct environmental agenda for long-term development across SSA countries. The results further indicate the positive correlation between (i) FDI inflows and CO_2 emissions with a coefficient value of 0.365, $p < 0.000$, (ii) trade openness and CO_2 emissions with a coefficient value of 0.077, $p < 0.050$, and (iii) population density and CO_2 emissions with a coefficient value of 0.121, $p < 0.000$. The results verified the pollution haven hypothesis and IPAT hypothesis in a panel of given countries. The impact of renewable energy consumption on carbon emissions is negative, which confirmed the importance of renewable energy consumption in mitigating high-mass carbon emissions that need to be include with more convincing policy options in the country's sustainability agenda. The correlation results with PM2.5 emission is surprisingly inverted with the carbon emissions estimates, as access to clean fuels and technologies, access to energy demand, financial development, FDI inflows, trade openness, and population density have a negative correlation with the PM2.5 emission, while renewable energy consumption has a positive correlation with the PM2.5; thus, the policy for

Table 4 Regressors endogeneity test for CO_2 equation

	Value	df	Probability
Difference in *J*-stats	15.112	9	0.087
J-Statistic summary			
	Value		
Restricted *J*-statistic	15.112		
Unrestricted *J*-statistic	0.000		
Endogeneity test for PM2.5 equation			
	Value	df	Probability
Difference in *J*-stats	9.683	9	0.376
J-statistic summary			
	Value		
Restricted *J*-statistic	9.683		
Unrestricted *J*-statistic	0.000		

Table 5 GMM estimates for CO_2 emissions

Dependent variable: CO_2

Variable	Coefficient	Std. error	*t*-Statistic	Prob.
C	1.915402	0.748660	2.558440	0.0107
$CO_2(-1)$	0.882950	0.101415	8.706341	0.0000
ACFT	0.014920	0.008146	1.831564	0.0674
AELEC	0.000206	0.004019	0.051201	0.9592
AFIN	−0.003455	0.001841	−1.876517	0.0610
FDI	2.79E−10	1.03E−10	2.709824	0.0069
GDPPC	−0.001255	0.000446	−2.814602	0.0050
SQGDPPC	1.21E−07	4.04E−08	2.994113	0.0028
REC	−0.018831	0.007312	−2.575301	0.0102
TOP	0.003475	0.002089	1.663635	0.0966
AFOOD	0.001022	0.000583	1.753543	0.0799
PD	−0.000850	0.001033	−0.823219	0.4106
R-Squared	0.735210	Mean dependent var		0.840077
Adjusted *R*-squared	0.731362	S.D. dependent var		1.569064
S.E. of regression	0.813250	Sum squared resid		500.6609
Durbin-Watson stat	1.104885	*J*-statistic		0.000000
Instrument rank	12			

Note: AR(1)—prob. value = 0.993, AR(2)—prob. value = 0.887. CO_2 shows carbon dioxide emissions; PM2.5 shows particulate matter 2.5 emissions; ACFT shows access to clean fuels and technologies; AELEC shows access to electricity; AFIN shows access to finance—domestic credit provided by foreign sector; DFD shows department of food deficit; FDI shows FDI inflows; GDPpc shows per capita GDP; SQGDPpc shows square GDP per capita; PD shows population density; REC shows renewable energy consumption; and TOP shows trade openness

sustainable development is still a challenge for the policymakers to refine existing environmental policies for long-term growth across SSA countries.

Figure 3 shows the differenced data plots for ready reference.

Before we proceed to the coefficient estimates, the study checks the possible endogeneity issues in the emissions model; for this purpose, the difference *J*-statistics would be used, as the significant *J*-statistics would confirm that the issue related with possible endogeneity exists in the emissions model, while insignificant estimates would confirm that the model is free from endogeneity problem. The results are presented in Table 4.

The results confirm that *J*-statistic of CO_2 emissions has a significant probability value; hence, it clearly exhibits that the CO_2 model has an endogeneity issue, which need to be resolved by using an appropriate econometric modeling. On the other hand, PM2.5 model has an insignificant *J*-statistic, which is verify that the model has no such endogeneity issues in the given set of regressors. Thus, the GMM estimator is the viable estimator to handle endogeneity issues from the given set of regressors, which is being used for parameter estimates in Table 5.

The results of GMM estimator for CO_2 emissions model clearly indicate the dynamics of the carbon model, as the initial lag value of carbon emissions positively influenced the system model that confirm the severity of carbon emissions in the previous years in SSA countries. The access to clean fuels and technology for cooking is positively influenced carbon emissions, which implies that high technology is associated with high-mass carbon emissions that need to be mitigate by cleaner technologies (see Huisingh et al. 2015). All these studies confined that clean technologies largely supported environmental sustainability agenda, which required cleaning mechanism in production and techniques of production to produce zero carbon emissions. The sound financial sector is helpful to determine the long-term country's growth by supporting business entities to reap sustainable profit, while renewable energy consumption further mitigates the high-mass carbon emissions; thus, both the positive results have been drawn by the given estimations, which confirmed that access to finance and renewable energy consumption substantially decreases carbon emissions across countries (see Shahbaz et al. 2013a, 2013b). These studies confined that financial development acts as a strong mediator to influence environmental pollutants that should be included in policy agenda for broad-based growth. The results verified the "pollution haven hypothesis," as FDI inflows have a positive association with carbon emissions, which implies that higher financial and trade liberalization policies given opportunity to the dirty polluting industries to find a place for unsustainable production and consumption due to ease of environmental regulations across countries. The tight environmental regulation and sustainable policies are imperative for sustainable development in a panel of countries (see Nourry 2008). These studies confined the role of dirty polluting industries that damages the environmental sustainability agenda in the form of high-mass carbon emissions and produces unsustainable goods and violates the environmental laws and regulations to get gains monetary incentives on the cost of health issues. The results do not support an inverted *U*-shaped EKC relationship between emission and economic growth, as economic growth initially decreases carbon emissions, while it increases carbon emissions in the later stages of economic development; thus, its supported *U*-shaped EKC relationship between them. The food production largely involved in high-mass carbon emissions, as unsustainable mode of production and unsustainable technologies damage the United Nation's sustainability agenda, which is the serious concern for country's economic development (see Soytas et al. 2007). These studies confirmed the EKC hypothesis for different air pollutants and provide sound policy inferences in this regard. The statistical tests confirmed the goodness-of-fit of the model by high adjusted R^2 value; instrumentation of regressors is confirmed by appropriate instrumental ranks and low *J*-statistics; and no auto-correlation problem is found by insignificant probability values of AR (1) and AR(2).

Figure 4 shows the confidence ellipse for CO_2 equation and confirmed that the given model is stable over a period of time,

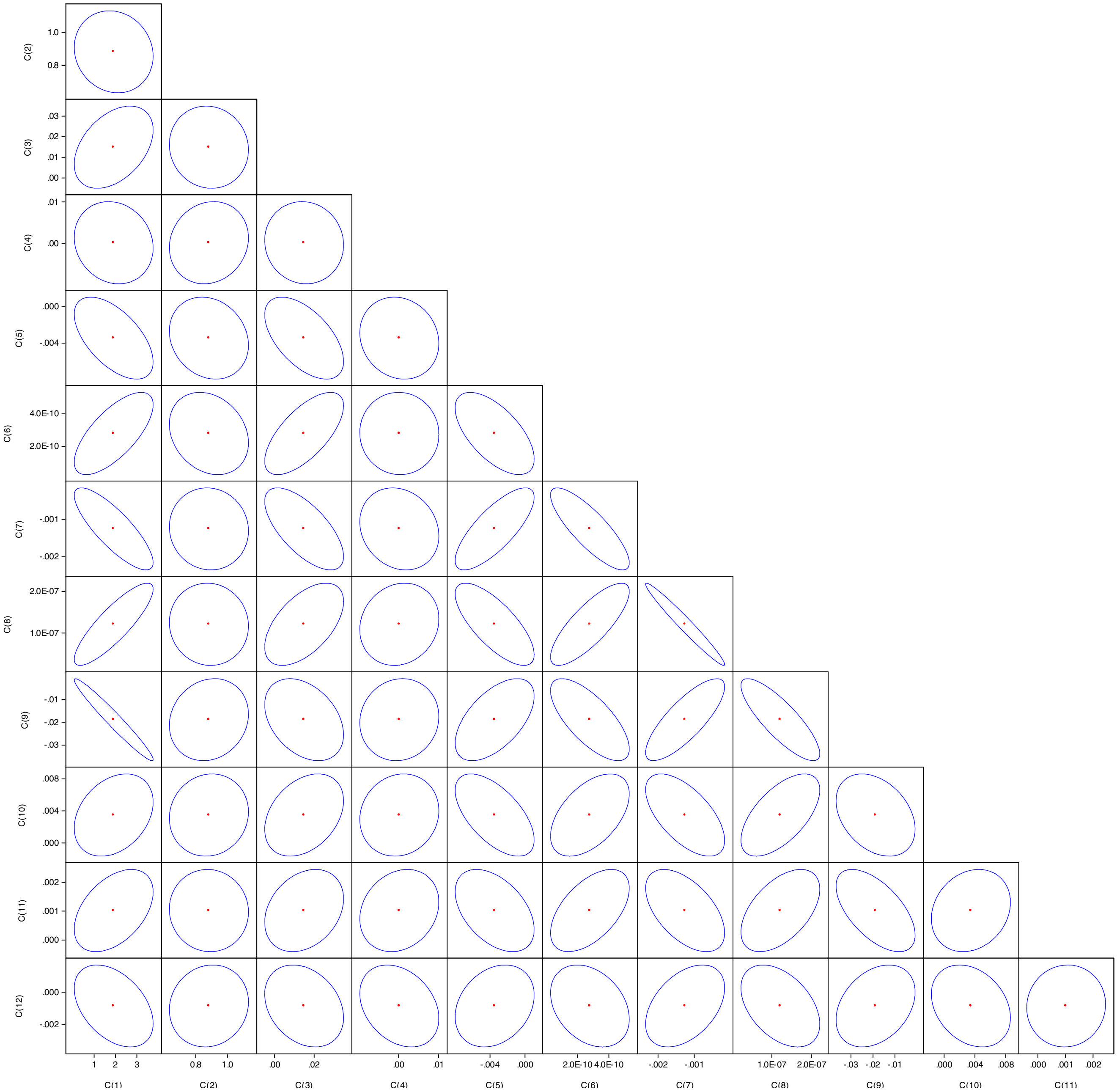


Fig. 4 Confidence ellipse for CO_2 equation

as the confidence ellipse is fall inside the critical boundary; thus, it confined the model diagnostic for carbon dynamism.

Table 6 shows the GMM estimates for PM2.5 equation and confirmed the significance of initial value of PM2.5 emissions that confirmed the system dynamics for long-run convergence of the model. The impact of FDI inflows and trade openness is negatively influenced with PM2.5 emissions that rejected the "pollution haven hypothesis." The results show that higher the trade and financial activities, the lower will be the PM2.5 emissions, which required more sound sustainable policies for reducing PM2.5 emissions by importing sustainable capital goods to reduce the emergence for better health and wealth.

The results confirmed the inverted *U*-shaped EKC relationship between PM2.5 and per capita income with a turning point of US$5540. The turning point of per capita income in constant US$2010 would only cause by 5 SSA countries that have such attained this high per capita income, namely Botswana, Gabon, Mauritius, Namibia, and South Africa. The other 30 countries as selected in the panel of SSA countries in this study does not have such high per capita income; thus in general, this turning point may not be achieved in such a high proportion of sample countries. In general, the results confirmed that per capita income first increases PM2.5 emission, while its second-order coefficient has a negative sign,

Table 6 GMM estimates for PM2.5 equation

Dependent variable: PM2.5

Variable	Coefficient	Std. error	*t*-Statistic	Prob.
C	−7.803974	5.807504	−1.343774	0.1794
PM25(−1)	0.952721	0.020535	46.39441	0.0000
ACFT	−0.098662	0.065122	−1.515031	0.1302
AELEC	−0.012687	0.028344	−0.447602	0.6546
AFIN	0.021895	0.015659	1.398230	0.1625
FDI	−1.48E−09	8.24E-10	−1.798693	0.0725
GDPPC	0.007866	0.004052	1.941301	0.0526
SQGDPPC	−7.10E-07	3.76E-07	−1.886338	0.0596
EKC turning point for GDPpc = $-\beta_1$ / $2\beta_2$ = US$ 5540				
REC	0.099979	0.055107	1.814263	0.0700
TOP	−0.029734	0.016642	−1.786625	0.0744
DFD	−0.005644	0.004650	−1.213682	0.2252
PD	0.003371	0.005455	0.617911	0.5368
R-Squared	0.843643	Mean dependent var		39.89478
Adjusted *R*-squared	0.841371	S.D. dependent var		19.02647
S.E. of regression	7.577904	Sum squared resid		43,470.45
Durbin-Watson stat	1.551028	*J*-Statistic		8.30E−43
Instrument rank	12			

Note: AR(1)—prob. value = 0.878, AR(2)—prob. value = 0.929. CO_2 shows carbon dioxide emissions; PM2.5 shows particulate matter 2.5 emissions; ACFT shows access to clean fuels and technologies; AELEC shows access to electricity; AFIN shows access to finance—domestic credit provided by foreign sector; DFD shows department of food deficit; FDI shows FDI inflows; GDPpc shows per capita GDP; SQGDPpc shows square GDP per capita; PD shows population density; REC shows renewable energy consumption; and TOP shows trade openness

which implies that the PM2.5 emissions decrease at the later economic stages of maturity. The impact of renewable energy consumption is positive on PM2.5 emission that opens another debate for the viability of renewable energy mix in SSA countries. The renewable energy sources have a huge potential to direct zero carbon emissions; however, it is required for the resource abundance to utilize country's resources for adopting energy mix to sustained economic activities (see Panwar et al. 2011). Menyah and Wolde-Rufael (2010) proclaimed the effectiveness of nuclear energy consumption that mitigate carbon emissions; however, it yet not been done due to country's economic shocks and political disagreement across the globe. Akella et al. (2009) concluded that conventional energy sources largely induced by high emissions that support country's economic activities on the cost of human health damages. The need of renewable energy sources is imperative for healthy economic output and well-being.

The high R^2 value confirmed the goodness-of-fit of the model, while instrumental ranks, *J*-statistics value, AR (1), and AR(2) values confirmed the significance of instrumentation of regressors and free from serial correlation issue in the given model. Figure 5 shows the confidence ellipse for PM2.5 equation that confirmed the model stability at 5% critical boundary.

Table 7 shows the estimates of IRF for CO_2 equation and PM2.5 equations. The estimates show that access to technology, energy, finance, per capita income, renewable energy consumption, and access to food will largely decline carbon emissions in the next 10-year period, while trade openness and population density both will increase carbon emissions over a time horizon. Thus, high-mass carbon emissions responsible for dirty polluting industries and high population growth that need to be controlled by tight environmental regulations and population-controlled strategies including fertility reduction campaigns, quality of child well-being, health provision, and education. These policies largely support to reduce unsustainable production and consumption across SSA countries.

The table further shows the response of PM2.5 emissions by specific regressors and found that access to clean technologies, electricity, per capita income, renewable consumption, and food deficit will largely influence PM2.5 emissions, while access to finance, trade openness, and population density will influenced negatively to PM.25 concentration among SSA countries over a time horizon. The results derive the need to adopt cleaner technologies for mitigating high concern of PM2.5 concentration that influenced by high energy demand, per capita income, and food deficit. The policies for sustainable consumption and production derive efficient instruments to reduce environmental concerns, which is imperative for healthy gains. Table 8 shows the estimates of VDA for both the CO_2 equation and PM2.5 equation.

The VDA estimates show that both the CO_2 equation and PM2.5 equation have their own innovation shocks by 98.942 and 97.820%, respectively; afterward, population density has a larger error variance, followed by access to clean technologies, per capita GDP, and renewable consumption. The least influence on CO_2 emissions are electricity demand over the next 10-year time period. In the second equation, PM2.5 emission will largely influence by high per capita income, followed by trade openness, access to clean technologies, and access to finance. The least influence will be electricity demand over a time horizon. Thus, the policies for sustainable development are highly desirable to reduce high population density and sustained growth specific factors for green growth.

Conclusions

The United Nation's SDGs are the paramount concerns for the developed and developing countries to achieve the set targets on priorities basis up to 2030. The environmental agenda is highly inflammable, as this is not a local or regional issue; it is a global concern, which need to be solved with coordinated and collaborative efforts for healthy and wealthy living. The

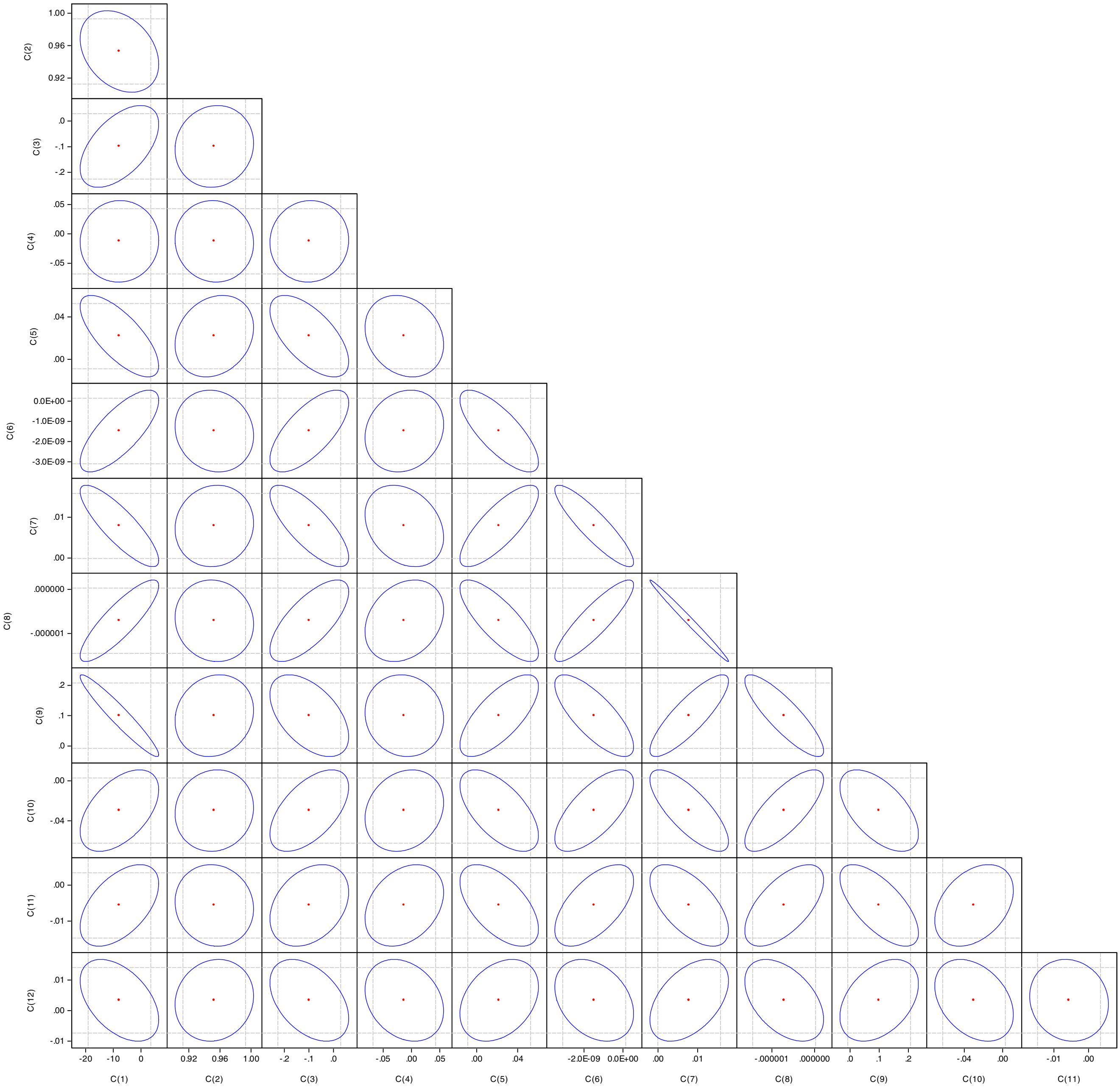


Fig. 5 Confidence ellipse for PM2.5 equation

SSA countries largely influenced environmental and economic resources that are eye opening for the policymakers to devise sustainable policies for mitigating high-mass carbon emissions from their food production, energy sector, trade, and finance. This study is the first comprehensive effort to highlight the serious socio-economic issues that influenced environmental sustainability agenda in a panel of selected SSA countries. The results show that clean fuels and technologies for cooking, FDI inflows, and food security challenges are largely inflamed high-mass carbon emissions that need to mitigate by cleaner technologies, tight environmental regulations, and sustainable food production and consumption. The results show the *U*-shaped EKC for CO_2 emissions, where per capita income first decreases and then increases CO_2 emissions that damage the sustainable development agenda in a panel of countries. The positive impact of renewable energy consumption confirmed the need to adopt renewable energy mix in the countries portfolio to minimize the risk of high-mass carbon emissions, which is imperative for sustainable growth. The results verified the inverted *U*-shaped EKC relationship for PM2.5 emissions, where per capita income has a quadratic relationship with the PM2.5 emission and has found a turning point at US$5540. The results of IRF for CO_2 emissions show that trade openness and population density are the

Table 7 Estimates of impulse response function

Response of CO_2									
Period	CO_2	ACFT	AELEC	AFIN	GDPPC	REC	TOP	DFD	PD
2017	0.526330	0	0	0	0	0.	0.	0.	0.
2018	0.504110	0.003107	0.004533	−0.005022	0.002552	−0.000641	0.013030	1.05E-05	0.003932
2019	0.474048	−0.003234	0.003622	−0.009981	−0.003306	−0.004717	0.013252	−0.002888	0.010489
2020	0.445214	−0.009708	0.002567	−0.011743	−0.008854	−0.008505	0.012796	−0.005523	0.016194
2021	0.417749	−0.015681	0.001636	−0.012086	−0.013274	−0.011626	0.012038	−0.007713	0.021269
2022	0.391741	−0.020991	0.000828	−0.011740	−0.016890	−0.014192	0.011169	−0.009591	0.025745
2023	0.367181	−0.025617	0.000142	−0.011102	−0.019903	−0.016277	0.010277	−0.011216	0.029669
2024	0.344026	−0.029579	−0.000433	−0.010352	−0.022435	−0.017944	0.009406	−0.012628	0.033083
2025	0.322218	−0.032920	−0.000907	−0.009580	−0.024565	−0.019248	0.008577	−0.013850	0.036027
2026	0.301694	−0.035692	−0.001293	−0.008827	−0.026347	−0.020235	0.007800	−0.014901	0.038541
Response of PM2.5									
Period	PM25	ACFT	AELEC	AFIN	GDPPC	REC	TOP	DFD	PD
2017	6.365248	0	0	0	0	0	0	0	0
2018	6.195891	0.043017	−0.010534	−0.043460	0.029124	0.036641	0.015180	0.004726	0.048402
2019	5.791245	0.113993	−0.010957	−0.096692	0.172224	0.061096	−0.113135	0.034599	−0.025618
2020	5.407739	0.178814	−0.012764	−0.117807	0.306824	0.080933	−0.218434	0.061825	−0.099594
2021	5.045068	0.232074	−0.011548	−0.122491	0.429659	0.098153	−0.306044	0.084878	−0.162401
2022	4.702842	0.276307	−0.007653	−0.119304	0.539568	0.112355	−0.378084	0.103528	−0.215180
2023	4.380511	0.313426	−0.001547	−0.112464	0.636397	0.123661	−0.436222	0.118078	−0.259030
2024	4.077340	0.344593	0.006287	−0.104239	0.720625	0.132318	−0.482132	0.128991	−0.294918
2025	3.792537	0.370603	0.015399	−0.095771	0.793008	0.138602	−0.517380	0.136752	−0.323721
2026	3.525279	0.392039	0.025387	−0.087623	0.854419	0.142796	−0.543401	0.141829	−0.346236

Table 8 Estimates of variance decomposition analysis

Variance decomposition of CO_2										
Period	S.E.	CO_2	ACFT	AELEC	AFIN	GDPPC	REC	TOP	AFOOD	PD
1	0.526330	100	0	0	0	0	0	0	0	0
2	0.728970	99.95341	0.001817	0.003867	0.004746	0.001226	7.74E−05	0.031952	2.06E−08	0.002909
3	0.869810	99.90775	0.002658	0.004450	0.016500	0.002306	0.002996	0.045654	0.001103	0.016586
4	0.977564	99.83845	0.011966	0.004213	0.027492	0.010029	0.009940	0.053277	0.004065	0.040573
5	1.063724	99.74312	0.031837	0.003794	0.036128	0.024041	0.020341	0.057803	0.008691	0.074245
6	1.134423	99.62297	0.062232	0.003390	0.042475	0.043305	0.033536	0.060516	0.014789	0.116783
7	1.193436	99.48015	0.102304	0.003064	0.047032	0.066940	0.048903	0.062095	0.022196	0.167321
8	1.243299	99.31723	0.150861	0.002835	0.050267	0.094241	0.065889	0.062938	0.030766	0.224971
9	1.285819	99.13702	0.206597	0.002701	0.052549	0.124611	0.084013	0.063294	0.040367	0.288844
10	1.322337	98.94238	0.268200	0.002649	0.054143	0.157523	0.102853	0.063325	0.050866	0.358061
Variance decomposition of PM2.5										
Period	S.E.	PM25	ACFT	AELEC	AFIN	GDPPC	REC	TOP	AFOOD	PD
1	6.365248	100	0	0	0	0	0	0	0	0
2	8.883360	99.98906	0.002345	0.000141	0.002393	0.001075	0.001701	0.000292	2.83E-05	0.002969
3	10.60769	99.92966	0.013193	0.000205	0.009987	0.027114	0.004510	0.011580	0.001084	0.002665
4	11.91532	99.79763	0.032977	0.000277	0.017691	0.087798	0.008188	0.042785	0.003551	0.009099
5	12.95446	99.59612	0.059992	0.000314	0.023907	0.184281	0.012668	0.092008	0.007297	0.023413
6	13.80323	99.33231	0.092911	0.000308	0.028528	0.315118	0.017784	0.156067	0.012053	0.044925
7	14.50933	99.01451	0.130752	0.000279	0.031827	0.477574	0.023359	0.231637	0.017531	0.072530
8	15.10456	98.65123	0.172697	0.000275	0.034131	0.668291	0.029228	0.315627	0.023469	0.105049
9	15.61144	98.25076	0.218019	0.000355	0.035714	0.883628	0.035243	0.405297	0.029643	0.141337
10	16.04657	97.82094	0.266045	0.000586	0.036785	1.119872	0.041277	0.498291	0.035870	0.180332

major detrimental factors, which will largely be influenced on CO2 emissions for the next 10-year time period; while in the case of PM2.5 emissions, it is visible that per capita income, technologies, and food deficit will impact on over a time horizon. The results of VDA show that the greater magnitude to influence CO_2 and PM2.5 emission is population density and per capita income, respectively, which will increase emissions intensity for the next 10-year time period. The significant discussions on the subject area proposed the following policy implications for SSA countries, i.e.:

i) The adoption of cleaner technologies is imperative for sustainable consumption and production.
ii) The sound financial system may helpful to conserve environment by giving technical expertise to the organizations to worked on sustainable logistics and green business growth, which minimize the concerns of high emissions intensity across countries.
iii) The high energy demand for economic production largely comes out with high emissions intensity; thus, it is viable to introduce renewable energy sources in country's existing energy portfolios to mitigate high-mass carbon emissions.
iv) The financial and trade liberalization policies should be environmental regulated, which decline the dirty production and consumption for better health outcomes.
v) The high economic growth is not only associated with the number game of high per capita income, while it is closely linked with socio-economic factors that need to sustain for inclusive growth.
vi) The search for better renewable energy source is the challenge for the SSA countries that should be explored by resource abundance and resource specialization, while biofuel and biomass are the optimized solution for energy production in countries.
vii) The food security issues are highly at risk in SSA countries, which should be reduced by better mechanization process, technological innovation, research and development expenditures, and resource conservation; all of these factors may helpful to reduce food challenges in countries.
viii) Population growth and density are another obstacle for sustainable development in SSA countries, as it increases the concentration of air pollutants in the atmosphere that need to be balanced by endogenous growth theories of fertility and resource conservation.
ix) The lack of political structure and poor institutional capacity further escalates the intensity of air pollutants that comply with leadership qualities and setup institutional framework in countries, and
x) Green policies in terms of green logistics activities, green transportation, ISO certification, environmental regulations, and sustainable production are the key policy initiatives that need to adopt by the countries for sustainable development.

These10-point agenda are highly desirable for African sustainable development program that will helpful to achieve United Nation's SDGs for healthy outcomes.

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