

Energy-water-food nexus under financial constraint environment: good, the bad, and the ugly sustainability reforms in sub-Saharan African countries

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Abstract Environmental sustainability agenda are generally compromised by energy, water, and food production resources, while in the recent waves of global financial crisis, it mediates to increase the intensity of air pollutants, which largely affected the less developing countries due to their ease of environmental regulation policies and lack of optimal utilization of economic resources. Sub-Saharan African (SSA) countries are no exception that majorly hit by the recent global financial crisis, which affected the country's natural environment through the channel of unsustainable energy-water-food production. The study employed panel random effect model that addresses the country-specific time-invariant shocks to examine the non-linear relationship between water-energy-food resources and air pollutants in a panel of 19 selected SSA countries, for a period of 2000–2014. The results confirmed the carbon-fossil-methane environmental Kuznets curve (EKC) that turned into inverted U-shaped relationships in a panel of selected SSA countries. Food resources largely affected greenhouse gas (GHG), methane (CH₄), and nitrous oxide (N₂O) emissions while water resource decreases carbon dioxide (CO₂), fossil fuel, and CH₄ emissions in a region.

Energy efficiency improves air quality indicators while industry value added increases CO₂ emissions, fossil fuel energy, and GHG emissions. Global financial crisis increases the risk of climate change across countries. The study concludes that although SSA countries strive hard to take some “good” initiatives to reduce environmental degradation in a form of improved water and energy sources, however, due to lack of optimal utilization of food resources and global financial constraints, it leads to “the bad” and “the ugly” sustainability reforms in a region.

Keywords Air pollutants · Food production · Energy resources · Improved water source · Environmental Kuznets curve · Sub-Saharan African countries

JEL classification C33 · O13

Introduction

The global financial crisis largely impacts the developed and developing countries that seizes country's economic and financial performance, including large reduction in the receipts of foreign aid, reduction in migrant worker remittances, collapsed primary commodity market, decreased foreign investment, and global trade imbalances (Arieff et al. 2010). These factors put a serious strain on the developing countries like sub-Saharan African countries that faced the challenges of food insecurity, higher energy prices, water resources, and environmental sustainability agenda across the countries.

The sub-Saharan African (SSA) countries experienced a momentous growth in population, labor force, and economic sectors; however, it further experienced a risk of local and global air pollutants including carbon emissions, greenhouse gas (GHG) emissions, and nitrous oxide emissions that impede

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the process of economic transformation in a region (Hogarth et al. 2015). The environmental and natural resources are abundant in most of the SSA countries; however, due to financial turbulence faced by the region, these resources seriously suffered further from natural calamities and climate change (Zerbo 2016). Table 1 shows the growth rate of selected SSA countries that are used as a sample in this study to evaluate energy, water, food, and environmental sustainability nexus during the two time periods, i.e., 1990 and 2014.

The food production index shows a positive growth rate in most of the SSA countries, except Mauritius and Zimbabwe that show a negative growth rate during the two time periods, i.e., 1990 and 2014. The largest growth rate in food production is found in Zambia, followed by Ethiopia and Tanzania that exceed the growth rate of 100%. The negative growth rate of “land used under cereal production” in hectares was found in Botswana, Namibia, Nigeria, and South Africa, whereas Mauritius and Tanzania exhibit a positive growth rate that exceeds 100%. The food deficit is found in Cote d’Ivoire, Namibia, and Zambia economies, while it is decreasing in the remaining SSA countries. The electricity from conventional sources including oil, gas, and coal largely is produced in Ghana, Mozambique, Namibia, and Tanzania, as the growth rate of these four nations surpasses 100% threshold, while there is a negative growth rate of electricity production in Botswana, Ethiopia, Kenya, Senegal, Sudan, Togo, Zambia, and Zimbabwe. The growth rate of GDP per unit of energy use considerably declines in Benin, Cote d’Ivoire, Gabon, Niger, Togo, and Zimbabwe economies, whereas the remaining SSA countries have a positive growth rate. The water resources in SSA countries have a positive growth rate except Sudan and Zimbabwe, where the growth rate tends to decline and shows a negative growth trend during the two time periods.

Table 1 further shows the concentration of air pollutants that noticeably increases in SSA countries, as CO₂ emissions majorly increase in Benin and Sudan, where the growth rate of carbon intensity exceeds the level of 100%. The CO₂ emission further increases to about 100% in Tanzania and more than 50% growth rate in Gabon and Mozambique. Among samples of the SSA countries, five of the SSA countries largely decrease the concentration of CO₂ emissions, i.e., Botswana, Cote d’Ivoire, Kenya, Nigeria, and Zimbabwe. The growth rate of CH₄ emissions largely increases in Mozambique and Tanzania, while it decreases in Gabon, Nigeria, Sudan, and Zimbabwe. The other SSA countries exert a positive growth rate in a region. In case of N₂O emissions, except Gabon and Zimbabwe, the other SSA countries show a positive growth rate. The dependency of fossil fuel energy consumption is largely found in Benin, Ghana, Niger, Sudan, and Tanzania, where the growth rate is about to 50%. The following SSA countries show a negative growth rate in Cote d’Ivoire, Kenya, Nigeria, and Zimbabwe. The GHG emissions show a negative growth rate in Benin, Nigeria, and South Africa, while in other SSA countries, they exhibit a positive growth rate.

The growth-specific factors show that per capita GDP consistently improves in Ethiopia and reached up to 131% followed by Nigeria (98%), Mozambique (93%), Zambia (77%), Ghana (71%), Sudan (73%), Tanzania (62%), Mauritius (56%), and Namibia (55%). Zimbabwe shows a negative per capita growth rate (i.e., -32%) during the two periods. Industrialization takes place in the following SSA countries, i.e., Ethiopia, Gabon, Kenya, Namibia, Niger, Senegal, Tanzania, Zambia, and Zimbabwe, while the population density is at minimum in Mauritius, i.e., 6% people per square kilometer of land and maximum in Niger economy, i.e., 70% people per square kilometer of land area. The other SSA countries have a positive growth rate during the study time period. These facts and figures presented the current economic situation of SSA countries including water-energy-food production, environmental quality, and growth-specific factors that lead to conclude “the good,” “the bad,” and “the ugly” transformation processes of environmental sustainability in SSA countries. The good deed is as follows:

1. The number of population has accessed with improved water sources in most of the SSA countries.
2. Energy efficiency considerably increases in terms of GDP per unit of energy use in most of the SSA countries.
3. The economic situation is well documented in most of the SSA countries, as per capita income has gained momentum since last decade that geared economic activities in the region.

The bad deed is as follows:

1. The dependency of conventional sources of electricity production, i.e., oil, gas, and coal production, increases gradually that affects the pace of economic transformation and natural resource degradation in a region.
2. The challenges of food security further deprived this region with malnutrition, poverty, and vulnerability.
3. Industrialization process turns up with new, unregulated and toxic pollutants due to improper waste recycling process, water pollution, and food waste.
4. Population density is the chief factor that exhausts the natural resources and put a strain on environment in a region.

The ugly deed is as follows:

1. The dependency of fossil fuel escalates in most of the SSA countries.
2. The local air pollutants, including CH₄ and N₂O emissions, increase in most of the SSA countries that hinder against the sustainability process of the region.

Table 1 Average growth rate of energy, water, food, and sustainability indicators in a sample of SSA countries between the two time periods, i.e., 1990 and 2014

Sub-Saharan countries	EPOGC	FPINDEX	LUCP	DFD	FFUEL	ENEF	CH ₄	N ₂ O	CO ₂	GDPPC	IWS	INDVAD	POPDEN	GHG
Benin	1.847	79.323	30.229	-63.415	68.240	-17.780	16.298	14.335	121.659	17.635	17.879	-27.192	52.510	-16.696
Botswana	-0.115	45.973	-8.083	-24.506	6.170	36.284	0.933	23.233	-5.638	48.235	1.584	-22.501	27.834	106.918
Cote d'Ivoire	20.599	32.452	14.818	5.495	-30.960	-33.073	35.120	16.096	-23.901	4.390	5.006	-1.901	34.140	13.788
Ethiopia	-93.322	112.020	41.310	-48.770	50.159	84.452	41.885	18.484	-4.159	131.105	91.696	20.169	45.926	0.912
Gabon	61.663	21.861	70.606	-37.500	33.868	-13.534	-22.957	-12.527	65.953	5.988	11.217	10.632	37.037	5.004
Ghana	4559.608	83.961	24.905	-80.620	85.668	63.751	9.010	3.538	21.046	71.338	24.255	-2.504	42.293	0.078
Kenya	-42.075	70.918	41.647	-37.220	-0.581	16.651	19.452	15.639	-2.320	30.566	21.815	14.405	44.415	17.442
Mauritius	12.845	-1.170	587.143	-28.000	13.428	17.478	62.948	28.587	37.891	56.240	0.706	-25.128	6.240	45.041
Mozambique	416.327	84.281	33.719	-38.486	36.650	79.300	107.537	3.801	77.562	93.935	23.844	-8.637	49.012	76.659
Namibia	466.990	8.278	-11.523	29.630	8.643	9.941	17.723	75.327	43.161	55.439	15.032	13.708	26.603	11.957
Niger	-0.903	89.641	49.267	-65.089	73.564	-1.820	26.686	24.108	18.430	17.435	32.952	9.817	70.285	3.026
Nigeria	32.088	42.399	-11.156	-36.066	-1.544	74.008	-11.510	9.455	-16.589	98.853	30.502	-53.553	44.434	-4.435
Senegal	-1.940	20.184	-3.404	-66.667	3.719	6.200	37.928	15.976	47.303	15.693	15.430	1.204	48.800	11.417
South Africa	0.731	27.172	-24.164	-54.286	2.934	16.992	16.223	15.269	10.501	25.410	7.283	-7.625	22.732	7.166
Sudan	-64.512	45.948	83.104	-11.111	82.671	75.933	-3.029	1.135	119.657	73.886	-10.484	-2.110	47.419	-7.042
Tanzania	402.839	110.953	156.002	-7.308	137.117	32.116	51.770	21.499	98.642	62.535	2.022	30.289	52.457	8.990
Togo	-64.264	48.800	64.322	-53.623	15.531	-4.801	22.554	32.412	14.771	4.691	16.418	-6.360	45.960	3.977
Zambia	-53.646	118.293	84.750	37.874	37.057	61.244	12.170	5.241	23.392	77.267	21.887	28.676	48.522	10.124
Zimbabwe	-13.564	-11.332	26.025	-25.360	-9.264	-29.397	-16.888	-10.125	-37.738	-32.213	-2.897	11.295	21.967	40.096

Source: World Bank (2015). EPOGC indicates electricity production from oil, gas, and coal sources; FPINDEX indicates food production index; LUCP indicates land under cereal production; DFD indicates depth of the food deficit; FFUEL indicates fossil fuel energy consumption; ENEF indicates energy efficiency; CH₄ indicates methane emissions; N₂O indicates nitrous oxide emission; CO₂ indicates carbon dioxide emissions; GDPPC indicates GDP per capita; IWS indicates improved water source; INDVAD indicates industry value added; POPDEN indicates population density; and GHG indicates GHG emissions

3. The global air pollutants including CO₂ and GHG emissions both increase along with global financial crisis that deteriorate natural environment of the region.
4. The improper utilization of economic resources and financial imbalances lead to obstruct the economic pace in a region.

The SSA countries required extensive environmental transformation to take some re-corrective measures for the bad and the ugly sustainable reforms to develop an interactive environmental model, where the water-energy-food resources comply according to the Copenhagen climate change protocol.

This study examined the relationships between water-energy-food production and air quality indicators under environmental Kuznets curve (EKC) framework in the times of financial crisis, using time series data of 2000–2014 in a panel of 19 SSA countries. The more specific objectives are as follows:

1. To establish an inverted U-shaped EKC in different air pollutants
2. To examine the impact of global financial crisis on different local and global pollutants
3. To analyze the relationship between water-energy-food production and different air pollutants that is mediated by global financial crisis in a region

The study utilized panel random effect model that controls the country-specific time-invariant shocks for robust inferences.

Literature review

This study reviewed three different streams of literature and makes them together to evaluate energy-water-food production and sustainability indicators in a global financial crisis to develop an integrated environmental model for sustainability. The first stream of literature is related with the inverted U-shaped EKC framework, which is transmitted by different air pollutants that respond differently with the economic growth. The EKC is a well-known and well-estimated functional relationship between the air pollutants and growth determinants in polynomial regression equations (Dinda 2004), which exert a positive relationship between air pollutants and growth determinants in a time of economic gains, while they exert a negative relationship between them, reaching the optimum threshold of economic maturity (Stern et al. 1996). There are a number of studies that confirmed the EKC relationship between different air pollutants and per capita income in different cross-sectional, time series, and longitudinal surveys; i.e., Selden and Song (1994) supported an inverted U-shaped EKC in SO₂, N₂O, PM_{2.5}, and CO in a cross-national panel of 2 low-income countries, 6 middle-income countries and 22

high-income countries. Hilton and Levinson (1998) supported an inverted U-shaped EKC relationship between automatic lead emissions and income of 48 countries by using 20-year time series data. Kaufmann et al. (1998) confirmed the sulfur-EKC relationship with spatial intensity of economic activity in developing countries. Bhattarai and Hammig (2001) established the deforestation-EKC relationship in Asia, Africa, and Latin American region. Perman and Stern (2003) proved the concave functional relationship between SO₂ emissions and per capita income in a panel of 74 countries. Akbostancı et al. (2009) did not confirm the inverted U-shaped EKC relationship in CO₂, SO₂, and PM_{2.5} in Turkey. Saboori et al. (2012) supported the carbon EKC in Malaysia. Shahbaz et al. (2013) confirmed carbon EKC in Romania. Al-Mulali et al. (2015) did not support the carbon-EKC in Vietnam. Zaman et al. (2016) supported carbon-EKC hypothesis in a panel of 34 diversified countries. Khan et al. (2016) established the resource depletion EKC hypothesis in a panel of developed countries, etc. These studies mainly debated on EKC hypothesis under different air pollutants, while this debate should be further linked with the energy-water-food resources for environmental sustainability across countries.

The second stream of literature focused on energy-water-food resources and air quality indicators to promote the sustainability agenda across the globe. Hellegers et al. (2008) discussed different direct and indirect channels through which environmental sustainability is affected, particularly, higher energy prices, water resources, food insecurities, energy sources, etc. The study concludes that water-energy-food nexus is linked with sustainability agenda, which is a prerequisite for global prosperity. Olsson (2013) emphasized the strong need for integration in water-food-energy (WFE) factors that shared the burden of climate change, food securities, population, and urbanization. The cleaner technologies, proper policy operations, and resource management are supposed to be the main factors that are helpful to integrate this WFE nexus for global sustainability. Perrone and Hornberger (2014) concluded that food security and energy demand both are connected with the water supply that mediated the energy supply to produce food grains across the globe. Ozturk (2015) concluded that economic and environmental reforms are prerequisite for environmental sustainability that are interlinked with the three-tier multifaceted factors including food resources, energy demand, and improved water resources and further argued that, if these resources are properly utilized, then it works like catalyst to support the “United Nations Kyoto Protocol” for resource conservation. Conway et al. (2015) discussed different mediating factors that affect climate change in Southern Africa and emphasized the need for water-energy-food nexus that mitigates the problem of environmental degradation through improved water sources, cleaner technologies, and consuming organic foods that are linked with sustainability agenda in a region. Gain

et al. (2015) discussed the importance of energy-water-food nexus, although this nexus is not yet in a policy document to integrate it and get benefited by it in developing countries like Bangladesh, which is the hard side of the story in academic arena. Rasul (2016) presented the sustainability framework for South Asia by utilizing water security, energy demand, and food resources and argued the need for strong binding in them through coherent economic and environmental policy for efficient use of resources in a region. Yillia (2016) emphasized to formulate an integrated environmental policy by managing the economic and environmental resources in a form of balancing the energy-water-food nexus for achieving sustainability goals.

The third stream of literature mainly focused on global financial crisis and air quality indicators, as the global financial crisis directly hit the developed countries while it further transmitted to less developed countries in a form of food security challenges, water pollution, energy demand, and climate change. Tienhaara (2010) discussed the twin global crisis, i.e., global financial crisis and global environmental concerns; both are mutually dependent, as one-side financial crisis reaches at maximum, the environmental crisis begins and it affects the long-run economic and environmental sustainability agenda across the globe. Rosset (2011) provoked the need for sustainable agricultural practices that support to reduce economic challenges, financial crisis, food insecurities, and energy issues across the countries. McCarthy (2012) pointed out that the recent waves of global economic crunch weakened the environmental support actions that have a big question on environmental sustainability reforms in USA. Tienhaara (2014) discussed different green environmental instruments in a time of crisis, including green economy, green stimulus, green new deal, and green capitalism. These greening concepts are close to the sustainability development goals to conserve natural resources and mitigate climatic concerns and provoked the agenda of global economic and environmental prosperity. Ziaei (2015) confirmed the volatility of global financial crisis on environmental quality and energy demand that obstructs the progress of sustainability agenda in different regions of the world. Zaman (2016) argued that human development required efficient energy resources to face globalization challenges in developing countries like Pakistan. The policies for cleaner technologies required renewable energy sources to reduce environmental concerns and confront the challenges of globalization in a country.

The previous discussion calls for sustainable policy agenda that are intact with energy-water-food resources, air quality indicators, growth-specific factors, and global financial crisis. The recent times economic and financial crisis damages the global environment along with global economic health that required sustainable production to confront food challenges, water pollution, and energy issues by sustainable food

technologies, improved water resources, and renewable energy sources with fiscal stimulus and economic incentives. The sound mechanism is needed to balance the twin crisis of economy and environment for healthy and wealthy future.

Empirical model

This study used panel random effect model to evaluate energy, water, and food production nexus in a panel of 19 selected SSA countries, by using time series data from 2000 to 2014. The environmental pollutants (*ep*) served as an endogenous variable, whereas energy (*enrg*), water (*h2o*), and food (*fd*) resources are used as explanatory factors of the study. The study explained this relationship in the inverted U-shaped EKC under financial crisis regime that affects the country's existing sustainability reforms as the good, the bad, and the ugly transformations in a region. The reduced form of regression equation is utilized for this purpose, i.e.,

$$ep_{it} = c + \alpha_t enrg_{it} + \beta_{i1} h2o_{it} + \gamma_{i2} fd_{it} + v_i + \psi_t + \varepsilon_{it} \quad (1)$$

where v_i shows the country's fixed effect, ψ_t shows the time-invariant shocks, " i " shows the classifications of countries as a panel of selected SSA countries ($i = 1, \dots, 19$), " t " shows the study time period ($t = 2000-2014$), and ε_{it} shows the error term.

Equation (1) further decomposed into different set of growth-specific regressors (*gr*) that explained environmental sustainability process under EKC framework, i.e.,

$$ep_{it} = c + \alpha_{i1} enrg_{it} + \beta_{i2} h2o_{it} + \gamma_{i3} fd_{it} + \lambda_{i4} gr_{it} + \sigma_{i5} gr_{it}^2 + v_i + \psi_t + \varepsilon_{it} \quad (2)$$

The study further added financial dummy-2008 (D_{2008}) to capture the effects of global financial crisis on environmental sustainability process in a region, i.e.,

$$ep_{it} = c + \alpha_{i1} enrg_{it} + \beta_{i2} h2o_{it} + \gamma_{i3} fd_{it} + \lambda_{i4} gr_{it} + \sigma_{i5} gr_{it}^2 + \omega_{i6} D_{2008_{it}} + v_i + \psi_t + \varepsilon_{it} \quad (3)$$

Equation (3) is the final version of the model that includes energy factors, water resource, food production, and growth factors in SSA countries during the time of financial crisis.

The study utilized the unit root process by the panel random effect method; i.e., the individual variable regressed with first lag of the respective variable by imposing a restriction that the candidate variable contains a unit root process, which is estimated by the Wald F -statistics. The Hausman test is applied to discriminate between fixed panel model and random effect model and decide for the selection of the model based on significant chi-squared statistics for fixed effect model while insignificant chi-squared statistics support the

random effect model. There are a number of advantages to using longitudinal data; i.e., it gives unbiased parameter estimates as it controls stochastic factors that move across the countries in the random effect model and move over time in case of the fixed effect model; due to this distinction, the chances of overestimation bias considerably reduce. The chances of intercorrelations between the exogenous factors are precisely less in panel modeling as compared to the time series analysis; i.e., the greater expected variations in the exogenous factors give more reliable estimates. The panel random effect model absorbed the county-specific time-invariant shocks and reduced the problem of serial correlation in the given set of variables. This distinction of panel regression modeling techniques allows to utilize panel technique for robust and reliable estimates.

Data

The following variables are used to estimate the food, water, and energy resources, i.e., food production index (2004–2006 = 100); land under cereal production in hectares; depth of the food deficit in kilocalories per person per day; electricity production from oil, gas, and coal sources as % of total energy consumption; GDP per unit of energy use in constant 2011 PPP \$ per kilogram of oil equivalent; and improved water source as % of population with access. The study used a set of endogenous variables, i.e., air quality indicators that include methane emissions in energy sector (thousand metric tons of CO₂ equivalent), nitrous oxide emissions in energy sector (thousand metric tons of CO₂ equivalent), CO₂ emissions (metric tons per capita), fossil fuel energy consumption (% of total), and total greenhouse gas emissions (kt of CO₂ equivalent). The growth-specific factors mediate the relationship between air quality indicators and water-energy-food resources including GDP per capita in purchasing power parity (constant 2011 international \$), industry value added (% of GDP), and population density (people per km² of land area). The World Development Indicators is used to collect the data of the respective variables, which is published by the World Bank (2015). The data series is filled by the preceding and subsequent values of the variables to prevent it from the loss of degree of freedom. Table 2 shows the variable description and a priori expectations between the estimated parameters.

Table 2 shows the theoretical and hypothetical expectations between the studied variables, as it is expected that the relationships between air quality indicators (including CO₂, FFUEL, CH₄, N₂O, and GHG emissions) and per capita income are positive; i.e., it first increases, and then, after reaching the economic maturity stage, air pollutants considerably decline, which support the carbon, fossil, methane, nitrous oxide, and GHG emission Kuznets curve hypothesis in a region. The food resources are expected to have a positive

relationship with the different environmental pollutants, as food resources if not properly utilized tend to increase the environmental pollutants that may damage the natural environment. The energy sources are expected to increase air pollutants; as electricity production from conventional sources increases, i.e., oil, gas, and coal consumption, more will be the emissions produced while energy efficiency in terms of increasing per unit of GDP may support to decrease the intensity of air pollutants in an atmosphere. Air pollutants may emerge in water resource due to leakage of large drain of recycled production wastes in water. The industry value added and population density are both expected to deteriorate the environment through the channel of massive smoke production, to meet the growing food demand of population needs. These theoretical and expected relationships are linked with the number of previous studies: Rööß et al. (2010) discussed carbon footprint in food production, Friedrich et al. (2009) indicated the association of increased water resources with environmental associated stress, and Peçala et al. (2010) described the energy emission nexus that constraints energy demand and optimal energy planning, etc.

The global financial crisis severely affected the economic growth and natural environment of the developed and developing countries. The developed countries, however, quickly rescues it by transforming their economic and ecological resources through sustainability growth reforms while the developing countries are unable to balance their economic and environmental resources due to their poor environmental reforms. SSA countries are one of the striking examples in a given scenario that are seriously affected by global financial crisis, and the recovery speed is very low that hinders the environmental sustainability agenda in a region. The SSA countries should require some policy measures to conserve the natural resources; however, the lack of economic resources may not attempt to produce desirable results that lead to the good, the bad, and the ugly sustainability reforms in credit to the region.

Results and discussions

The result of descriptive statistics and correlation matrix is presented in Table 3. The mean value of methane (CH₄) emissions is 6444.378 t of CO₂ equivalent with a maximum value of 45,868.560 thousand t and a minimum value of 21.647 thousand t. The depth of food deficit has a minimum value of 16 kcal per person per day and a maximum value of 488 kcal with average kilocalories of 169.926 per person per day. The carbon emissions have an average value of 1.110 t per capita, where as energy efficiency in a form of GDP per unit of energy use has an average value of 6.650 \$ per kilogram of oil equivalent. The maximum value of electricity production from conventional sources including oil, gas, and coal is about 100% of total energy consumption, and an

Table 2 Description of variables

Variables	Unit	Symbol	Theoretical expectations	Hypothetical relationships
Dependent variables				
- Air quality indicators				
Carbon dioxide emissions	Metric tons per capita	CO ₂	Carbon Kuznets curve	
Fossil fuel energy consumption	% of total energy consumption	FFUEL	Fossil energy Kuznets curve	
Methane emissions in energy sector	Thousand metric tons of CO ₂ equivalent	CH ₄	Methane Kuznets curve	
Nitrous oxide emissions in energy sector	Thousand metric tons of CO ₂ equivalent	N ₂ O	Nitrous Kuznets curve	
Greenhouse gas emissions	kt of CO ₂ equivalent	GHG	GHG Kuznets curve	
Independent variables				
- Food resources				
Food production index	2004–2006 = 100	FPINDEX	Positive	Food production stimulate air pollutants
Land under cereal production in hectares	Hectares	LUCP	Positive	
Depth of the food deficit	Kilocalories per person per day	DFD	Positive	
- Energy resources				
Electricity production from oil, gas, and coal sources	% of total energy consumption	EPOGC	Positive	Electricity production increases the intensity of air pollutants
Energy efficiency measured by GDP per unit of energy use	Constant 2011 PPP \$ per kg of oil equivalent	ENEF	Negative	Energy efficiency supports air quality indicators to improve environment
- Water resource				
Improved water source	% of population with access	IWS	Positive	Water resource increase air pollutants
- Growth-specific factors				
GDP per capita, PPP	Constant 2011 international \$	GDPPC	Positive	Inverted U-shaped EKC
Square of GDP per capita		(GDPPC) ²	Negative	
Industry value added	% of GDP	INDVAD	Positive	Industrial production increases the intensity of air pollutants
Population density	People per km ² of land area	POPDEN	Positive	Population density increases air pollutants

(GDPPC)² represents square of GDPPC

average value is approximately half of the maximum value. The average value of fossil fuel energy, food production index, GHG emissions, GDP per capita, and industry value added is about 34.196% of total energy consumption; 107.929 production index; 148,444.700 kt of CO₂ equivalent; 4862.382 US\$ per capita; and 27.274% of GDP, respectively. The mean value of improved water sanitation, land under cereal production, nitrous oxide (N₂O) emissions, and population density is about 69.827% of population with access; 3,472,899 ha; 540.606 thousand t of CO₂ equivalent; and 80.824 people per km² of land area, respectively, with high kurtosis value and positively skewed distribution.

The correlation matrix in Table 3 shows that there is a negative correlation of depth in food deficit, energy efficiency,

food production, and improved water sanitation with the methane emissions, whereas the positive correlation has been found with electricity production, GDP per capita, industry value added, land under cereal production, and population density in a region. There is a negative correlation of carbon emissions and fossil fuel energy consumption with the food resources and positive correlation with the energy resources, water source, and growth-specific factors, which confirmed that carbon emissions and fossil fuel energy escalate with the energy demand, water source, and growth factors, while optimal usage of food production factors considerably decreases carbon emissions and fossil energy across the countries. There is a positive correlation between GHG emissions and food production resources, while there is a negative

Table 3 Descriptive statistics and correlation matrix

	CH ₄	DFD	CO ₂	ENEF	EPOGC	FFUEL	FPINDEX	GDPPC	GHG	INDVAD	IWS	LUCP	N ₂ O	POPDEN
Mean	6444.378	169.926	1.110	6.650	50.176	34.196	107.929	4862.382	148,444.700	27.375	69.827	3,472.899	540.606	80.824
Maximum	45,868.560	488	9.545	15.662	100	88.149	184.370	18,536.770	634,374.700	66.293	99.900	19,410,000	2683.311	621.150
Minimum	21.647	16	0.057	1.386	0.077	3.756	67.750	555.560	2438.997	10.185	28.900	14	11.462	2.305
Std. Dev.	10,621.770	114.532	1.981	3.810	36.934	24.490	21.160	5000.584	159,538.900	10.616	17.205	4,446,207	707.314	131.095
Skewness	2.489	0.532	3.188	0.663	-0.098	0.745	1.140	1.335	1.062	1.380	0.049	1.768	1.825	3.388
Kurtosis	7.989	2.468	12.728	2.314	1.530	2.399	4.376	3.372	2.848	5.252	1.968	5.545	5.113	13.873
Panel correlation matrix														
CH ₄	1													
DFD	-0.332	1												
CO ₂	0.441	-0.373	1											
ENEF	0.221	-0.424	0.157	1										
EPOGC	0.189	-0.535	0.386	0.224	1									
FFUEL	0.051	-0.472	0.744	0.637	0.442	1								
FPINDEX	-0.057	-0.002	-0.049	-0.079	-0.017	-0.108	1							
GDPPC	0.087	-0.419	0.603	0.758	0.290	0.711	-0.072	1						
GHG	0.559	0.140	0.300	-0.324	-0.153	-0.120	0.093	-0.100	1					
INDVAD	0.114	-0.236	0.267	0.546	0.191	0.379	-0.082	0.713	-0.042	1				
IWS	-0.086	-0.465	0.554	0.704	0.384	0.862	-0.024	0.777	-0.311	0.578	1			
LUCP	0.700	-0.107	-0.106	-0.280	0.105	-0.352	-0.001	-0.284	0.472	-0.177	-0.503	1		
N ₂ O	0.891	-0.167	0.539	-0.356	0.068	0.057	-0.012	0.015	0.621	-0.099	-0.163	0.628	1	
POPDEN	0.027	-0.349	0.145	0.354	0.158	0.341	-0.082	0.313	-0.204	-0.093	0.321	-0.039	-0.036	1

EPOGC indicates electricity production from oil, gas, and coal sources; FPINDEX indicates food production index; LUCP indicates land under cereal production; DFD indicates depth of the food deficit; FFUEL indicates fossil fuel energy consumption; ENEF indicates energy efficiency; CH₄ indicates methane emissions; N₂O indicates nitrous oxide emission; CO₂ indicates carbon dioxide emissions; GDPPC indicates GDP per capita; IWS indicates improved water sources; INDVAD indicates industry value added; POPDEN indicates population density; and GHG indicates GHG emissions

correlation of energy efficiency and growth-specific factors with GHG emissions. The results reveal that GHG emissions increase along with the increase in food production, while there is no visible evidence of increasing GHG emissions with energy sources and growth-specific factors in a region. The relationship between nitrous oxide emissions and other possible determinants is differential in nature, as depth of food deficit, energy efficiency, food production index, industry value added, improved water source, and population density have a negative correlation with nitrous oxide emissions, while there is a positive correlation of electricity production, per capita income, and land under cereal production with the methane emissions across the countries. Figure 1 shows the plots of level data for ready reference.

Table 4 shows the estimates of panel unit root test that is performed by random effect model. The studied variables individually regressed by its first lag as a regressor in a panel random setting and obtained an estimated coefficient value, while an imposing restriction by the Wald F -statistics (i.e., the lagged coefficient value is equal to unity) confirmed that the

given variable does not contain a unit root process. The results rejected the null hypothesis of unity and concluded that the given variables contained a unit root process, as the Wald F -statistics has a significant probability value at 5% level, which justified the panel random regression model for further estimating the functional relationship between the variables.

Table 5 shows the estimates of panel random effect model with five distinct air quality indicators and their potential predecessors; i.e., in a first model, carbon dioxide emissions are explained by food, water, and energy resources under the EKC framework and reveal that as depth of food deficit decreases, it subsequently increases carbon emissions in a panel of selected countries; i.e., if there is a 1% decrease in depth in food deficit, CO₂ emissions increase by -0.176 percentage points. Although there is a less elastic relationship between the two variables, however, its intensity to affect CO₂ emissions is far larger than the other two food resources, i.e., food production index and land under cereal production, as both are insignificant with CO₂ emissions in a region. The energy efficiency that is measured by GDP per unit of energy use

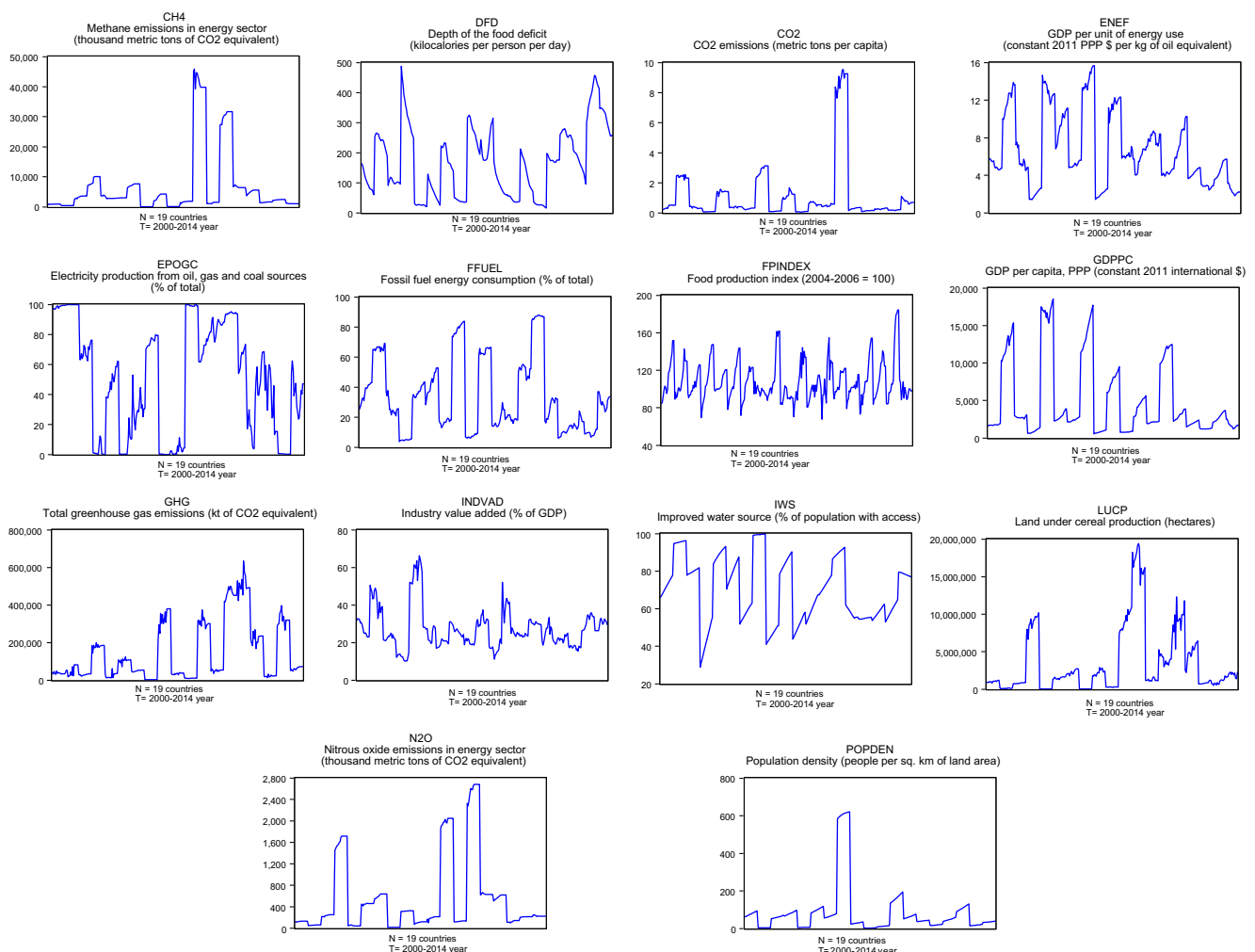


Fig. 1 Plots of level data. Source: World Bank (2015)

Table 4 Results of panel unit root tests by fixed effect regression

	LEPOGC	LFPINDEX	LLUCP	LDFD	LFFUEL	LENEF	LCH ₄	LN ₂ O
LEPOGC(-1)	0.964*							
LFPINDEX(-1)		0.894*						
LLUCP(-1)			0.988*					
LDFD(-1)				1.014*				
LFFUEL(-1)					0.985*			
LENEF(-1)						0.982*		
LCH ₄ (-1)							0.994*	
LN ₂ O(-1)								0.997*
LCO ₂ (-1)								
LGPPC(-1)								
LIWS(-1)								
LINDVAD(-1)								
LPOPDEN(-1)								
LGHG(-1)								
H0: a1 = 1	4011.926*	1056.790*	28,551.90*	18,111.06*	27,178.08*	14,077.81*	177502*	156,611.4*
	<hr/>							
	LCO ₂	LGPPC	LIWS	LINDVAD	LPOPDEN	LGHG		
LEPOGC(-1)								
LFPINDEX(-1)								
LLUCP(-1)								
LDFD(-1)								
LFFUEL(-1)								
LENEF(-1)								
LCH ₄ (-1)								
LN ₂ O(-1)								
LCO ₂ (-1)	0.991*							
LGPPC(-1)		0.995*						
LIWS(-1)			0.964*					
LINDVAD(-1)				0.959*				
LPOPDEN(-1)					1.002*			
LGHG(-1)								
H0: a1 = 1	45,063.17*	39,998.80*	258,445.9*	5200.869*	1074162.0*			0.981*
								11,181.44*

H0:a1 = 1 is a Wald test for the estimated coefficient on the lagged dependent variable equal to one. "L" denotes natural logarithm. (-1) denotes first lag of the respective variables
* and ** indicate 1 and 5% levels of significance, respectively

Table 5 Estimates of panel random effect model

Variables	LCO ₂	LFFUEL	LCH ₄	LN ₂ O	LGHG
Constant	-14.556*	-3.721*	-5.091*	2.331***	8.748*
Food resources					
LFPINDEX	0.006	0.111	0.065	0.056	0.277* ^a
LLUCP	-0.017	-0.007	0.104*	0.127*	0.183*
LDFD	-0.176*	-0.194*	-0.066***	-0.013	0.030
Energy resources					
LEPOGC	0.007	0.025*	0.001	0.005	-0.006
LENEF	-0.775*	0.077	-0.347*	-0.275*	-0.313***
Water resource					
LIWS	-0.938*	-0.490*	-0.222	0.008	-0.240
Growth factors					
LGDPPC	3.558*	1.769*	2.892*	0.171	-0.036
(LGDPPC) ²	-0.139*	-0.086*	-0.154*	0.0006	0.017
LINDVAD	0.190*	0.225*	-0.102**	-0.108*	0.180***
LPOPDEN	0.017	0.019	0.039	0.170	-0.022
D ₂₀₀₈	-0.0008	0.014	0.013	-0.011	0.142*
Statistical tests					
R ²	0.482	0.422	0.386	0.290	0.218
Adjusted R ²	0.461	0.399	0.361	0.261	0.187
F-statistics	23.109*	18.185*	15.638*	10.158*	6.951*

EPOGC indicates electricity production from oil, gas, and coal sources; FINDEX indicates food production index; LUCP indicates land under cereal production; DFD indicates depth of the food deficit; FFUEL indicates fossil fuel energy consumption; ENEF indicates energy efficiency; CH₄ indicates methane emissions; N₂O indicates nitrous oxide emission; CO₂ indicates carbon dioxide emissions; GDPPC indicates GDP per capita; IWS indicates improved water sources; INDVAD indicates industry value added; POPDEN indicates population density; D₂₀₀₈ indicates financial dummy-2008; and GHG indicates GHG emissions. “L” denotes natural logarithm

(LGDPPC)² represents square of LGDPPC

*, **, and *** indicate 1, 5, and 10% significance levels

^a Coefficient value is estimated when all other variables are being kept constant

significantly declines the CO₂ emissions, which implies the need for optimal utilization of energy resources that considerably decrease the CO₂ emissions across the countries. There is a significant and negative relationship between improved water source and CO₂ emissions, as the higher the improved water resources, the lower will be the concentration of carbon emissions, which considerably decreases the prospects of water pollution in a region. The growth-specific variables confirmed the viability of inverted U-shaped carbon-EKC, as carbon emissions increase along with an increase in per capita income, which substantially decreases with economic maturity at the later stages of economic development. Industry value added deteriorates the environment in a panel of SSA countries. There is no visible impact of global financial crisis on CO₂ emissions during the study time period. The results of the study supported by a number of previous studies including Akkerman et al. (2010) emphasized the sustainable pattern of food production through operation management and address food sustainability, food quality, and safety across the globe. Ericksen (2008) built a sustainable food system that aligned with global environmental change to

confront societal issues, i.e., ecological services, food security, and human's vulnerability. Wognum et al. (2011) discussed the three pillars of sustainability in terms of food supply chain process, i.e., environmental regulations, sustainability in food production process, and stakeholders' profit. These pillars of sustainability are required food safety process, origin of food, and food distribution channel that are helpful for developing sustainable food supply channel across countries. Godfray et al. (2010) discussed the food security challenges under the light of water issues, land distribution, and energy demand that escalate the food sustainability problem and threat to climate change, which required global integrated policy agenda for equitable food security and sustainability.

The relationship between fossil energy and energy-water-food resources analyzed in a next regression apparatus shows that the higher the depth of food deficit, the lower will be the fossil energy demand, while the electricity production from conventional sources of energy including oil, gas, and coal considerably increases fossil resources in a region. The improved water sources decrease the fossil dependency of energy

Table 6 Long-run elasticity estimate calculated using the estimates of panel random effect model

Variables	LCO ₂	LFFUEL	LCH ₄	LN ₂ O	LGHG
LFPINDEX	0.666	7.400	10.833	18.667	14.579
LLUCP	-1.888	-0.467	17.333	42.333	9.632
LDFD	-19.555	-12.933	-11.000	-4.333	1.579
LEPOGC	0.777	1.667	0.167	1.667	-0.316
LENEF	-86.111	5.133	-57.833	-91.667	-16.474
LIWS	-104.222	-32.667	-37.000	2.667	-12.632
LGDPCC	395.333	117.933	482.000	57.000	-1.895
(LGDPCC) ²	-15.444	-5.733	-25.667	0.200	0.895
LINDVAD	21.111	15.000	-17.000	-36.000	9.474
LPOPDEN	1.888	1.267	6.500	56.667	-1.158
D ₂₀₀₈	-0.088	0.933	2.167	-3.667	7.474

EPOGC indicates electricity production from oil, gas, and coal sources; FPINDEX indicates food production index; LUCP indicates land under cereal production; DFD indicates depth of the food deficit; FFUEL indicates fossil fuel energy consumption; ENEF indicates energy efficiency; CH₄ indicates methane emissions; N₂O indicates nitrous oxide emission; CO₂ indicates carbon dioxide emissions; GDPCC indicates GDP per capita; IWS indicates improved water sources; INDVAD indicates industry value added; POPDEN indicates population density; D₂₀₀₈ indicates financial dummy-2008; and GHG indicates GHG emissions. “L” denotes natural logarithm

(LGDPCC)² represents square of LGDPCC

consumption, which is further connected with the inverted U-shaped fossil EKC, as fossil energy increases with the income in the initial stage of development that decreases at later stages. The industry value added is strongly linked with the increased fossil energy consumption that is cumbersome in the sustainability policies in a region. Although the positive coefficient sign is associated in relation with global financial crisis and fossil fuel energy demand, however, it is statistically insignificant that may not confine its impact on fossil energy resources across countries. The methane emissions, in another regression apparatus, show that its impact is positive and significant with the land used under cereal production, i.e., 0.104, $p < 0.000$, while energy efficiency and industry value added both reduce the share of CH₄ emissions; however, the intensity of energy efficiency to reduce CH₄ emissions is larger than the impact of industry value added to decrease the CH₄ emissions across countries. The results confirmed the inverted U-shaped methane-EKC hypothesis; i.e., CH₄ increases with initial per capita income that is turned down with the mature economic growth at later stages of economic development. The relationship between nitrous oxide emission and land used under cereal production is positive, which implies that the greater cereal land production produces larger N₂O emissions that badly affect the sustainability policy agenda across countries. The impact of energy efficiency and industry value added both considerably reduces the share of N₂O emissions; however, energy efficiency exerts a larger impact on reduction of N₂O emissions as

compared to the industry value added. In addition, the study does not support the inverted U-shaped relationship between N₂O emissions and per capita income in a region.

Finally, the GHG emissions are affected by food production index and land used under cereal production, as if there is a 1% increase in the food production index and cereal production land, GHG emissions increase by 0.277 and 0.183%, respectively. The impact of food production index has a greater share in order to increase the GHG emissions as compared to the cereal production requiring greater land. The energy efficiency decreases the GHG emissions, while industry value added largely contributes to increased GHG emissions in a region. There is no visible sign of EKC relationship with GHG emissions, which turned to affect largely the sustainability agenda framework across countries. The global financial crisis largely affected the sustainability agenda, as GHG emissions considerably increase along with the increased global financial constraints in a region. Among all air quality indicators, GHG emissions are considered the most potent pollutant that is affected by global financial crisis during the study time period. The GHG emissions are the global air pollutant like CO₂ emissions, while the remaining fossil fuel, N₂O emissions, and CH₄ emissions are the local air pollutants; therefore, the impact of financial crisis largely affected the global air pollutants across countries. The results are in line with the previous studies; for example, Wheeler and Von Braun (2013) argued that due to the variability in the global food supply, the risk of stability of food production process increases the threat of climate change that raises social issues including malnutrition, hunger, poverty, vulnerability, etc. The “smart food choice strategy” and investment for sustainable food process are the optimal solution to confront the food security challenges and environmental concerns across the globe. Gregory et al. (2005) discussed the dynamic relationship between global food security and climate change and concluded that climate change directly affects the food competitive market by rising the food prices, food production process, and its distribution, whilst it has an indirect impact through crop production that is affected by floods, drought, global warming, etc. The overall impact of climate changes is visible that throws into food turmoil, and it leads to increase socioeconomic impacts. Palm et al. (2010) discussed different tradeoffs between climate change and global food security in SSA countries and interlinked both of the twin crisis with land degradation and deforestation that increases poverty and vulnerability in a region. The environmental sustainability success rate is possible by carbon financing to upgrade land distribution and reducing forest depletion that would be helpful to reduce the threat to climate change in a region.

Policy analysis

Table 6 shows the long-run elasticity estimates by using the (i) short-run elasticity of Table 5 and (ii) unit root transformation

process of Table 4. The long-run results are estimated through short-run elasticity estimates, which are further divisible by one minus lagged dependent term.

The results of Table 6 show that food production index has a larger share to increase N₂O emissions, followed by GHG emissions, CH₄ emissions, fossil fuel, and carbon emissions, whereas land used in cereal production increases N₂O emissions and CH₄ emissions and decreases carbon emissions, GHG emissions, and fossil fuel energy as per their contributing share in prescribed models. Except GHG emissions, the depth of food deficit decreases CO₂ emissions, CH₄ emissions, N₂O emissions, and fossil fuel energy demand, while GHG emissions increase the depth of food deficit in a region. The air quality indicators considerably increase along with the increase in electricity production from conventional sources, whereas they do considerably decrease the share of GHG emissions across the countries. Energy efficiency supports to reduce air quality indicators except fossil fuel energy, as it escalates along with an increase in GDP per unit use of energy. Water quality improves environmental indicators except N₂O emissions. In the long run, the EKC hypothesis is confirmed with CO₂ emissions, fossil fuel, and CH₄ emissions, while N₂O emissions increase at initial and later stages of economic development. The U-shaped EKC relationship is established between GHG emissions and per capita income across countries. Industry value added substantially increases CO₂ emissions, fossil fuel energy, and GHG emissions, while it decreases CH₄ emissions and N₂O emissions in the long run. Population density considerably increases air pollutants except GHG emissions in the long run. The global financial crisis largely affects GHG emissions, followed by CH₄ emissions and fossil fuel energy demand, while it decreases CO₂ emissions and N₂O emissions in a panel of countries.

Conclusions

This study examined the relationships between air quality indicators and energy-water-food resources under the EKC framework in a financial constraint environment in a panel of 19 selected SSA countries, during a period of 2000–2014. The study used diversified factors of food, water, and energy resources that affected different local and global air pollutants including CO₂, CH₄, N₂O, fossil fuel, and GHG emissions in order to evaluate environmental sustainability policies of the region. The results of panel random effect model reveal that food production index is associated with increased GHG emissions, while cereal production increases CH₄, N₂O, and GHG emissions across countries. Energy efficiency, on one hand, supports to reduce CO₂, CH₄, N₂O, and GHG emissions, while on the other side, electricity production from conventional sources increases fossil fuel energy. The air pollutants, including CO₂, CH₄, and fossil fuel energy, considerably

decrease along with improved water source, while industry value added escalates CO₂, fossil fuel, and GHG emissions in a region. The results confirmed the existence of an inverted U-shaped relationship between carbon-methane-fossil and per capita income, while there is a flat relationship between nitrous oxide (and GHG emissions) and per capita income across countries. The global financial crisis increases GHG emissions that severely affected global climate change through a channel of improper utilization of food-energy-water resources in a panel of SSA countries. The study concludes with some policy recommendations for the better environmental management in SSA countries that would be helpful to give a clear direction for their efforts towards sustainability agenda, i.e.,

- Short-term policy: The sustainable food production is the main problem in front of the environmental sustainability framework in SSA countries, as the food's carbon footprint is largely lucid with the non-organic farming methods that have a higher impact on the environment. The policy recommendation is to avoid non-organic food that is radiated by different artificial methods of animal and crop farming. In addition, it is advisable to reduce food waste (as much possible) that largely occurred during processing in the industries. The organic food farming methods of cultivation of crops and breeding the animals and reduction of the food waste during processing and consumption of goods are the desirable policy instruments that would have a comparable lower impact on the environment with conventional methods of food production and farming styles. The good deed is as follows:

1. To avoid chemical agriculture.
2. To eat more vegetables and less of meat.
3. To avoid food wastes.
4. To eat domestically produced goods and organic foods.
5. Sustainable water and energy efficient resources should be used.
6. To support green supply chain management practices.
7. To support clean energy technologies, etc.

- Medium-term policy: Energy demand played a vital source to expedite the process of economic transformation and industrialization process; however, it is furnished with high energy prices, increased combustion of burning fossil fuel, and climate change. The SSA countries required a blend of renewable energy sources such as wind energy, solar energy, and wave power energy that are helpful to mitigate the concern of global climate change, while energy efficiency leads to decreased energy prices that sustained industrial value added by low-carbon technologies. The good deed is as follows:

1. To improve industrial practices by cleaner production techniques.
 2. To support green electricity.
 3. Switching from high- to low-carbon fuels that resulted less emissions.
 4. To promote biomass energy, as it is less sensitized to the carbon emissions.
 5. To regulate carbon emissions by “command-and-control” approach for mitigation GHG emissions.
 6. Climate-friendly policies would be helpful to offset the environmental degradation.
 7. Lower energy prices share the burden of environment to promote green energy.
 8. Energy efficiency helpful to reduce carbon emissions and conserve energy resources in a region.
- Long-term policy: The global financial crisis severely affected global food security that further damages the natural environment of SSA countries through a channel of climate change and air-water pollution that slow down the pace of economic activities in a region. The long-term policies are required to combat the financial crisis by sound economic and sustainable framework that mitigate climate change and support food policies. The good deed is as follows:
1. Using green technologies and low-carbon investment.
 2. Financial integration linked with sustainable development goals that are helpful during the “transformative phase” of financial management and natural resource conservation through fiscal stimulus across countries.
 3. Financial turmoil should be balance with low energy prices and improved water sources that support the global food security.

United Nations Kyoto Protocol for mitigating GHG emissions and conserving natural resources is the viable instrument for devising sustainable policies across the globe. Although the Kyoto Protocol is not linked with the financial integration of the competitive markets, it is linked through resource market to reduce the strain of environmental pressure by least flexible and cost-effective mechanisms such as clean development, emission trading, and joint implementation programs, which helpful to reduce the supply of emissions in the atmosphere. SSA countries should have to consider these resource instruments for mitigating climate change and balancing the natural flora that further support the financial sectors to export carbon-free goods and import sustainable instruments to produce healthy goods. It ultimately reduces the risk of food insecurity-, water pollution-, and energy-associated emissions in a region. The good sustainability reforms are associated with optimization of economic resources, while the bad sustainability reforms may be linked with political obsessions

that are derived with political instability, and the ugly reforms may occur due to stochastic factors including financial turbulence, trade imbalances, new toxic industrialized pollutants, etc. that are transmitted through developed countries and hit the least developing countries. The “win-win” approach of the developed countries leads to damage in the sustainability agenda of the least developed countries (LDCs) in most of the cases, while the joint-hand and collaborative efforts are needed to support sustainable policies of the LDCs for our tomorrows’ healthy and wealthy future.

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