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The Nexus between Economic Growth, Energy Consumption, Agricultural Output, and CO_2 in Africa: Evidence from Frequency Domain Estimates

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Abstract: This study examined the nexus between economic growth, energy consumption, and the environment with the moderating role of agricultural value addition and forest in Africa based on data sourced from 1980 to 2019. We employed both the time domain and frequency domain panel Granger causality estimation techniques to compare results across the different horizons. Extant literature suggests the inability of time domain estimation techniques to account for causality at different frequencies. The study also accounts for the nexus among our variables both at the single-country and multi-country levels. The results at the single-country level are at best mixed. The results of the panel Granger causality at the frequencies domain suggest that a bi-directional relationship exists between energy consumption and economic growth, and that energy consumption Granger causes carbon emissions in Africa. The results align with the feedback hypothesis on the one hand but contradict the conservation hypothesis on the other hand. The study has some policy implications.

Keywords: energy consumption; carbon emissions; agricultural output; economic growth; Africa

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1. Introduction

In attaining sustainable development, energy, economics, and the environment play significant roles [1–5]. For instance, energy is crucial to the human economic and social development of any nation. It is estimated that global energy consumption will increase by about 56% from its current state in 2010 by the year 2040, as global aggregate demand is expected to double, given the expected increase in population [6–12]. However, the projected increase in total energy consumption is expected to be accompanied by an increase in carbon dioxide (CO_2) emissions, which is a core factor in total greenhouse emission (GHG). The energy sector is responsible for about 61.4% of the total global GHG [13–16]. Ref. [7] noted that the contributions of agriculture sector to the GHG are estimated to be between 14–30%, though evidence abounds to show that the agricultural sector possesses the ability to reduce GHG by 80–88%. It is opined that forests possess the capacity to accumulate atmospheric carbon after converting CO_2 into carbon and oxygen, and that about 430 tons of carbon per hectare is absorbed in the wet forest, hence, halting the effects of carbon emissions [17–22].

In the same vein, environmental degradation plays a crucial role in the continuous occurrence of natural disasters with unprecedented impacts on the economy. Disasters related to oil spillage, water pollution, solid waste management, deforestation, soil erosion, salinity and water, logging, and desertification, among others, affects the socio-economic wellbeing of a nation and increases climate change. Environmental degradation worsens with the exploitation of fossil fuels [23–27]. In order to mitigate this without losing a significant part of the energy output, economies over the years have opted for renewable energy sources [28–30]. Renewable energy offers clean and safer energy and can be derived from solar, tidal, wind, geothermal, hydro and biofuel power. Besides its alternative energy potential, it is useful in supporting employment, output, income, and job creation. Extant literature shows that the increase in economic growth and agricultural outputs have a positive impact on renewable energy [31,32]. Furthermore, given a global temperature increase of between 2–2.4 °C, renewable energy can help reduce carbon emissions by 50% by the year 2050. Besides its positive impact on the environment, renewable energy can reduce overdependency on foreign energy, given the fact that it is sourced domestically [33,34].

The United Nations Sustainable Development Goals (SDGs) emphasized the need to eradicate hunger (SDG 2), achieve clean energy utilization (SDG 7), achieve sustainable economic growth (SDG 8), adopt sustainable production and consumption (SDG 12), mitigate climate change through a sustainable clean environment (SDG 13), and adopt a global partnership model to achieve these goals (SDG 17). The nexus between these laudable metrics for sustainable development is key to exploring the linear and circular economic growth in any economy, be it regional or single country (Sarkodie 2020). Sub-Saharan Africa needs more energy than most continents of the world, given its ever-increasing, teaming population and quest for sustainable growth [35]. Even though the continent is endowed with an abundance of non-renewable energy like petroleum and other fossil fuels, the negative impacts of fossil fuel on the environment, such as the increase in GHG and other pollutants, calls for concerns. Although the contribution of Africa to global warming at present may be negligible compared with other continents, it is obvious that the continent will be disproportionately affected by its impact if nothing is done. To mitigate the impact of GHG on the continent, the African Development Bank (AfDB) adopted a ten-year green growth strategy (2013–2022) with an emphasis on developing the renewable energy potential capable of promoting resource efficiency and sustainable development.

Several theoretical models exist that explain the links between energy, the economy and the environment. For instance, Environmental Kuznets Curve (EKC) models suggest that at the initial stage of development, a direct positive relationship exists between economic growth proxy by real gross domestic product (RGDP) and environmental pollution, but the relationship becomes indirect after a threshold level of income is achieved. The pollution haven model suggests that in developing economies characterized by weak pollution protection laws, trade and investment liberalization laws often induce environmental degradation as pollution-intensive firms will find it easier to produce in such economies than in developed economies with stringent environmental protection policies. The causality model employs unit roots, cointegration and causality measures to examine the nexus between energy consumption and economic growth. This model offers four possibilities, firstly (i) the growth-led hypothesis, which suggests the existence of unidirectional causality from economic growth to energy consumption. This suggests that conservation policies will have no impact on economic growth. This is common in energy-sufficient economies. Secondly, (ii) the energy-led hypothesis, which suggests that energy consumption stimulates growth, therefore, energy conservation policies will impact negatively on economic growth, thus, energy expansion policies are required. This is common in economies that are energy-dependent like most developing economies. Third is (iii) the feedback model, which suggests the existence of a bi-directional causality between energy consumption and economic growth. The model suggest that both constructs are jointly determined and affected simultaneously. Lastly is (iv) the neutrality model, stating that no causality exists between energy consumption and economic growth. It also suggests that environmentally-friendly policies can be achieved without obstructing economic growth.

Extant literature has attempted to examine the link between the environment, energy, and the economy with mixed results. For instance, Refs. [36–38] were of the view that causality runs from economic growth to energy consumption while Refs. [39–43] opined that causality is from energy consumption to economic growth. Furthermore, Refs. [41,42,44,45] noted that causality runs from economic growth to CO_2 emissions. The bulk of these studies focused on developed economies with little attention on African economies. Africa is faced with plurality of issues, key among them being the need to stimulate growth, ensure a sustainable environment and reduce energy poverty. The World Bank global monitoring report (2008) highlights the need for the continent to be on a sustainable development path that embraces clean energy, a sustainable environment, and accelerated growth, noting the continuous increase in CO_2 emission and fall in per capita water resources. Given the low state of renewable energy development and the potential environmental hazards emanating from existing conventional fossil fuel amidst the desire to stimulate growth, it is imperative to examine the nature of the relationship between energy consumption (renewable and non-renewable), economic growth, and CO_2 emissions with the moderating impact of agriculture and agro-allied resources in Africa. Our study presents a short, intermediate, and long run analysis for 34 African economies. Unlike existing studies that employed time domain estimates like the traditional Granger causality estimates, VAR and other time domain estimates [16,30,46–49], the current study employed both the single and multi-country frequency domain Granger casualty estimates based on datasets sourced from 1980–2019. Even though frequency domain techniques offer better estimation models, because they allow for examination of the direction and level (strength) of the nexus at heterogeneous scales for frequency [2,3,9,50–52], they are yet to be explored especially in studies in Africa.

Our choice of Africa was induced by the fact that Africa is endowed with an abundance of potential energy resources (both renewable and non-renewable). It is estimated that in Africa, the potential energy generation capacity is up to 1.2 terawatts, excluding solar, and more than 10 terawatts including solar, with a high potential of achieving more than a 25% increase in clean energy by 2040 [8,53,54]. The continent is the world's youngest and fastest urbanizing continent, but it is the least energy-supplied, with annual consumption being 518 kwh in sub-Saharan Africa, equivalent to what a single member country of the OECD will use. Economic indices show that recently, African economies largely outperformed the global average (IMF, WB 2019) with the continent's overall GDP increasing 3.8% against the global average of 3.4%. Data availability large influences the choice of sample economies.

Against this background, this research attempts to know whether various energy policies in the continent offer the ability to end Africa's energy poverty, stimulate growth, and promote environmental sustainability. We intend to answer the following questions: (i) What drives the African economic, energy and environmental nexus—an environmental Kuznets curve, causality, or the pollution haven model? (ii) What is the nature of the causality between energy consumption (renewable and non-renewable) and economic growth, carbon emissions, and agricultural output in Africa? (iii) If causality is established, to what extent will the increase in energy consumption support economic growth, agricultural output, and reduce carbon emissions in Africa economies? Answering our questions will provide insights into at least five SDGs: SDG 2—zero hunger; SDG 7—achieve clean energy utilization; SDG 8—achieve sustainable economic growth; SDG 12—adopt sustainable production and consumption; and SDG 13—mitigate climate change through a sustainable clean environment.

This study will make essentially four contributions to the literature. First, in terms of methodology, we will provide a frequency-based panel Granger causality analysis that offers short, intermediate and long run casual estimates of the nexus between economic growth energy and the environment with a focus on African economies. Our method provides individual estimates for each of the economies studied, unlike the conventional methods that offer lump-sum causality estimates. Second, the study will calibrate the moderating impact of agriculture and agro-allied resources to the discourse on energy, economics and the environment in Africa. Africa is largely agrarian and to the best of the author's knowledge, no literature of the African extraction has considered the moderating role of agriculture in absorbing carbon emissions in the economic-energy-environmental nexus. Thirdly, in term of coverage and scope, our study will cover more African economies than most of the existing studies and use more recent data when compared with others. Fourthly, our study will also calibrate both the energy conservation and expansion policies into the energy, environment, and economic growth discourse. Our finding offers some policy implications for policy makers at both the national and regional levels, as well as for international organizations and researchers on the link between energy, economic and the environment. The rest of the study is as follows: Section 2 presents the literature review; Section 3 offers the data and methodology; Section 4 deals with the presentation of results, while Section 5 concludes the study and offers some policy implications.

2. Literature Review

A critical assessment of extent literature clearly suggests that frequency domain estimates are yet to be sufficiently employed in examining the nature of the relationship between energy, economics and the environment with the moderating role of agriculture, especially based on evidence from Africa, despite its attractiveness and potential strength in providing measures in shaping the African policy space. Africa economies are in dire need of energy, with the need to advance economic growth at the front of the policy framework amidst the global quest to reduce CO_2. It is pertinent, especially when faced with few publications on the subject matter, to examine the moderating role of agriculture in mitigating CO_2 emissions, stimulating economic growth and ending energy poverty. Such effort would not only offer a valuable platform to examine the nature of cointegration and the direction of causation, among the variables (energy, economics, environment and agriculture), it will equally initiate and stimulate further research and model specifications.

Table 1 presents the result of extent literature on the nexus between energy, economic growth, agriculture, and carbon emissions for a number of economies across the globe. The results as presented can be categorized into four main streams—methodological, results (findings), hypothesis or policy trust and variables employed. In methodological strands, a number of studies employed cointegration and/or Granger causality methods to investigate the link between energy, economic growth, and the environment [6,16,19,20,22,23,28,49,55–63] with mixed results. For instance, while [19] noted that a bi-directional relationship exists between non-renewable energy and climate change and that climate change Granger causes renewable energy for 16 African countries, ref. [16] observed that causation is from RGDP to renewable energy in the long run for China, with a negative impact on renewable energy in the short run. Similarly, ref. [13] documented the existence of a bi-directional relationship between renewable energy and non-renewable energy for India and South Africa, suggesting validity of the feedback hypothesis. The study further noted that causality runs from non-renewable energy to economic growth for Brazil and USA, an indication that the growth hypothesis is valid in these economies but noted no causal relationship exists between non-renewable energy and economic growth for Russia, India and South Africa, implying the validity of the neutrality hypothesis. For South Africa, ref. [6] noted that growth hypothesis is valid as the direction of causation is from energy use to RGDP. Ref. [19] offers multifaceted results, for instance, the authors documented that bi-directional relationships exist between fossil fuel and RGDP, between fossil fuel and CO_2, and between CO_2 and RGDP for the oil-exporting economies. These results support the feedback hypothesis from oil prices to each of RGDP and CO_2 for the oil-consuming economies, suggesting the validity of the growth hypothesis. Ref. [57] results are at variance with those of [22–24,28,29,58] who noted causality is from RGDP to CO_2, and that no causality exist between energy consumption and economic growth, thereby supporting the validity of the neutrality hypothesis in the studied economies.

Table 1. Summary of Literature review.

S/n	Authors	Period of Study	Variable	Methods	Countries	Results →←
1	[55]	1980–2014	Renewable energy, non-renewable, economic growth, climate change	Group-ARDL-PMG, ARDL-MG, Granger causality	16 African countries	Non-Renewable ↔ Climate change Climate change → Renewable energy Feedback hypothesis holds.
2	[64]	1980–2019	Economic growth; CO_2 emission, inflation, population	Panel econometric methods of statistical analysis, Granger causality	6 west African countries	Positive relationship exists between the variables
3	[13]	1990–2013	GHG, fossil energy and economic growth	A recursive system of three equations	41 sub-Saharan African economies	Fossil energy → GHG, Economic growth does not Granger cause CO_2 emissions
4.	[65]	1996–2014	RGDP, non-renewable energy, CO_2, policy uncertainly	One-step-system GMM	32 sub-Sahara African countries	RGDP → CO_2 Non − renewable energy → CO_2 Policy uncertainty → CO_2 Renewable energy reduce → CO_2
5	[15]	2000–2015	RGDP, solid cooking fuels	Panel unit root, panel cointegration panel Granger causality	46 sub-Sahara African countries	A negative causal relationship exists from solid cooking fuel to RGDP
6.	[16]	1997–2017	Renewable energy, economic growth and financial development	Granger causality ARDL-PMG	China, Western China Eastern China	RGDP → RE (long run), financial development negatively impacts RE in the long run. RGDP negatively impacts RE in the short run; financial development positively impacts RE in of S/R
7	[17]	1990–2015	RGDP, NRE, RE, CO_2	System GMM	31 transitional economies	CO_2 has unconditional negative effects on human devt. RGDP; RGDP → RE, RE → CO_2N − RE → CO_2
8	[66]	1990–2018	Natural resources, energy consumption, gross capital formation, financial openness, RGDP	Structural equation modeling techniques	Pakistan	Negative relationship exists between natural resources and RGDP; RE and NRE → RGDP Fin. openness → RGDP. Gross capital formation ↔ RGDP
9	[67]	1971–2014	Fossil oil RGDP	N-ARDL, asymmetric panel causality test	19 African countries	Mixed results
10	[14]	1971–2017	Electricity consumption, RGDP, agricultural output, govt. effectiveness trade	System GMM, advanced dynamic panel threshold regression model	17 African economies	Electricity → RGDP Growth hypothesis
11	[18]	1980–2015	Petroleum, natural gas, CO_2, RGDP	N-ARDL	Oil producing Africa economies	RE reduces CO_2 (Nigeria) RE → RGDP (Gabon) RE does not Granger cause CO_2 (Angola and Egypt). Growth and Neutrality hypotheses hold
12	[68]	1995–2014	Renewable energy labor, capital, RGDP	P-DOLS, F MOLS	15–Western Africa countries	RE slows down growth

Table 1. *Cont.*

S/n	Authors	Period of Study	Variable	Methods	Countries	Results →←
13	[56]	1996–2015	RE, NRE, R&D, RGDP	Unit root tests, panel Granger causality	BRICS	RE ↔ NRE (India and SA) Feedback hypothesis hold RE does not granger cause NRE (Brazil) NRE → GDP (Brazil and SA) Growth hypothesis NRE–R&D (Russia, India, SA) Neutrality hypothesis hold
14	[6]	1960–2016	Capital, labor, CO_2, RGDP, energy consumption	ARDL, Granger causality test	South Africa	Energy use → RGDP growth hypothesis holds
15	[19]	1990–2015	Oil price, CO_2, RGDP, fossil energy consumption	PMG panel ARDL, bootstrap panel cointegration	22 African countries	Fossil ↔ RGDP Fossil ↔ CO_2 CO_2 → RGDP for non-oil exporter co_2RGDP ↔ oil exporter Oil prices → RGDP, CO_2 and oil consumption for all
16	[25]	2001–2017	Energy consumption CO_2, RGDP	System GMM	68 developed, emerging and MENA countries	Energy consumption → RGDP Energy consumption → CO_2 CO_2 → RGDP in all countries except in MENA
17	[57]	1973–2014	Growth role of kg oil equivalent per capital energy usage, RGDP ecological foot print	ARDL Toda–Yamamoto	South Africa	Ecological footprint → RGDP Kg oil equivalent → eco. footprint Kg oil equivalent → RGDP
18	[69]	1990–2012	CO_2-equivalent, RGDP, energy usage, international trade	Environmental input-output model	Angola, Ethiopia, Kenya, Nigeria, south Africa	RE reduces CO_2-equivalent
19	[28]	1971–2010	Energy consumption CO_2, economic growth	ARDL, Granger causality	12 sub-Sahara Africa	Mixed results RGDP → CO_2 short run for Benin, DRC, Ghana, Nigeria, and Senegal RGDP ↔ CO_2, Long run for Congo, Gabon Energy consumption → CO_2 in of long run for Benin, DRC, Nigeria, Senegal, South Africa, and Togo
20	[58]	1973–2017	Energy consumption, oil prices, trade openness, urbanization and RGDP	ARDL, ECM	African OPEC Countries	No causality between energy consumption and RGDP. Energy consumption does not Granger cause RGDP
21	[29]	1990–2017	RDGP, energy consumption, renewable energy	Neural network analysis	25 African economies	RGDP → CO_2
22	[6]	1990–2014	Energy intensity RE, CO_2, RGDP	ARDL, Toda Yamamoto	Romania	RE → RDGP, Energy intensity ↔ RGDP
23	[20]	1975–2017	CO_2, RGDP, carbon income, trade openness, energy use	ARDL, Toda-Yamamoto	India	Energy use → GDP Energy use → CO_2

Table 1. *Cont.*

S/n	Authors	Period of Study	Variable	Methods	Countries	Results →←
24	[59]	1980–2018	RE, CO_2, financial devt., trade openness, FDI, urbanization	A panel quantile regression	Global panel of 192 countries	Fin. devt → RE, inverse relationship exists between RE and CO_2
25	[21]	1990–2017	CO_2, trade, RGDP, RE, environmental innovation	A battery of panel co-integration methodologies	G7 countries	Long run relationship exists among CO_2, trade, RGDP, RE and environmental innovation. Environmental degradation does not cause RGDP, RE reduces CO_2
26	[70]	1980–2014	CO_2, RGDP, RE, urbanization, NRE	FMOLS and GMM	28 sub-Sahara African Countries	NRE → CO_2 (S/R) NRE, RE → CO_2 (L/R) RGDP → CO_2
27	[22]	1978–2016	CO_2, RGDP, RE, urbanization and Agriculture	ARDL	Malaysia	RGDP, Urbanization → CO_2 RE and agriculture significantly CO_2
28	[23]	1990–2014	CO_2, RGDP, RE, nuclear energy real coal prices	Panel cointegration and Granger causality test	30 developed and emerging economies	LR relationship exists among the variables; NE does not lead to CO_2 reduction RE → CO_2 reduction RE → RGDP
29	[24]	2012–2014	Energy usage, CO_2, electricity consumption, fossil fuel, biomass	ANOVA and Tukey multiple comparison test	Sri Lanka	Elect → CO_2 Fossil → CO_2, RGDP does not → CO_2
30	[16]	1997–2017	RE, fin. devt and economic growth	ARDL-PMG Granger causality test	China	Economic growth → RE Negative relationship exists between fin. devt and RE
31	[30]	1995–2014	RE, CO_2, RGDP	GS2SLS	EU	EC ↔ RE feedback ECC ↔ CO_2 RE does not → CO_2
32	[46]	1990–2015	RE, NRE, RGDP	Local liner dummy variable estimation (LLDVE)	40 OECD and non-OECD countries	Both NRE and RE impact economic growth positively
33	[31]	1990–2017	RGDP, fin. inclusion, RE, NRE, CO_2, trade openness	Augmented mean group, Dumitrescu –Hurlin non-causality test	15 highest emitting countries	Bidirectional causality exists between fin. devt, economic growth, renewable energy utilization and ecological footprint; unidirectional causality runs from non-renewable energy and trade openness to ecological footprint, unidirectional relationship runs from economic growth to RE and trade openness. Feedback hypothesis holds
34	[32]	1990–2018	RE, RGDP, CO_2, NRE, Capital and labor	DOLS, FMOLS and Heterogeneous non-causality model	38 renewable energy consuming countries	LR relationship exist between RE and RGDP; RE, NRE, capital and labor impacts on RGDP
35	[71]	2005–2016	NRE intensity, urbanization, per capital income	Panel threshold regression	OECD countries	Positive and non-linear relationships exist between renewable energy and economic growth

Table 1. *Cont.*

S/n	Authors	Period of Study	Variable	Methods	Countries	Results →←
36	[72]	1990–2010	GDP, GDPPC, Total renewable energy, share of renewable energy to total energy consumption, gross fixed capital formation, number of employed people in of economy; R&D	Panel quantile regression	OECD economies	The impact of RE on economic growth is at best unused, i.e., positive for lower, and low-middle–quantities, and negative for middle, high middle and higher quantities
37	[73]	1991–2015	GDP and RE	Spatial Dublin model	26 European economies	Spatial dependences impact on the nexus between RE and GDP
38	[33]	1990–2014	CO_2, RE, EC	FMOLS and VECM	15 major RE consuming nations	EC ↔ RE for both S/R and LR supporting the feedback hypothesis; CO_2 does not cause RE in the LR, CO_2 ↔ RE in the SR, EC ↔ CO_2 both in the LR and SR
39	[60]	1990–2014	RE, pollution, EC, urbanization	Cointegration, Granger causality, impulse response function	Selected 106 countries	Both bidirectional and unidirectional relationship exists among the variables
40	[34]	1991–2014	RGDP, CO_2, technological innovation, trade and RE	Pedroni and Westerlund panel cointegration tests	Argentina, Brazil, Mexico, Colombia, Chile and Guatemala	Negative relationship exists between RE and CO_2 RGDP, technological innovation, and trade positively and significantly impact on RE production
41	[47]	1980–2017	Non-oil exports, tourism, RE and RGDP	ARDL, Johansen cointegration and Gregory –Hensen cointegration	Saudi Arabia	Non-oil export and tourism impact growth positively, long run cointegration exist between RE tourism, capital and RGDP
42	[61]	1960–2015	RE, RGDP, trade, urbanization, CO_2	ARDL, VECM Granger Causality tests	Australia and Canada	RGDP → CO_2 both in LR and SR for Australia; VECM results shows that RGDP, trade and RE → CO_2 in d LR and SR for Australia; for Canada, Trade → CO_2 for both LR and SR; RGDP, urbanization → CO_2 in of LR
43	[48]	1990–2014	RE, NRE, RGDP	Pedroni unit root tests, FMOLS, P-DOLS, Dumitrescue–Hurlin (2012)	5 South Asia countries	Positive impact of RE, NRE and fixed capital formation on growth RGDP → RE
44	[74]	1990–2014	Energy, efficiency, RE, RGDP	Fixed-effect panel quantity regression analysis	BRICS	Feedback hypothesis is valid RGDP ↔ EE RGDP ↔ RE EE → RE
45	[75]	1981–2016	Energy production, energy consumption, GDP	Hatemi –J cointegration, structural breaks, FMOLS, CCR VECM, Granger causality test	China	EP, EC → GDP, GDP → Gas consumption (supporting conservation hypothesis)
46	[49]	1971–2014	Ecological footprint, GDP, EC, GFCF	N-ARDL; asymmetric causality techniques	Pakistan	Environmental quality → EC neutrality hypothesis is valid among environmental quality, economic growth and capital

Table 1. *Cont.*

S/n	Authors	Period of Study	Variable	Methods	Countries	Results →←
47	[76]	2002–2011	CO_2, RE, NRE, RGDP	GMM and PMG	42	RE consumption leads to reduction in CO_2; RE has positive impact on RGDP; NRE has negative effect on RGDP in LR, substitute relationship exists between NRE and RE
48	[77]	1980–2015	NRE, GDP, human capital index, globalization, urbanization, added value of services	Threshold regression FEMOLS	27 developed OECD countries	Economic development does not reduce non-renewable energy consumption; Human capital development reduces NRE. LR relationship exist among globalization, urbanization, services and RE
49	[62]	1990–2015	Ecological footprint, per capital income, RE, life expectancy, population density	Cointegration tests, cross-sectional augmented autoregressive distributed lag	8 developing South and South-East Asian economies	The association between per capital income and ecological footprint is N-shaped, RE reduces ecological footprint, increase in population leads to increase in pollution emissions.
50	[54]	1992–2016	EC, financial development, urbanization, per capital GDP, gross domestic capital formation	A battery of static and dynamic econometric models	44 African economies	EC and fin devt, deteriorates the environment; urbanization impacts on the environment asymmetrically; per capital GDP has an asymmetric effect on the environment.
51	[63]	1995–2017	Total energy consumption RE, NRE, HCI, FD; eco-innovation, energy intensity, GDP, gross fixed capital formation R&D	Westerlund and Edgerton panel cointegration and augmented mean group	G7 countries	Negative relationship exists among HCI, eco-innovation, energy price, R&D and TEC, NREC. Positive relationship exists between financial development, and each of TEC and NREC. HCI, eco-innovation, energy price, R&D enhances REC. Financial development reduces REC
52	[8]	1990–2014	Energy efficiency RE, CO_2, NE	Panel quantity regression (PQR)	66 developing economies	EE reduces carbon emissions across all quantities. RE reduces CO_2 with substantial effect at 10th quartile. GDP increases CO_2
53	[78]	1980–2016	CO_2, RE, HCI, globalization, trade openness	ARDL	China	RE does not impact on CO_2, HCI reduces environmental degradation; globalization, trade openness, and income impact on pollution
54	[63]	1965Q1–2017Q4	EC, ecological footprint, NRE economic complexity	QARDL quantile Granger causality test	USA	Economic complexity and fossil fuel energy consumption significantly enhance ecological footprint; causality exist among economic complexity, energy consumption and ecological footprint
55	[36]	1990–2016	RE, RGDP	Bootstrap panel causality test	17 Emerging economies	Neutrality hypothesis holds for all the economies except Poland (no causality from either of the variables) RE → RGDP for Poland
56	[79]	1998–2018	RE, financial development, CO_2 Innovation RGDP	P-ARDL Dumitrescu–Hurlin Panel causality test	ASEAN + 3 group	Financial development → RE CO_2 and economic freedom has negative impact on RE positive relationship exist between innovation, RGDP and RE
57	[80]	1965Q1–2017Q4	RE, NRE, RGDP ecological footprint	QARDL Granger causality	Turkey	RE decreases ecological footprint in of LR; NRE and RGDP positively impact ecological footprint
58	[81]	1991–2012	RE, RGDP, institutions, CO_2	System-GMM FMOLS	85 developed and developing countries	RE positively impacts RGDP RE negatively impacts CO_2 institution positively impacts RGDP; institution negatively affect CO_2

Table 1. *Cont.*

S/n	Authors	Period of Study	Variable	Methods	Countries	Results →←
59	[82]	1990–2015	RE, NE, CO_2, RGDP, financial development	CIPS, FMOLS, bootstrap cointegration	74 countries	NRE has positive impact on CO_2. RE has negative impact on CO_2. Financial development has negative impact on CO_2
60	[83]	1980–2014	TE, RE, NRE, RGDP	NARDL	G7 countries	Asymmetric relationship exists between TE and RGDP
61	[22]	1978–2016	CO_2, RGDP, RE, urbanization, agriculture	ARDL	Malaysia	CO_2 is not directly influenced by modernization. Calibrating RE to agricultural sec tor will help in achieving sustainable agriculture and mitigate CO_2 emissions; CO_2 significantly decrease due to RGDP and urbanization

Note: ARDL, NARDL, GMM, FMOLS, DOLS, VECM, ARDL-PMG are autoregressive distributed lag, nonlinear autoregressive distributed lag, general moment method, vector error correction model, error correction model, fully modified ordinary least square, dynamic ordinary least square, autoregressive distributed lag model based on pooled mean group estimation, respectively.

The second strand of literature employs nonlinear models like quantile regression, system frequency domain estimate PMG, threshold regression, bootstrap estimates, NARDC, and recursive to examine the nature of relationship between energy, economic growth and CO_2 emissions with mixed results. For instance, [8,13,18,36,49,63,71,72,77,79,80,83] employed different versions of nonlinear models to examine the nexus between energy, economic growth, and CO_2 emissions with different results. Ref. [13] noted that fossil energy causes GHG, and that economic growth does not cause CO_2 emissions for 41 sub-Sahara African economies. Ref. [18] results from N-ARAL observed mixed findings; for example, the study noted that renewable energy reduces CO_2 emission for Nigeria, but no causality was documented between renewable energy and CO_2 for Angola and Egypt. The study further noted that renewable energy causes economic growth for Gabon, suggesting the validity growth hypothesis. Ref. [84] employed panel threshold for some selected OECD economies and reported the existence of positive and non-linear relationships between renewable energy and economic growth, an indication that the growth hypothesis holds. Ref. [49] employed the N-ARAL model and noted that environmental quality causes economic growth and that the neutrality hypothesis is valid, based on the results from environmental quality and capital stock. In a related development, [8] employed panel quantile regression to examine the nature of the relationship between energy, economic growth, and CO_2 for some selected 66 developing economies and noted that renewable energy reduces CO_2 with substantial effect at the 10th quantile, and that GDP increases CO_2. Ref. [63] results, based on quantity ARDL, suggest the validity of the feedback hypothesis among economic complexity, energy consumption and the ecological footprint. For emerging economies [36] employed a bootstrap panel causality test and noted that the neutrality hypothesis is valid for all the economies except Poland, whose results suggest that causality is from renewable energy to economic growth. The single country (Turkey) estimates from [80] analysis shows that renewable energy reduces the ecological footprint in the long run; surprisingly, the results documented that non-renewable energy and economic growth positively impact on the ecological footprint.

3. Materials and Methods

This study examined the nature of the relationship between CO_2 emissions, energy consumption, agriculture and economic growth for some selected [34] Africa economies. Though Africa is made up of 54 independent countries, the selection of countries is largely influenced by data availability. The collected data cover the period 1980–2019. This period and the countries covered allow for examination of convergence issues inherent in the literature with adequate geographical covering of the African continent. The variables employed are annual data of GDP per capita (constants are 2010 and USD); CO_2 emissions per capita (metric tons); EC representing energy consumption; agriculture proxy by agricultural value added (AVA) per capita contribution of agriculture to GDP; and forest area (forest area as percentage of total land mass). The variables are expressed in natural forms such that $InCO_2$, $In\gamma$, $InEC$, $InAVA$; $InFoR$ represent carbon emissions, economic growth, energy consumption, agricultural value chain and forest area, respectively. The data for the study are sourced as follows: CO_2 and RGDP from World Development Indicators (various issues), agriculture value addition and forest areas from Food and Agricultural Organization (various issues), and energy consumption data were from the OECD.

Methodology

As stated earlier, the study employed a frequency domain analysis to examine the relationship among energy, economic growth, and carbon emissions with the moderating impact of agriculture. Our preference of frequency domain estimates over time domain techniques is largely influenced by the weakness noticed in time domain estimates. For instance, time domain estimates cannot examine causality at different frequencies as they can only calculate a single test statistic over time [85–87]. Further, if the nexus among the variables is connected to more than one frequency, the ability of time dimension estimate to explore the information from the original data set becomes ineffective [88,89]. To overcome this, Geweke (1982) developed the Wald test procedure that employed linear constraints on coefficient parameters to test Granger causality in a certain frequency range. This procedure was extended by [90,91] as single country frequency domain causality test [85]. The [91] single country frequency domain causality test was further extended to a multi-country model by [92]. This extended frequency domain (panel Granger causality test) allows us to determine if the predictive power is concentrated at quick or slow fluctuating components. The current study aims at examine the nexus between the variables using both single-country and multi-country causality tests by following [85,93–95]. The tests are thus presented.

Single-Country Causality Test:

We begin our single country causality test by following [2] Gorus and Aydin 2019 specification of the [90] single test procedure stated as follows:

$$X_t = \sum_{j=1}^{p}\theta_{11.j}X_{t-j}+\sum_{j=1}^{p}\theta_{12.j}Y_{t-j}+\varepsilon_{1t} \tag{1}$$

Here, θ_{11} and θ_{12}, are the coefficients of the polynomials, ε_{1t} represents the error term, p represent the lag length, the constraint is on the first VAR, we express the constraints on the null hypothesis of "no Granger causality from Y_t to X_t at the frequency w" as stated below:

$$\sum_{j=1}^{p}\theta_{12.j}cos(jw) = 0,$$

$$\sum_{j=1}^{p}\theta_{12.j}sin(jw) = 0. \tag{2}$$

To test these constraints, we employed the incremental R^2 measurement test, calculated as follows:

$$R_I^2 = R^2 - R_*^2 \tag{3}$$

Here, R^2 and R_*^2 are derived from the unrestricted and restricted models, respectively. (**) The null hypothesis is rejected if this condition is observed:

$$R_I^2 > F_{(2T-2p,\ 1-\propto)}\ \frac{2}{T-2p}\left(1-R^2\right) \tag{4}$$

Multi-Country Causality Test:

Following [92], the study employed the seemingly unrelated regression (SVR) model stated as follows:

$$X_{i,t} = \sum_{j=1}^{p}\beta_{i,j}X_{i,t-j} + \sum_{j=1}^{p}\gamma_{i,j}Y_{i,t-j} + \varepsilon_{i,t},\ i=1,\ 2,\ 3,\ \ldots,\ N. \tag{5}$$

Here, $X_{i,t}$ and $Y_{i,t}$ are the variables of country i at time t, p is the lag length, N represent the number of countries and $\varepsilon_{i,t}$ represents the error term at time t of country i. The null hypothesis constraints are expressed as follows:

$$\sum_{j=1}^{p}\gamma_{i.j}cos(jw) = 0,\ i = 1,\ 2,\ 3,\ \ldots,\ N$$

$$\sum_{j=1}^{p}\gamma_{i,j}sin(jw) = 0,\ 1,\ 2,\ 3,\ \ldots,\ N. \tag{6}$$

We tested these constraints using the incremented R^2 measured test, expressed as follows:

$$R_I^2 = R^2 - R_*^2 \tag{7}$$

Here, R^2 represent the unrestricted and R_*^2 represents the restricted McElroy R^2 value expressed as follows:

$$R_I^2 > F_{(2N,\ N(T-2P),\ 1-\propto)} \frac{2N}{N(T-2p)} \left(1 - R^2\right) \quad (8)$$

We rejected the null hypothesis of no Granger causality from Y_t to X_t at the frequency 'w' in the studied countries if Equation (8) was observed.

4. Results

The descriptive statistics and normality results of the variables employed in this study are presented in Table 2. The results suggested that the value of the Jarque-Bera statistics was greater than 5% for the variables, suggesting validity of normality in each of the variables studied.

Table 2. Descriptive statistics of the variables.

Variables	Descriptive Analysis				Normality Analysis (Natural Log-Form)			
	Mean	**Max.**	**Min.**	**SD**	**Skewness**	**Kurtosis**	**Jarque-Bera**	**Probability**
$In\gamma$	175.98	298.77	142.67	39.09	−0.78	2.44	4.97	0.07
$InEC$	63.18	28.07	32.62	32.12	−0.48	2.14	4.22	0.06
$InAVA$	158.78	197.09	102.11	28.09	−0.55	3.09	498	0.08
$InCO_2$	1.97	2.41	1.66	0.31	0.17	1.55	3.21	0.22
$InFOR$	2.99	4.01	1.98	0.55	0.05	1.61	2.76	0.22

Source: Authors' computations 2022.

The results of both the cross-section dependency (CD) tests and the panel unit root tests are presented in Table 3. We began our analysis by investigating the cross-section dependency (CD) of the series, followed by conducting a check on the stationary properties of the series using the panel unit root test. The result in Table 3 suggest that cross-sectional dependency exists among the variables. This implies that shocks in any of the economies study can affect any of the rest. Having established cross-sectional dependency, we employed the cross-sectional augmented Dickey-Fuller test developed by [96], which is effective in detecting stationary properties of panel data as used in the current study [85,94,95]. The results suggests that $In\gamma$ and $InAVA$ are stationary at the first different I(1), and that $InEC$, $InCO_2$, and $InFOR$ are stationary at their level value I(0).

Table 3. Cross-section dependence and panel unit root tests for the series.

Variables	CD_{BP}	CD_{LM}	CD	CIPS Statistics
$In\gamma$	457.899 ***	76.558 ***	3.234 ***	−0.988
$InEC$	417.219 ***	51.521 ***	3.004 ***	−0.918
$InAVA$	398.881 ***	47.908 ***	9.176 ***	−2.955 **
$InCO_2$	366.098 ***	56.897 ***	8.077 ***	−2.344 **
$InFOR$	564.092 ***	41.179 ***	12.098 ***	−3.756 **
$\Delta In\gamma$	-	-	-	−3.665 ***

Note: *** and ** suggest the rejection of the null hypothesis at 1% and 5% significance level, respectively. CIPS Statistics provides the simple average of the individual CADF statistics ($\overline{CADF_i}$).

5. Discussion

Frequency Domain Results

As earlier stated, the study intends to examine the nature of relationship among energy, economic growth, carbon emissions, forests, and agricultural added value at three (3) clear frequencies: short, intermediate and long run denoted as 2.5, 1.5 and 0.5, respectively. Results in the long run (0.5) implies that a permanent causality exists while the results in the short run (2.5) suggest temporary causality exists. In Tables 4–10, we present the results of the frequency domain causality based on single-country estimates. Table 4 presents the results of the link between economic growth and CO_2 emission for each of the 34 African economies. The results as presented suggest that a unidirectional (at the three spectra) causality runs from economic growth to CO_2 emission for Algeria, Angola, Benin, Burkina Faso, Ghana, Kenya, Morocco, Nigeria, Senegal, South Africa, and Zambia. The findings are in line with [13,29,61], but contradict [17,18,67] The results further reveals that a one-way causality both at the intermediate and long run is noted to exist from emission to economic growth for Congo, Madagascar, Mali, Rwanda and Zimbabwe. The results from the rest of the economies studied suggest that no link can be established between CO_2 and economic growth. This finding supports the validity of the neutralization hypothesis in these economies; thus, emission curbing policies can be applied in these economies. The results from Algeria, Angola, Benin, Burkina Faso, Ghana, Kenya, Morocco, Nigeria, Senegal, South Africa, and Zambia suggest that environmental protection laws could be harmful to the economy.

In Table 5, we present the results of the link between energy consumption and economic growth for the selected African economies. The results suggest that a bi-directional relationship exist between the two for the economies of Algeria, Ghana, Kenya, Morocco, and Nigeria (at the three periods), South Africa (at intermediate and long run), Egypt (at the short run and intermediate), and at least one for each of Cameroon, Guinea, and Madagascar. These results support the validity of the feedback hypothesis in these economies. The results further reveal that an un-directional causality runs from economic growth to energy consumption for the economies of Mozambique, Namibia, Tanzania and Uganda in the short run, this suggests that the conservation hypothesis is rational in these economies. The growth hypothesis is validated based on the existence of causality from economic growth to energy consumption for the economies of Algeria, Ghana, Kenya, Morocco and Nigeria. The results are in line with the findings of [30,33,74].

Table 6 presents the results of the nexus between energy consumption and CO_2 emissions in the studied economies. The results reveal that energy consumption Granger causes carbon emissions in Nigeria, Algeria, Egypt, Tunisia and Ghana, suggesting that the pollution haven hypothesis is valid for these economies at short, intermediate and long runs. The results support the findings of [65] but disagree with [55].

The results of the causality between economic growth and agricultural value addition, as presented in Table 7, suggest that bi-directional causality is noted for almost all the studied economies at the short, intermediate, and long runs. The result is not surprising because agriculture constitutes the bulk of African GDP.

Table 8 shows that for most the studied economies, a unidirectional relationship runs from forestry to economic growth; this suggests that wood sourced from the forest support economic growth in the studied economies.

In Table 9, we present the results of the relationship between energy consumption and agricultural value addition across the three spectra of our analysis. The results reveal that there is a unidirectional causality from energy consumption to agricultural value addition in Egypt, Ghana, Tunisia and Uganda, whereas a bi-directional causality is documented for the economies of Nigeria, South Africa, Angola. This suggests that the feedback hypothesis is validated based on the relationship between energy consumption and agriculture in these economies. The results of the relationship between forestry and energy consumption are almost the same with those of agriculture and energy consumption, except that a one-way causality is noted to exist between forestry and energy consumption, suggesting the validity of the conservative hypothesis in these economies.

Table 10 we present the results of causality between CO_2 emission and agricultural value addition for the selected Africa economies. Our results reveal that no causality exists between these variables for the economies studies.

Table 4. Granger causality tests in the frequency domain estimates ($In\gamma,\ InCO_2$).

Panel A								
Countries	**H$_0$: $In\gamma \nrightarrow InCO_2$**				**H$_0$: $InCO_2 \nrightarrow In\gamma$**			
	w = 0.5	**w = 1.5**	**w = 2.5**	**c.v. = 10%**	**w = 0.5**	**w = 1.5**	**w = 2.5**	**c.v. = 10%**
Algeria	0.013 ***	0.055 ***	0.128 ***	0.111	0.023	0.027	0.034	0.111
Angola	0.017 ***	0.005 ***	0.005 ***	0.009	0.034	0.036	0.044	0.113
Burkina Faso	0.096 ***	0006 ***	0.001 ***	0.009	0.023	0.027	0.054	0.112
Benin	0.073 ***	0.054 ***	0.022 ***	0.072	0.026	0.028	0.034	0.114
Cameron	0.091	0.071	0.004	0.014	0.019	0.016	0.045	0.116
Congo (Brazzaville)	0.009	0.002	0.005	0.012	0.029	0.019	0.034	0.112
Congo (DRC)	0.047 ***	0.008 ***	0.006	0.009	0.03 *	0.021 **	0.045	0.111
Egypt	0.004 ***	0.044 ***	0.007 ***	0.008	0.023	0.028	0.054	0.112
Ethiopia	0.021	0.046	0.017	0.065	0.033	0.038	0.048	0.118
Gabon	0.009	0.032	0.014	0.008	0.035	0.037	0.039	0.112
Ghana	0.019 ***	0.044 ***	0.011 ***	0.011	0.045	0.054	0.037	0.114
Guinea	0.009	0.008	0.012	0.116	0.037	0.031	0.038	0.132
Kenya	0.022 ***	0.045 ***	0.011 ***	0.113	0.039	0.032	0.045	0.161
Lesotho	0.031	0.032	0.012	0.114	0.029	0.024	0.055	0.115
Madagascar	0.011 ***	0.017 ***	0.014	0.111	0.018 **	0.021 **	0.034	0.113
Malawi	0.032	0.019	0.001	0.102	0.024	0.027	0.049	0.112
Mali	0.022 ***	0.039 ***	0.009	0.019	0.032	0.036	0.054	0.122
Mauritius	0.005	0.033	0.004	0.112	0.036	0.037	0.032	0.141
Morocco	0.007 ***	0.032 ***	0.007 ***	0.133	0.029	0.031	0.035	0.112
Mozambique	0.046	0.037	0.006	0.121	0.017	0.021	0.041	0.116
Namibia	0.033	0.081	0.009	0.114	0.029	0.037	0.039	0.114
Nigeria	0.044 ***	0.033 ***	0.014 ***	0.111	0.025	0.028	0.057	0.123
Rwanda	0.006 ***	0.023 ***	0.012	0.112	0.044 **	0.034 **	0.045	0.114
Sao Tome and Principe	0.045	0.012	0.009	0.115	0.031	0.028	0.055	0.152
Senegal	0.044 ***	0.008 ***	0.006 ***	0.117	0.022	0.026	0.055	0.143
Sierra Leone	0.032	0.091	0.008	0.111	0.019	0.021	0.053	0.122
South Africa	0.031	0.023	0.005	0.112	0.022 *	0.026 *	0.058 *	0.144
Tanzania	0.029	0.033	0.006	0.111	0.027	0.029	0.059	0.115
Togo	0.031	0.034	0.009	0.122	0.032	0.035	0.077	0.122
Tunisia	0.033	0.023	0.008	0.111	0.028	0.031	0.056	0.127
Uganda	0.045	0.031	0.006	0.121	0.029	0.031	0.055	0.157
Zambia	0.033	0.022	0.009	0.111	0.019	0.022	0.054	0.138
Zimbabwe	0.046	0.036	0.045	0.123	0.021	0.023*	0.067*	0.136

***, **, * represent 1%, 5%, 10% significant levels, respectively.

Table 5. Granger causality tests in the frequency domain estimates $In\gamma,\ \ InEC$.

Countries	H$_0$: $In\gamma \nrightarrow InEC$				H$_0$: $InEC \nrightarrow In\gamma$			
	w = 0.5	**w = 1.5**	**w = 2.5**	**c.v. = 10%**	**w = 0.5**	**w = 1.5**	**w = 2.5**	**c.v. = 10%**
Algeria	0.023 ***	0.031 ***	0.022 ***	0.012	0.031 ***	0.029 ***	0.027 ***	0.111
Angola	0.001	0.004	0.003	0.002	0.041 ***	0.037 ***	0.034 ***	0.112
Burkina Faso	0.007	0.012	0.011	0.005	0.029	0.044	0.027	0.099
Benin	0.012	0.014	0.019	0.006	0.031	0.039	0.027	0.122
Cameron	0.018	0.019 *	0.012	0.009	0.014	0.037 *	0.034	0.117
Congo (Brazzaville)	0.021	0.016	0.014	0.021	0.016	0.039	0.029	0.112
Congo (DRC)	0.064	0.044	0.032	0.017	0.018	0.068	0.029	0.110
Egypt	0.017	0.022 ***	0.026 ***	0.005	0.031	0.039 ***	0.033 ***	0.117
Ethiopia	0.024	0.022	0.033	0.006	0.042	0.054	0.039 ***	0.102
Gabon	0.021 ***	0.019 ***	0.017 ***	0.011	0.033	0.056	0.027	0.115
Ghana	0.031 ***	0.021 ***	0.019 ***	0.013	0.067 ***	0.011 ***	0.034 ***	0.111
Guinea	0.026	0.024 *	0.021	0.004	0.028	0.032 *	0.045	0.115
Kenya	0.021 ***	0.019 ***	0.017 ***	0.021	0.028 ***	0.034 ***	0.054 ***	0.119
Lesotho	0.016	0.019	0.022	0.024	0.021	0.044	0.048	0.167
Madagascar	0.017	0.021 *	0.025	0.031	0.027	0.045 *	0.039 ***	0.109
Malawi	0.014	0.017	0.022	0.024	0.029	0.056	0.037	0.114
Mali	0.022	0.025	0.029	0.001	0.41	0.059	0.038	0.112
Mauritius	0.019	0.015	0.011	0.005	0.039	0.041	0.045	0.109
Morocco	0.021 ***	0.022 ***	0.023 ***	0.017	0.033 ***	0.039 ***	0.055 ***	0.112
Mozambique	0.022	0.021	0.029	0.013	0.028	0.034 **	0.034	0.119
Namibia	0.031	0.023	0.034	0.014	0.032	0.041 **	0.049	0.166
Nigeria	0.027 ***	0.028 ***	0.029 ***	0.011	0.031 ***	0.044 ***	0.054 ***	0.112
Rwanda	0.003	0.031	0.022	0.009	0.027	0.033	0.032	0.114
Sao Tome and Principe	0.009	0.010	0.013	0.002	0.025	0.029	0.035	0.141
Senegal	0.023 ***	0.025 ***	0.027 ***	0.003	0.029	0.049	0.041	0.117
Sierra Leone	0.031	0.041	0.034	0.008	0.023	0.044	0.039	0.118
South Africa	0.052 ***	0.024 ***	0.027	0.003	0.028	0.046 ***	0.057 ***	0.114
Tanzania	0.023	0.022	0.027	0.011	0.031	0.041 **	0.045	0.119
Togo	0.054	0.042	0.034	0.014	0.038	0.038	0.055	0.109
Tunisia	0.037 ***	0.031 ***	0.029 ***	0.011	0.037	0.039	0.045	0.115
Uganda	0.044	0.032	0.029	0.023	0.033 ***	0.031 ***	0.054 ***	0.167
Zambia	0.022	0.031	0.033	0.015	0.028	0.033	0.048	0.117
Zimbabwe	0.023	0.034	0.039	0.014	0.024	0.032	0.039	0.115

***, **, * represent 1%, 5%, 10% significant levels, respectively.

Table 6. Granger causality tests in the frequency domain estimates $InEC,\ InCO_2$.

Countries	H_0: $InEC \nrightarrow InCO_2$				H_0: $InCO_2 \nrightarrow InEC$			
	w = 0.5	**w = 1.5**	**w = 2.5**	**c.v. = 10%**	**w = 0.5**	**w = 1.5**	**w = 2.5**	**c.v. = 10%**
Algeria	0.023 ***	0.027 ***	0.031 ***	0.091	0.029 ***	0.028 ***	0.034 ***	0.032
Angola	0.034	0.036	0.041	0.007	0.023 ***	0.031 ***	0.044 ***	0.014
Burkina Faso	0.023	0.027	0.029	0.012	0.028	0.010	0.054	0.006
Benin	0.026	0.028	0.031	0.014	0.031	0.025	0.034	0.044
Cameron	0.019 **	0.016 **	0.014 **	0.017	0.038 ***	0.041 ***	0.045 ***	0.009
Congo (Brazzaville)	0.029	0.019	0.016	0.019	0.037	0.024	0.034	0.018
Congo (DRC)	0.037	0.021	0.018	0.081	0.033	0.022	0.045	0.092
Egypt	0.023 ***	0.028 ***	0.031 ***	0.089	0.028	0.042	0.054	0.078
Ethiopia	0.033	0.038	0.042	0.091	0.024	0.031	0.048	0.099
Gabon	0.035	0.037	0.033	0.071	0.029	0.032	0.039	0.077
Ghana	0.045 ***	0.054 ***	0.067 ***	0.009	0.023	0.031	0.037	0.101
Guinea	0.037	0.031	0.028	0.008	0.028	0.034	0.038	0.111
Kenya	0.039	0.032	0.028	0.045	0.029	0.028	0.045	0.098
Lesotho	0.029	0.024	0.021	0.076	0.018	0.031	0.055	0.102
Madagascar	0.018	0.021	0.027	0.089	0.024	0.010	0.034	0.111
Malawi	0.024	0.027	0.029	0.090	0.032	0.025	0.049	0.133
Mali	0.032	0.036	0.41	0.039	0.036	0.041	0.054	0.122
Mauritius	0.036	0.037	0.039	0.051	0.029	0.024	0.032	0.121
Morocco	0.029	0.031	0.033	0.044	0.017	0.022	0.035	0.090
Mozambique	0.017	0.021	0.028	0.062	0.029	0.042	0.041	0.112
Namibia	0.029	0.037	0.032	0.082	0.025	0.031	0.039	0.122
Nigeria	0.025 ***	0.028 ***	0.031 ***	0.095	0.044	0.032	0.057	0.124
Rwanda	0.044	0.034	0.027	0.083	0.031	0.031	0.045	0.154
Sao Tome and Principe	0.031	0.028	0.025	0.076	0.029	0.034	0.055	0.101
Senegal	0.022	0.026	0.029	0.049	0.018	0.028	0.055	0.111
Sierra Leone	0.019	0.021	0.023	0.078	0.024	0.031	0.053	0.121
South Africa	0.022	0.026	0.028	0.065	0.024	0.010	0.058	0.132
Tanzania	0.027	0.029	0.031	0.007	0.032	0.025	0.059	0.122
Togo	0.032	0.035	0.038	0.009	0.036	0.041	0.077	0.176
Tunisia	0.028 ***	0.031 ***	0.037 ***	0.065	0.029 **	0.024 **	0.056 **	0.109
Uganda	0.029	0.031	0.033	0.098	0.017 **	0.022 **	0.055 **	0.101
Zambia	0.019	0.022	0.028	0.097	0.029	0.042	0.054	0.102
Zimbabwe	0.021	0.023	0.024	0.008	0.025	0.031	0.067	0.111

***, **, represent 1%, 5% significant levels, respectively.

Table 7. Granger causality tests in the frequency domain estimates $In\gamma,\ InAVA$.

Countries	H$_0$: $In\gamma \nrightarrow InAVA$				H$_0$: $InAVA \nrightarrow In\gamma$			
	w = 0.5	**w = 1.5**	**w = 2.5**	**c.v. = 10%**	**w = 0.5**	**w = 1.5**	**w = 2.5**	**c.v. = 10%**
Algeria	0.029 ***	0.031 ***	0.034 ***	0.023	0.014 ***	0.045 ***	0.035 ***	0.019
Angola	0.038 ***	0.042 ***	0.045 ***	0.009	0.015 ***	0.015 ***	0.045 ***	0.098
Burkina Faso	0.034 **	0.044 **	0.047 *	0.008	0.093 *	0008 **	0.053 **	0.116
Benin	0.022 **	0.026 *	0.029 ***	0.012	0.072 **	0.053 **	0.034 *	0.122
Cameron	0.023 *	0.027 **	0.029 *	0.019	0.093 *	0.072 **	0.047 **	0.138
Congo (Brazzaville)	0.021 **	0.026 **	0.029 **	0.076	0.007 **	0.009 *	0.034 ***	0.129
Congo (DRC)	0.022 **	0.025 **	0.028 *	0.027	0.043 *	0.005 **	0.045 *	0.147
Egypt	0.019 **	0.023 **	0.029 **	0.098	0.007 **	0.042 **	0.053 **	0.126
Ethiopia	0.018 *	0.022 **	0.027 **	0.056	0.027 ***	0.041 **	0.047 **	0.091
Gabon	0.016 **	0.019 **	0.022 **	0.039	0.005 **	0.033 **	0.041 **	0.125
Ghana	0.022 *	0.025 **	0.029 ***	0.044	0.015 **	0.042 **	0.037 *	0.087
Guinea	0.018 **	0.021 **	0.027 *	0.087	0.005 *	0.006 **	0.034 ***	0.099
Kenya	0.007 ***	0.012 **	0.019 ***	0.069	0.027 *	0.046 ***	0.053 **	0.102
Lesotho	0.018 **	0.011 **	0.019 **	0.081	0.038 **	0.036 **	0.059 **	0.009
Madagascar	0.019 **	0.022 **	0.026 **	0.072	0.016 *	0.016 *	0.039 *	0.122
Malawi	0.022 *	0.023 **	0.026 **	0.098	0.036 *	0.016 *	0.047 **	0.134
Mali	0.027 *	0.029 *	0.031 *	0.099	0.026 *	0.036 **	0.054 *	0.177
Mauritius	0.032 *	0.028 *	0.024 *	0.062	0.009 **	0.038 *	0.045 **	0.187
Morocco	0.009 *	0.014 *	0.019 **	0.073	0.009 *	0.037 **	0.065 **	0.138
Mozambique	0.007 **	0.009 *	0.011 **	0.079	0.047 *	0.034 **	0.044 ***	0.166
Namibia	0.009 ***	0.012 **	0.019 ***	0.092	0.037 **	0.083 **	0.098 *	0.147
Nigeria	0.011 ***	0.014 *	0.019 **	0.095	0.047 ***	0.034 **	0.059 **	0.123
Rwanda	0.021 **	0.025 **	0.028 *	0.093	0.009 *	0.024 **	0.043 **	0.122
Sao Tome and Principe	0.012 *	0.018 *	0.022 **	0.091	0.047 **	0.015 **	0.058 ***	0.111
Senegal	0.024 **	0.027 *	0.032 ***	0.084	0.049 **	0.005**	0.058 *	0.145
Sierra Leone	0.022 **	0.026 ***	0.029 *	0.079	0.039 **	0.094 *	0.054 **	0.118
South Africa	0.011 *	0.016 *	0.019 **	0.099	0.039 **	0.025 **	0.056 **	0.128
Tanzania	0.022 **	0.026 *	0.028 **	0.078	0.041 **	0.035 **	0.055 *	0.101
Togo	0.021 **	0.025 **	0.029 *	0.055	0.033 **	0.035 *	0.074 *	0.109
Tunisia	0.009 **	0.011 *	0.016 **	0.089	0.034 *	0.025 **	0.053 **	0.154
Uganda	0.019 *	0.023 **	0.029 **	0.037	0.047 *	0.035 **	0.055 *	0.111
Zambia	0.021 *	0.026 *	0.031 *	0.088	0.037 *	0.025 **	0.055 *	0.122
Zimbabwe	0.007 *	0.011 **	0.019 *	0.089	0.043 **	0.035 **	0.064 **	0.143

***, **, * represent 1%, 5%, 10% significant levels, respectively.

Table 8. Granger causality tests in the frequency domain estimates $In\gamma,\ InFOR$.

Countries	H_0: $In\gamma \nrightarrow InFOR$				H_0: $InFOR \nrightarrow In\gamma$			
	w = 0.5	w = 1.5	w = 2.5	c.v. = 10%	w = 0.5	w = 1.5	w = 2.5	c.v. = 10%
Algeria	0.009	0.011 *	0.019	0.091	0.005	0.033	0.044	0.093
Angola	0.004	0.012 *	0.019	0.009	0.009	0.005	0.048	0.098
Burkina Faso	0.011 *	0.015	0.019	0.017	0007	0.023	0.056	0.099
Benin	0.003	0.009	0.011	0.019	0.005	0.024	0.037	0.092
Cameron	0.005 ***	0.009 ***	0.012 ***	0.089	0.001	0.029	0.048	0.091
Congo (Brazzaville)	0.002 ***	0.006 ***	0.009 ***	0.079	0.002	0.036	0.037	0.078
Congo (DRC)	0.003 ***	0.007 ***	0.022 ***	0.097	0.008	0.034	0.049	0.103
Egypt	0.006	0.009 *	0.011	0.087	0.004	0.032	0.057	0.099
Ethiopia	0.011	0.017 *	0.021	0.057	0.006	0.032	0.056	0.094
Gabon	0.008	0.012 *	0.022	0.023	0.002	0.039	0.044	0.109
Ghana	0.007	0.014 *	0.021	0.028	0.004	0.041	0.039	0.111
Guinea	0.003	0.008 *	0.011	0.055	0.008	0.034	0.040	0.104
Kenya	0.008 ***	0.013 ***	0.019 ***	0.089	0.005 *	0.039 **	0.047 *	0.101
Lesotho	0.009	0.022 **	0.029	0.082	0.002	0.039	0.058	0.099
Madagascar	0.014	0.023 *	0.029	0.044	0.007	0.031	0.038	0.102
Malawi	0.021	0.022 **	0.028	0.043	0.009	0.037	0.056	0.101
Mali	0.008	0.044 *	0.054	0.049	0.009	0.045	0.057	0.078
Mauritius	0.014	0.021 *	0.034	0.076	0.003	0.045	0.055	0.099
Morocco	0.022	0.025 *	0.029	0.077	0.002	0.042	0.053	0.089
Mozambique	0.028	0.031 *	0.045 *	0.073	0.007	0.031	0.045	0.098
Namibia	0.027	0.031 *	0.048 *	0.071	0.001	0.043	0.048	0.067
Nigeria	0.021 ***	0.027 ***	0.037 ***	0.082	0.003	0.048	0.057	0.089
Rwanda	0.011	0.033	0.054	0.091	0.003	0.041	0.045	0.098
Sao Tome and Principe	0.023 *	0.043	0.055	0.027	0.002	0.020	0.054	0.044
Senegal	0.011 ***	0.033 ***	0.058	0.031	0.008	0.035	0.053	0.056
Sierra Leone	0.012	0.027	0.039	0.036	0.001	0.051	0.054	0.019
South Africa	0.009 ***	0.014 ***	0.051 ***	0.042	0.003	0.034	0.052	0.110
Tanzania	0.019	0.026	0.031	0.043	0.003	0.032	0.053	0.101
Togo	0.008	0.015	0.029	0.055	0.004	0.052	0.071	0.089
Tunisia	0.007	0.017	0.032	0.069	0.003	0.041	0.052	0.091
Uganda	0.009 ***	0.032 ***	0.054 ***	0.072	0.001	0.042	0.052	0.088
Zambia	0.011	0.028	0.038	0.058	0.002	0.041	0.052	0.078
Zimbabwe	0.013	0.029	0.054	0.098	0.006	0.044	0.062	0.098

***, **, * represent 1%, 5%, 10% significant levels, respectively.

Table 9. Granger causality tests in the frequency domain estimates $InEC$, $InAVA$.

Countries	H_0: $InEC \nrightarrow InAVA$				H_0: $InAVA \nrightarrow InEC$			
	w = 0.5	**w = 1.5**	**w = 2.5**	**c.v. = 10%**	**w = 0.5**	**w = 1.5**	**w = 2.5**	**c.v. = 10%**
Algeria	0.009	0.014	0.029	0.121	0.024	0.029	0.033	0.101
Angola	0.011 ***	0.026 ***	0.037 ***	0.019	0.024	0.032	0.042	0.103
Burkina Faso	0.008	0.039	0.044	0.019	0.024	0.012	0.052	0.102
Benin	0.029	0.044	0.039	0.082	0.034	0.023	0.032	0.104
Cameron	0.011	0.029	0.037	0.024	0.034	0.043	0.041	0.106
Congo (Brazzaville)	0.028	0.031	0.039	0.032	0.034	0.022	0.031	0.102
Congo (DRC)	0.027	0.058	0.068	0.019	0.035	0.023	0.041	0.101
Egypt	0.013 ***	0.025 ***	0.039 ***	0.018	0.025	0.043	0.052	0.102
Ethiopia	0.029	0.033	0.054	0.095	0.025	0.032	0.044	0.108
Gabon	0.011	0.023	0.056	0.008	0.024	0.033	0.035	0.102
Ghana	0.013 ***	0.028 ***	0.011 ***	0.101	0.025	0.033	0.034	0.104
Guinea	0.016	0.022	0.032	0.016	0.025	0.035	0.034	0.102
Kenya	0.012	0.024	0.034	0.013	0.024	0.024	0.043	0.101
Lesotho	0.014	0.026	0.044	0.104	0.019	0.035	0.053	0.105
Madagascar	0.011	0.033	0.045	0.101	0.023	0.014	0.033	0.103
Malawi	0.009	0.045	0.056	0.101	0.033	0.024	0.042	0.102
Mali	0.006	0.054	0.059	0.009	0.032	0.045	0.051	0.102
Mauritius	0.008	0.023	0.041	0.102	0.021	0.025	0.037	0.101
Morocco	0.007	0.033	0.039	0.103	0.019	0.024	0.034	0.102
Mozambique	0.004	0.021	0.034	0.101	0.022	0.044	0.043	0.106
Namibia	0.006	0.025	0.041	0.104	0.023	0.034	0.033	0.104
Nigeria	0.009 ***	0.029 ***	0.044 ***	0.101	0.041 ***	0.033 ***	0.054 ***	0.103
Rwanda	0.012	0.028	0.033	0.102	0.034	0.036	0.043	0.104
Sao Tome and Principe	0.009	0.026	0.029	0.105	0.019	0.033	0.052	0.112
Senegal	0.007	0.028	0.049	0.107	0.019	0.023	0.057	0.103
Sierra Leone	0.006	0.039	0.044	0.101	0.021	0.034	0.056	0.102
South Africa	0.005 ***	0.028 ***	0.046 ***	0.114	0.022 ***	0.014 ***	0.054 ***	0.104
Tanzania	0.017	0.021	0.041	0.113	0.033	0.023	0.053	0.195
Togo	0.022	0.029	0.038	0.124	0.031	0.043	0.073	0.102
Tunisia	0.017 ***	0.022 ***	0.039 ***	0.112	0.021	0.023	0.053	0.107
Uganda	0.018 ***	0.023 ***	0.031 ***	0.123	0.019	0.024	0.053	0.107
Zambia	0.012	0.028	0.033	0.112	0.019	0.041	0.052	0.108
Zimbabwe	0.014	0.029	0.032	0.124	0.021	0.032	0.062	0.119

*** represent 10% significant level.

Table 10. Granger causality tests in the frequency domain estimates $InCO_2$, $InAVA$.

Panel G								
Countries	H_0: $InCO_2 \nrightarrow$, $InAVA$				H_0: $InAVA \nrightarrow InCO_2$			
	w = 0.5	w = 1.5	w = 2.5	c.v. = 10%	w = 0.5	w = 1.5	w = 2.5	c.v. = 10%
Algeria	0.006	0.023	0.034	0.019	0.013	0.032	0.049	0.114
Angola	0.005	0.033	0.044	0.027	0.017	0.052	0.059	0.115
Burkina Faso	0.002	0.032	0.054	0.025	0.096	0.043	0.069	0.118
Benin	0.009	0.029	0.034	0.025	0.073	0.056	0.061	0.117
Cameron	0.011	0.023	0.045	0.023	0.091	0.058	0.062	0.111
Congo (Brazzaville)	0.012	0.029	0.034	0.021	0.009	0.055	0.069	0.124
Congo (DRC)	0.021	0.032	0.045	0.089	0.047	0.055	0.062	0.101
Egypt	0.024	0.044	0.054	0.099	0.004	0.058	0.061	0.102
Ethiopia	0.022	0.033	0.048	0.094	0.021	0.074	0.051	0.108
Gabon	0.012	0.022	0.039	0.072	0.009	0.054	0.052	0.123
Ghana	0.009	0.029	0.037	0.011	0.019	0.054	0.051	0.124
Guinea	0.019	0.029	0.038	0.011	0.009	0.054	0.061	0.102
Kenya	0.015	0.028	0.045	0.056	0.022	0.066	0.069	0.101
Lesotho	0.013	0.039	0.055	0.076	0.031	0.037	0.049	0.112
Madagascar	0.021	0.029	0.034	0.019	0.011	0.052	0.059	0.117
Malawi	0.025	0.023	0.049	0.091	0.032	0.044	0.058	0.115
Mali	0.005	0.032	0.054	0.071	0.022	0.055	0.064	0.102
Mauritius	0.014	0.024	0.032	0.080	0.005	0.051	0.054	0.101
Morocco	0.011	0.028	0.035	0.049	0.007	0.051	0.069	0.102
Mozambique	0.012	0.013	0.041	0.069	0.046	0.051	0.052	0.119
Namibia	0.018	0.029	0.039	0.089	0.033	0.051	0.058	0.119
Nigeria	0.022	0.041	0.057	0.099	0.044	0.071	0.072	0.129
Rwanda	0.021	0.032	0.045	0.089	0.006	0.051	0.064	0.117
Sao Tome and Principe	0.012	0.039	0.055	0.072	0.045	0.056	0.065	0.155
Senegal	0.022	0.033	0.055	0.091	0.044	0.056	0.058	0.141
Sierra Leone	0.014	0.023	0.053	0.071	0.032	0.067	0.069	0.128
South Africa	0.022	0.034	0.058	0.069	0.031	0.034	0.071	0.148
Tanzania	0.008	0.023	0.059	0.009	0.029	0.055	0.071	0.112
Togo	0.006	0.032	0.077	0.011	0.031	0.044	0.059	0.121
Tunisia	0.008	0.029	0.056	0.066	0.033	0.055	0.062	0.121
Uganda	0.009	0.022	0.055	0.093	0.045	0.053	0.064	0.150
Zambia	0.019	0.021	0.054	0.091	0.033	0.056	0.068	0.132
Zimbabwe	0.021	0.029	0.067	0.009	0.046	0.056	0.064	0.131

The results of the panel Granger causality in the frequency domain for all the examined African economies suggest the existence of bi-directional relationships across the three spectra between economic growth and energy consumption. The results further reveal that a one-way Granger causality runs from energy consumption to CO_2 emission in the studied economies. A further examination of the results also suggests that there is a causal nexus between carbon emissions and economic growth for the entire spectra studied, and that no evidence suggests that causality runs from economic growth to carbon emissions. In term of theoretical underpinning, one can deduce that the feedback hypothesis is valid for the relationship between energy consumption and economic growth in the studied African economies. This suggests that African economies could grow their economies by increasing energy consumption, and that energy consumption could also be enhanced by growing the economy, suggesting that demand for energy consumption is a booster of economic growth. For the nexus between energy consumption and CO_2 emission, the results suggest the validity of the pollution haven hypothesis, as energy consumption has a bi-directional relationship with growth driving carbon emissions in African economies, thus, Africa economies, while pursuing growth, should start looking at clean energy consumption. Though the results of the study suggest that no causality runs from economic growth to carbon emissions, ruling out the possibility of the pollution haven hypothesis, the existence of causality from energy consumption to carbon emissions points to the existence or potential of the pollution haven hypothesis, which could be from an indirect perspective. On the meditating role of agricultural value addition and forests, the results noted that the impact of both forests and agricultural value addition is only significant on economic growth across all the spectra, and on energy consumption in the short run. No causality is established between either of forests and agricultural value addition, and CO_2 emission for the studied economies.

For comparison, we conducted time domain estimates for the entire region by employing the Dumitrescu–Hurlin panel causality estimate. From the results, it could be deduced that a bi-directional relationship exists between economic growth and energy consumption, and that a one-way causality runs from energy consumption to carbon emissions. The results suggest the feedback hypothesis is valid on the nexus between energy and economic growth in Africa. The results of the one-way nexus, however, suggest that the conservation hypothesis is not valid in Africa. Unlike the frequency domain estimate, the moderating variables failed exhibit any form of causality in the time domain model.

The study has made some significant contribution to knowledge by being among the first set of studies that has examined the nexus among energy, environment and economic growth in Africa within the context of frequency domain estimate, and that calibrated the moderating roles of forest and agricultural value addition to this nexus.

6. Conclusions

The essence of this study was to examined the causal relationships between energy consumption, economic growth and CO_2 emission with the moderating roles of forestry and agricultural value addition in Africa, by employing both time domain and frequency domain estimates to analyzed data sourced from 1980 to 2019. The study provides both single-country and multi-country estimates of this nexus. The results of the single country estimate are at best mixed across the various frequencies. The study recommends that policymakers in the studied economies should take into consideration these empirical findings when designing policy tools to achieving the correct mix of energy that will stimulate economic growth without causing havoc to the environment.

The results of the panel Granger causality estimates in the frequency domain suggest that a bi-directional relationship exists between energy consumption and economic growth in Africa economies. This implies that to achieve economic growth, the energy sector should be enhanced, and that enhanced energy space will further drive or stimulate growth. The results further suggest the existence of a one-way causality from energy consumption to carbon emissions, ruling out the validity of the conservation hypothesis in these economies. This could be a result of heavy dependency/consumption of non-renewable energy in the region. It is therefore recommended that policymakers in this region should start looking at movement toward clean energy consumption. Our results are in line with the findings of Aydin (2019 for OECD economies, Gorus and Aydin 2018 for MENA economies, but contradicts [33,97].

The study is not an all-inclusive one, as there are limitations, which could be areas to be considered by other studies. For instance, alternative estimation techniques could be employed, other variables like ecological footprints, macroeconomic variables like foreign direct investment, and socio-political variables, among others. Other studies could examine the cost-benefit analysis of different energy options as they relate to the environment, economic growth, among others. Future research can employ multi-criteria analyses useful for quantifying the nexus between the different components.

The global economy is moving towards adopting renewable energy with the intension of mitigating climate change and reducing CO_2 emissions; hence, the economies of Africa should make concerted efforts to develop their renewable energy potential to support economic growth. This is in line with the UN resolution of the 2015 Paris Agreement that by the 21st Conference of Parties (COP21) of the United Nations Framework Convention on Climate Change (UNFCCC), countries should focus on investing in sustainable energy and de-emphasizing the consumption of fossil fuel, among others. African economies are encouraged to formulate and implement policies that will encourage consumption of renewable energy technologies such as laws protecting the production and usage of domestic solar panels, wind turbine production, granting tax incentives to renewable energy investments, stimulate green bonds and investment, among others.

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Data Availability Statement: The data for the study are sourced as follows: CO_2 and RGDP from World Development Indicators (various issues), agriculture value addition and forest areas from Food and Agricultural Organization (various issues), and energy consumption data was from OECD.

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