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Exploring the impact of renewable energy on economic growth and carbon emissions: Evidence from partial least squares structural equation modeling

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Data Availability Statement: The data for the study is gotten from two sources which are the World Bank Indicators (https://databank.worldbank.org/source/world-development-indicators) and International Monetary Fund (https://www.imf.org/en/Data). The data for the study is from 1990 to 2021. The variables of the study are; renewable energy consumption (independent variable), foreign direct investment,

Abstract

The concern for environmental sustainability comes along with sustainable energy for consumption. Therefore, this study aims to explore the direct and indirect effects of renewable energy on economic growth and carbon emissions by employing Partial Least Square Structure Equation Modeling and Granger Causality Test and the data for this study is from 1990 to 2021. The results from the Partial Least Squares Structure Equation Modeling indicate that renewable energy consumption causes carbon emissions and has no effect on economic growth. Financial inclusion and foreign direct investment have positive effects on carbon emissions. However, renewable energy has an indirect negative effect on carbon emissions through economic growth. Foreign direct investment affects economic growth positively. Furthermore, the results from the Granger causality test indicate that renewable energy has a unidirectional causality relationship with financial inclusion and foreign direct investment and has a feedback causality relationship with economic growth. In addition, there is a feedback causal effect between financial inclusion and carbon emissions, a unidirectional effect running from carbon emissions to foreign direct investment, and a causal effect from economic growth to foreign direct investment. This study has suggested comprehensive policy recommendations for policymakers based on the findings.

1 Introduction

Recently, the debate around climate and sustainable energy has gained more attention from researchers, policymakers, government institutions, non-governmental institutions, and environmentalists than before as global warming is still considered as one of the biggest global challenges. The main source of global warming is carbon emissions as the result of the burning of fossil fuels. The condition has affected land use patterns, ecosystems, and atmospheric gaseous composition [1]. The attention environmental degradation has gained has resulted in all concerned individuals putting measures in place to combat carbon emissions. As a means of

trade liberation, economic growth, and financial inclusion (the mediators), and carbon emissions (the dependent variable). The statistical description of the variables and the correlational effect between the variables are examined and presented in Tables 1&2 respectively.

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promoting green and sustainable future for the globe by 2030, measures are recommended to be implemented by every country through the United Nations Sustainable Development Goals and the Paris Climate Change Agreement [2]. Simionescu and Cifuentes-Faura [3] stated that the 2030 Agenda was approved to encourage the use of affordable and clean energy (Sustainable Development Goal (SDG 7), promote sustainable cities (SDG 11), and climate actions (SDG 13). The underlying motivation is to ensure the safety of the world and to protect and secure a sustainable environment for the future generations. In addition, to meet energy demand for production without threatening the quality of the environment [4]. As part of ensuring environmental sustainability to protect the ecosystem, the major environmental problems the world is still battling were exposed during the COP26 Summit [5]. The purpose for the battle against the factors that put the environment at risk is to protect and improve the environment [6]

The position of energy particularly fossil fuels in the development of the world's economy over the past decades cannot be overlooked [7]. However, the impact of fossil fuel on environmental quality and climate change has caused stakeholders and policymakers to worry about the sustainability of the environment. Global warming is a result of the over-reliance on fossil fuels which has resulted in high carbon emissions [8]. Nonetheless, renewable energy is considered to be a more sustainable energy source to opt for instead of fossil fuels. In the view of Maji et al [9], renewable energy does not emit carbon emissions during production unlike fossil fuel. Abokyi et al [10], further indicated that the combustion of fossil fuel has led to the high emission of greenhouse gas in the world. Removing fossil fuel from the equation for economic growth raises the issue of continuity and prosperity since renewable energy has the potential to minimize carbon emissions. However, the improper use of renewable energy could lower productivity and have a detrimental impact on the economy [11].

The rate at which energy demand is increasing, its effect on the environment and demand for sustainable energy in both the southern and northern hemispheres have all been the subject of a global discussion [12]. The level of global development would slow down without energy or if the energy demand is not met [13]. In order to avoid this situation, it is essential to invest in sustainable energy systems such as renewable energy, encourage energy-efficient practices, put clean energy technology and infrastructure in place, and promote the use of alternative energy in public buildings [14].

It is argued that one of the effective ways to reduce the threat of climate change is to use innovative and sustainable energy production methods. According to the special report on global warming that was commissioned in 2019, it was recommended by the International Panel on Climate Change (IPCC) that by the year 2050, sustainable energy sources should account for 80% of all energy use. For example, there was a significant drop in global economic growth as the effect of COVID-19 pandemic in the year 2020 which resulted in a five-point reduction in global emissions. Compared to the year before, the consumption of fossil fuels increased by 5.3% in 2021. Recent attempts to cut greenhouse gas emissions to battle global warming have reached a key turning point according to the 27th Edition of the United Nations Climate Change Conference (COP27) which was held in Sharm el-Sheikh (Egypt) in November 2022. Agyekum & Nutakor [15] revealed that the use of sustainable energy (renewable energy) would reduce carbon emissions.

Through the use of Nationally Determined Contributions (NDCs), Ghana has attempted to fulfill its commitment to ensuring environmental sustainability. In the attempt of implementing sustainable policies, the issue of globalization, population increase, and economic growth have all contributed to Ghana's recent struggles with a consistent supply of electricity and this has been a worry to the nation. According to Lin & Agyeman [16] the use of fossil fuels has been a major contributor to Ghana's economic growth. To fuel the various thermal plants that

constitute Ghana's main source of electricity generation, natural gas is delivered from Nigeria. As the country's energy needs continue to rise, Ghana must diversify its energy mix in order to meet both its present and future energy needs [15]. However, promoting the use of renewable energy sources in Ghana's energy mix is anticipated to reduce the country's excessive reliance on non-renewable energy sources in the near future. And these could be a major force behind Ghana's efforts to develop a low-carbon economy that can creatively replace the country's nonrenewable energy sources.

This study aims to add to the existing body of knowledge on the debate concerning the connection between energy, economic growth, and carbon emissions by exploring their direct and indirect effects by employing the Granger causality test and Partial Least Squares Structural Equation Modeling. Although, the factors that cause carbon emissions are well studied by several researchers as the means of finding a way to mitigate carbon emissions. Firstly, the position of energy in carbon emissions mitigation and economic growth has been examine by several studies [17–21]. However, to the best of our knowledge, these studies failed to examine the indirect effect that energy might have on economic growth and carbon emissions. Despite the in depth study on this topic, the earlier studies focused more on the direct relationship between the variables neglecting the indirect effect that might occur between the variables. Nevertheless, Gyimah et al [11] tried to explain the indirect effect of renewable energy on economic growth using mediation model and granger causality test. This study improves on that study by employing Partial Least Squares Structural Equation Modelling and Granger Causality Test to examine the direct and indirect effects of renewable energy on economic growth and carbon emissions. This study further uses recent data to improve on the said previous study, and added additional dependent variable. Secondly, financial inclusion has become one of the topics that researchers are debating about due to its effect on environmental sustainability and economic growth [22]. However, regarding the relevance of this topic in latest battle against carbon emissions, few studies have been done on the topic [23–25]. This has not revealed the entire potentials of financial inclusion on the issue of global warming. Regarding the few studies that have been done, different outcomes have been captured in the literature depending on geographical location and economic development level. In this respect, this study aims at exploring the direct and indirect effect of financial inclusion on economic growth and carbon emissions. The direction of this study will bring forth new knowledge to the field to improve the debate of financial inclusion on global warming. The findings would provide possible policy implications that would be relevant to encourage economic growth and mitigate carbon emissions through financial inclusion. Thirdly, there are other variables that are considered as part of the major factors that determine environmental quality. This study considered these variables as control variables to analyze their position as mediators in the fight against global warming. In the same way, the granger causality will help to further examine the direct relationship between these control variables on carbon emissions and economic growth while they will serve as mediators in the indirect effect using the PLS-SEM.

The study is structured as; literature review in section 2, methodology in section 3, results and discussion in section 4, and conclusion and policy implication in section 5.

2 Literature review

2.1 Energy and Carbon emissions

The relationship between energy and carbon emissions over the years has been studied by many researchers and three effects have been captured for their relationship either positive, negative, or no effect. The difference in the outcomes can be attributed to geographical location, methodology, and data. Revealing some of the effects that have been captured in the

literature for the two variables, a study in the United States to examine the causality effect between energy, income, and carbon emissions revealed that energy consumption over the long-term has a direct causal effect on carbon emissions [26]. Acaravci & Ozturk [27] study on 19 European countries using the Autoregressive Distributed Lag (ARDL) bound test indicated that there is an existence of long-term elasticity of emissions to energy at 1% significant which was found in countries like Denmark, Germany, Italy, and Portugal. Waheed et al [28] employing the ADRL model to examine the relationship between renewable energy, forest and agriculture production, and carbon emissions revealed that renewable energy and forest would have a significant negative effect on carbon emissions which could be translated as the rise in both variables would reduce carbon emissions. Examining the impact of energy, economic growth, and carbon emissions in 19 industrialized and developing countries, the study revealed a significant inverse relationship between nuclear energy consumption and carbon emissions, but the relationship between renewable energy and carbon emissions is not significant [7]. To support the positive impact of renewable energy on environmental sustainability, Dogan & Inglesi-Lotz [29] research indicated that the use of biomass energy significantly lowers the rate of carbon emissions. Using the Vector Error Correlation Model (VECM) in an analysis, the outcome revealed that there is a feedback effect between energy use and carbon emissions which implies that the two variables affect each other [30]. Another study conducted by Danish et al [19] in Pakistan proved that renewable energy helps in carbon emissions mitigation while nonrenewable energy escalates carbon emissions. A study by Khan et al [31] on 176 countries using the dynamic fixed effect and generalized method of moments revealed that renewable energy improves ecological quality. In the same regard, Mohsin et al [32], emphasized that the increased use of renewable energy would lessen the ecological harm from trade and industrial development in 25 Asian countries. Again, a study by Dong et al [33] using the Environmental Kuznets Curve to explain the relationship between energy and carbon emissions in China concluded that the use of renewable energy and nuclear energy would reduce environmental degradation while fossil fuel destroys environmental quality. According to the findings of Durani et al. [34] study, the impact of renewable energy helps control carbon emissions. The study of Uche et al. [35] further revealed that renewable energy use in BRICS countries helps in carbon emissions mitigation. Bhowmik et al. [36] study revealed that Climate Change Mitigation technology helps to control carbon emissions from the transport sector. However, Hashmi et al. [37] study in USA indicated that climate policy uncertainty worsens carbon emissions in both short and long-runs in residential, commercial, and electric power sectors. In addition, Liu et al. [38] study indicated that energy efficiency in both the long and short runs helps curb emissions. Makhdum et al. [39] study also indicated that renewable energy helps diminish ecological footprint.

H1*: *renewable energy has an influence on carbon emissions

2.2 Energy, economic growth, and carbon emissions

The energy, economic growth, and carbon emissions relationship have dominated the research on global warming and are still relevant to date because the challenge of global warming is still a global concern. According to Lorente et al. [40], clean energy is part of the major influencers in the financial markets and very crucial in controlling geopolitical risk. The existing literature have captured either unidirectional, bidirectional, or neutral effect for these three variables. Some of the empirical evidence that have been captured in the literature are; a study on Malaysia using ARDL bound test revealed that energy and Gross Domestic Product (GDP) (economic growth) have an effect on carbon emissions [41]. Using Granger causality to explain the

effect between energy, economic growth, and carbon emissions, the result revealed that there is no correlation between economic growth and carbon emissions, and energy and carbon emissions are not drivers of economic growth [42]. A study on nine industrialized countries revealed a short-term unidirectional causal effect between energy use and economic growth and a long-term bidirectional causality effect between carbon emissions and economic growth [43]. The results from the causality test by Magazzino [44] in determining the relationship between real GDP, Carbon emissions (CO2) emissions, and energy use in the South Caucasus nations showed that real GDP improves both energy consumption and CO2 emissions in Armenia. Bidirectional causality effect between economic growth and energy utilization in Azerbaijan and Georgia. Cai et al [45] study revealed that there is no co-integration between real GDP per capita, greenhouse gas emissions, and clean energy consumption for Canada, Italy, the United States, France, and the United Kingdom although different results were captured for Japan and Germany. The results further revealed a unidirectional causal effect from renewable energy to real GDP per capita in Canada, Germany, and United States of America (USA). In addition, feedback causality effect is revealed among renewable energy and carbon emissions in Germany and unidirectional causality effect from renewable energy to carbon emissions in USA. A study conducted in 170 countries revealed that energy, economic growth, and urbanization have impact on carbon emissions [46]. According to a research conducted in Malaysia from 1978 to 2016 using the ARDL test co-integration on urbanization, renewable energy, economic development, carbon emissions, and the agro-industry, it was revealed that economic growth and urbanization significantly increase carbon emissions, however, cultivated plants, aquaculture, and renewable energy sources significantly reduce carbon emissions [47]. Another study by Syed and Bouri [48] indicated that in the short-run economic policy uncertainty contributes to high carbon emissions while it curbs carbon emissions in the long-run. Moreover, the findings of Anser et al. [49] study revealed that economic policy uncertainty measured by world uncertainty index in both short and long-runs worsens carbon emissions in ten highest carbon emitter countries.

H2*: *renewable energy consumption improves economic growth

H3*: *Economic growth affects the level of carbon emissions

A study using Fully Modified Ordinary Least Squares (FMOLS) was conducted to assess the impact of carbon emissions, GDP, renewable energy, hydropower, and trade openness on Brazil's economy. The results showed that GDP and renewable energy have a negative impact on carbon emissions, and that carbon emissions has a positive impact on economic growth [50]. Another research used symmetric and asymmetric analysis to evaluate the relationship between carbon emissions, oil price, and economic growth in Pakistan from 1971 to 2014. The symmetric result suggested that economic growth and foreign direct investment deepen carbon emissions over the long and short terms, while oil price increases emissions over the short-term while decreasing emissions over the long-term [51]. A study in Africa divided 22 African nations into two groups: crude exporters and non-exporters. The study's findings showed that, in both the long- and short-terms, there is a bilateral causal relationship between the use of fossil fuels and economic growth and the use of fossil fuels and carbon emissions. However, when comparing the long and short-terms, there is a unilateral causal relationship from carbon emissions to economic growth for non-oil exporters [52]. A research conducted by Magazzino et al [53] predicted that Brazil's GDP is likely to rise due to the increased use of green energy during the COVID-19 period. The assessments using the Artificial Neutral Network (ANNs) model revealed that a greater amount of green energy could support Brazil's economic development and growth. As a result, increasing GDP growth in Brazil's economy

determines the growth in the use of green energy. The results further showed that green energy is further anticipated to make economic growth in Brazil stable. A study by [54] in Kuwait using ARDL and VECM revealed that economic growth and FDI affect carbon emissions positively.

H4*: *FDI improves economic growth

H5*: *trade openness facilitates economic growth

H6*: *FDI has an effect on carbon emissions

Lin & Agyeman [55] study on Sub-Saharan Africa revealed that energy and GDP have impact on carbon emissions. A study on West African countries, the result revealed that there is a positive correlation between biomass consumption, carbon emissions, and economic growth in five countries namely; Gambia, Togo, Burkina Faso, Mali, and Nigeria [56]. A study on E7 countries revealed that for China, Mexico, Indonesia, and Turkey, the variables economic growth, energy, and carbon emissions are not co-integrated. However, Brazil, Russia, and India had a co-integration relationship among the variables. Again, the study revealed a causal effect from energy to carbon emissions and from economic growth to carbon emissions in India, Brazil, Mexico, and China. Additionally, a unidirectional causal effect was revealed from economic growth to energy in China, Mexico, and Indonesia [57].

2.3 Trade openness, financial inclusion, renewable energy, and economic growth

Financial inclusion has been revealed to have a positive impact on the transition to renewable energy and economic growth. In support of this, a study by Halkos & Tzeremes [58] on the impact of macroeconomic variables on these two variables revealed that there is a clear correlation between public debt and economic growth, however, there is a significant effect from economic growth intermediation to energy use. In addition, a study revealed a positive feedback relationship between financial development and energy. The possible effect of financial inclusion on energy use has raised the debate about its effect on carbon emissions. It is argued to have a negative effect on carbon emissions since it promotes renewable energy, others argued that it has a positive effect on carbon emissions, and others do not see its effect on carbon emissions. In a study on 31 countries, it was discovered that greater financial inclusion leads to higher carbon emissions [59]. However, another study revealed that in both the long and short terms, financial inclusion helps in carbon mitigation [60]. Zhang et al. [61] study revealed promoting green financing positively influences energy usage structuring. A study on trade liberation, energy use, economic growth, and financial development revealed that all the variables are integrated into the long term [62].

H7*: *financial inclusion encourages economic growth

H8*: *renewable energy helps to improve trade liberation

H9*: *renewable energy promotes financial inclusion

H10*: *financial inclusion has effect on carbon emissions

These studies have provided empirical evidence to support either one of the three effects that are expected to exist between energy, economic growth, and carbon emissions but failed to examine the indirect effect of these variables. Fig 1 gives the summary of the hypotheses under study. Trying to fill this gap, this study has employed Partial Least Squares and Granger Causality to examine both the direct and indirect effects of these three variables and their

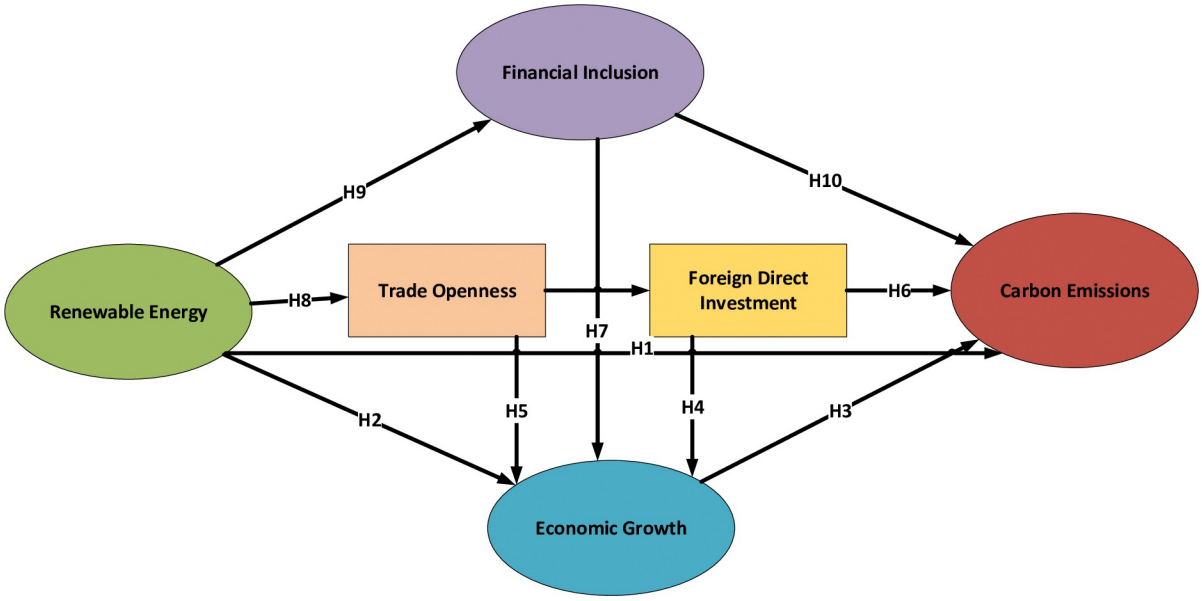

Fig 1. The pathway diagram.

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control variables. The control variables in the indirect effect will serve as the mediators. The outcome of the study would complement and improve on the already existing literature by providing the indirect effect of energy on carbon emissions and energy on economic growth.

2.4 Theoretical background

The theoretical background that explains the relationship between energy, economic growth, and carbon emissions is the Environmental Kuznets Curve hypothesis. The EKC hypothesis argues how economic growth influences the environment at each stage of development. According to the hypothesis, at the initial stage of economic development, the energy use and the economic activities put the environment at risk but the will be a turnover when a certain level of growth is attained [63]. Several studies have used this hypothesis to explain the effect on economic growth and energy use on carbon emissions [64, 65]. As the world is in the era of industrial revolution, many countries especially those in developing countries are putting measures in place to meet with the global growth of development. This situation puts many countries in a place to use energies that are not environmentally friendly. As the world is fighting against climate change, it is of relevant to explore how the type of energy use contributes to economic development and environmental quality. In this respect, this study employs the PLS-SEM and the Granger Causality model to explain the effect of renewable energy on economic growth and carbon emissions. Gyimah et al [11] used mediation model to explain the effect of renewable energy on economic growth without considering environmental implications. Therefore, this study seeks expand the scope by assessing the effect on the environment as well as both direct and indirect effects.

3 Methodology

Since environmental sustainability is a global responsibility, various studies with different models have tried to examine the connection between renewable energy use, economic growth, and carbon emissions. Different effects have been captured in the literature and

different hypotheses have been employed to explain the effect. Charfeddine & Kahia [18] employed a panel vector autoregressive (PVAR) analysis to analyze the connection between these variables in Middle East and Northern Africa (MENA) countries. Bhattacharya et al [66] used System-Generalized Method of Moments and FMOLS models to examine the connection between the variables in 85 developed and developing economies. Danish et al [19] examined the same effect in Pakistan using FMOLS, DOLS, and VECM Granger Causality test. Most of the existing literature tries to examine the direct effect of the variables [7, 67–69]. However, this study uses Partial Least Square Structural Equation Modelling and Granger Causality test to examine both the direct and indirect effects of the variables understudy. This model is able to examine how the variables affect each other. This makes our study different from other studies since we are examining two effects thus direct and indirect effects. The Granger Causality test would further help examine the causality effects between the variables. From Eqs 1–6 represent how the variables are assessed in the Granger Causality test.

$$\ln c_t = \gamma_0 + \gamma_1 \ln f_t + \gamma_2 \ln e_t + \gamma_3 \ln fi_t + \gamma_4 \ln t_t + \gamma_5 \ln r_t + \varepsilon_t \quad (1)$$

$$\ln e_t = \gamma_0 + \gamma_1 \ln f_t + \gamma_2 \ln c_t + \gamma_3 \ln fi_t + \gamma_4 \ln t_t + \gamma_5 \ln r_t + \varepsilon_t \quad (2)$$

$$\ln fi_t = \gamma_0 + \gamma_1 \ln f_t + \gamma_2 \ln e_t + \gamma_3 \ln c_t + \gamma_4 \ln t_t + \gamma_5 \ln r_t + \varepsilon_t \quad (3)$$

$$\ln t_t = \gamma_0 + \gamma_1 \ln f_t + \gamma_2 \ln e_t + \gamma_3 \ln fi_t + \gamma_4 \ln c_t + \gamma_5 \ln r_t + \varepsilon_t \quad (4)$$

$$\ln r_t = \gamma_0 + \gamma_1 \ln f_t + \gamma_2 \ln e_t + \gamma_3 \ln fi_t + \gamma_4 \ln t_t + \gamma_5 \ln c_t + \varepsilon_t \quad (5)$$

$$\ln f_t = \gamma_0 + \gamma_1 \ln c_t + \gamma_2 \ln e_t + \gamma_3 \ln fi_t + \gamma_4 \ln t_t + \gamma_5 \ln r_t + \varepsilon_t \quad (6)$$

From the equations, ln*c* stands for carbon emissions, ln*t* stands for trade liberation, ln*f* stands for foreign direct investment, ln*r* stands for renewable energy consumption, ln*e* stands economic growth, and ln*fi* stands for financial inclusion. These are the variables for the study. The symbols *t* stands for time, γ_0 stands for the constant value, γ_1–γ_5 stands for the coefficients, and εstands for the error term.

3.1 Data

The data for the study is gotten from two sources the World Bank Indicators (https://databank.worldbank.org/source/world-development-indicators) and International Monetary Fund (https://www.imf.org/en/Data). The data for the study is from 1990 to 2021. The variables of the study are; renewable energy consumption (independent variable), foreign direct investment, trade liberation, economic growth, and financial inclusion (the mediators), and carbon emissions (the dependent variable). The statistical description of the variables and the correlational effect between the variables are examined and presented in Tables 1 and 2 respectively.

4 Results and Discussion

4.1 Stationary test

Table 3 represents augmented dickey-fuller (ADF) test which is employed to assess the stationary of the variables. The (ln) stands for the variables at levels and (Δ) stands for the variables at first difference. There are two hypotheses that explain the stationarity check thus null hypothesis which states the variables are not stationary and alternative hypothesis which states the

Table 1. Descriptive statistics.

	ln*r*	ln*c*	ln*f*	ln*fi*	ln*t*	ln*e*
Mean	4.0416	-0.9331	1.2796	-2.0586	4.3832	0.9722
Median	4.04890	-0.9991	1.490971	-2.1164	4.3415	0.8683
Max	4.3673	-0.4529	2.2478	-1.7455	4.7540	2.4248
Min	3.7252	-1.4723	-0.0453	-2.2568	4.1069	-0.8931
Std. Dev	0.2065	0.2969	0.7248	0.1711	0.1863	0.7450

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variables are stationary. The variables must not be stationary at levels and must be stationary at the first difference. The results of the test indicate that the variables are not stationary at levels but stationary at first difference. This shows that the variables are suitable for co-integration test. To examine the co-integration test of the variables, Johansen and Juselius 1990 method is employed [70].

4.2 Co-integration test

The outcome of the co-integration test is presented in Table 4. The outcome reveals that the trace statistics and max-eigen value are greater than their corresponding critical value at 0.05. Therefore the null hypothesis which states that there is no co-integration must be rejected and the alternative hypothesis which states the variables are co-integrated must be accepted. In this regard, it can be concluded that there is co-integration among the variables.

4.3 The direct effect

Table 5 shows the results of PLS-SEM direct effects. The table shows how the independent and mediating variables directly affect each other. The summary of the discussion has been presented in Figs 2 and 3 and below are the outcomes of the hypotheses.

4.3.1 H1: Renewable energy consumption has an influence on carbon emissions. The outcome reveals a positive significant effect of renewable energy on carbon emissions at 5% significance (0.046). The result indicates that renewable energy causes environmental degradation. The finding of our study is contradicted by the study of Hu et al. [71] whose finding revealed that renewable energy helps in the fight against climate change by reducing carbon emissions. Hayford et al [72] further revealed that renewable energy consumption is the best substitute for fossil fuels since it reduces carbon emissions. Studies on renewable energy and carbon emissions have revealed that renewable energy positively or negatively or does not affect carbon emissions. The result can be attributed to the fact that at the initial stage of economic development, the use of renewable energy is necessary but cannot be used effectively. The use of renewable energy is expensive and this has caused many developing countries not able to utilize renewable energy sources to their maximum potentials. This situation can be

Table 2. Correlation.

	ln*c*	ln*f*	ln*e*	ln*fi*	ln*t*	ln*r*
ln*c*	1					
ln*f*	0.6873	1				
ln*e*	0.2641	0.3366	1			
ln*fi*	0.8609	0.5441	0.1872	1		
ln*t*	-0.4942	-0.5488	-0.0833	-0.3952	1	
ln*r*	-0.9550	-0.7242	-0.3347	-0.8839	0.5190	1

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Table 3. The stationary test outcome.

	t-stat	Critical value 0.05	Prob
ln*c*	-0.8569	-3.6999	0.7861
Δln*c*	-5.9542	-4.3393	0.0002
ln*f*	-2.4827	-4.2846	0.3337
Δln*f*	-4.8208	-2.6443	0.0000
ln*e*	-1.7485	-2.6534	0.0763
Δln*e*	-7.0466	-2.6607	0.0000
ln*fi*	-0.0434	-3.7696	0.9443
Δln*fi*	-6.2216	-37696	0.0000
ln*t*	-2.5763	-4.2846	0.2927
Δln*t*	-7.3989	-4.2967	0.0000
ln*r*	-0.8615	-3.6999	0.9933
Δln*r*	-5.7800	-3.6999	0.0001

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connected to the Environmental Kuznets Curve. Various studies like [73, 74] have tried to incorporate renewable energy in the Environmental Kuznets Curve (EKC) due to its effect on carbon emissions. Although renewable energy has been confirmed to have a negative effect on carbon emissions which validates the EKC hypothesis, studies like Acheampong et al [75] research on 46 selected Sub-Sahara African countries, a study in Turkey by Bölük & Mert [76], and study in USA by Dogan & Ozturk [77] do not validate the EKC hypothesis for renewable energy. Moreover, Al-Mulali et al [78] study in Vietnam revealed that the usage of renewable energy does not have any effect on carbon emissions and Jebli & Youssef [79] study in North Africa also indicated that renewable energy use causes carbon emissions. However, there has been a massive demand for renewable energy in various countries ever since it was discovered to be the best replacement for fossil fuels. Most countries especially global north countries have sharply shifted to renewable energy as a means of protecting the environment. According to Gyimah & Yao [63], renewable energy encourages environmental sustainability through the reduction of carbon emissions. The effect of using renewable energy is recommendable for the fight against carbon emissions. However, for countries to fully shift from fossil fuels to renewable energy and further enjoy its impact there should be a massive investment in the sector.

4.3.2 H2: renewable energy consumption improves economic growth. The outcome of the study shows no significant effect of renewable energy on economic growth. The result implies that the rate of renewable energy consumption does not affect the level of economic growth. The findings of our study is in contrast with the work of Makhdum et al. [39] who finding indicated that renewable energy use triggers economic growth. In addition, the findings of Zhang and Cheng [42] study revealed that energy use has significant effect on economic growth. Energy is the pillar for economic growth since the economic activities rely on energy

Table 4. Co-integration test result.

	Trace Statistics	Critical value 0.05	Max-Eigen Statistics	Critical value 0.05
None	110.031	95.7537	43.9120	40.0776
At most 1	66.1191	69.8189	30.7807	33.8769
At most 2	35.3384	47.8561	18.4490	27.5843
At most 3	16.8894	29.7971	11.3223	21.1316
At most 4	5.5671	15.4947	5.4570	14.2646
At most 5	0.1101	3.8415	0.1101	3.8415

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Table 5. Direct effect from the PLS-SEM estimation.

Effect	Coefficient	Prob
ln*r*→ln*fi*	-0.7808	0.000
ln*r*→ln*t*	0.0872	0.626
ln*fi*→ln*c*	0.7856	0.000
ln*e*→ln*c*	0.1438	0.344
ln*f*→ln*c*	0.4371	0.009
ln*r*→ln*c*	0.4049	0.046
ln*fi*→ln*e*	0.0143	0.967
ln*t*→ln*e*	0.1421	0.502
ln*f*→ln*e*	0.5673	0.001
ln*r*→ln*e*	0.1944	0.534
ln*r*→ln*f*	0.0542	0.762

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to attain maximum productivity. However, it is argued that at a certain point in time, the demand for either renewable energy or fossil fuel is mostly determined by the level of economic growth. In the argument of Salim et al [80], the rise in energy consumption is as the result of the rise in economic growth. The demand for energy to fuel household luxurious commodities is as the result of the rise in economic activities. A rise in household income increases energy demand. Renewable energy sources when harnessed effectively lead to green economic growth, create jobs for the people, attracts foreign investors, and improve innovations [81]. Renewable energy plays a crucial role in carbon mitigation to improve environmental quality which is vital to economic development and continuity [82]. Gyimah et al [11] explained the connection between energy and economic growth in four ways. The first is the proposition that explains the importance of energy in economic growth thus the growth hypothesis. The hypothesis emphasizes on the unidirectional causality effect from energy use to economic growth. The second way is the conservation hypothesis which explains the importance of economic growth in determining the use of energy. The unidirectional causality of this effect runs from economic growth to energy use. The third way is the feedback hypothesis

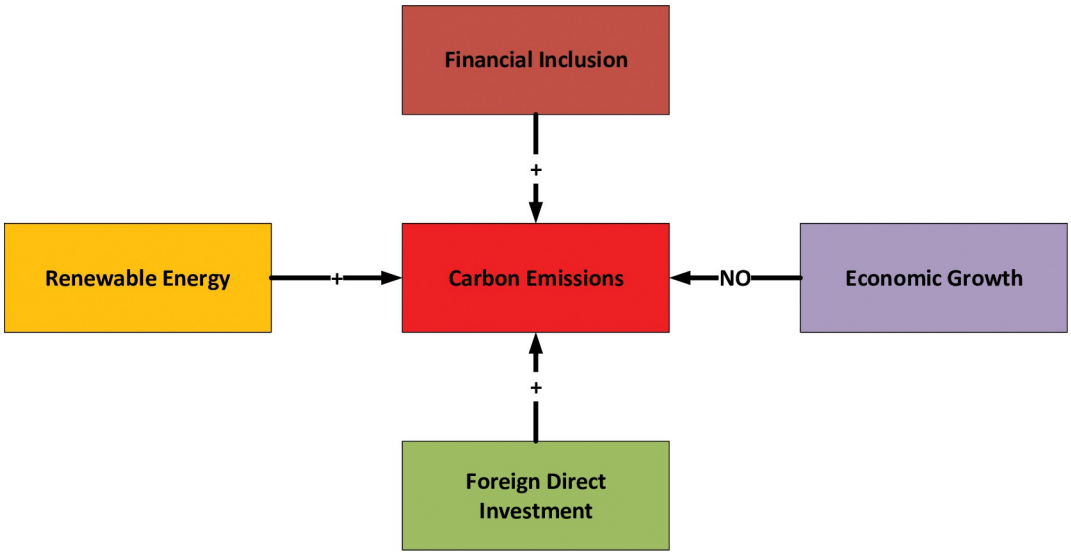

Fig 2. The direct effect on carbon emissions.

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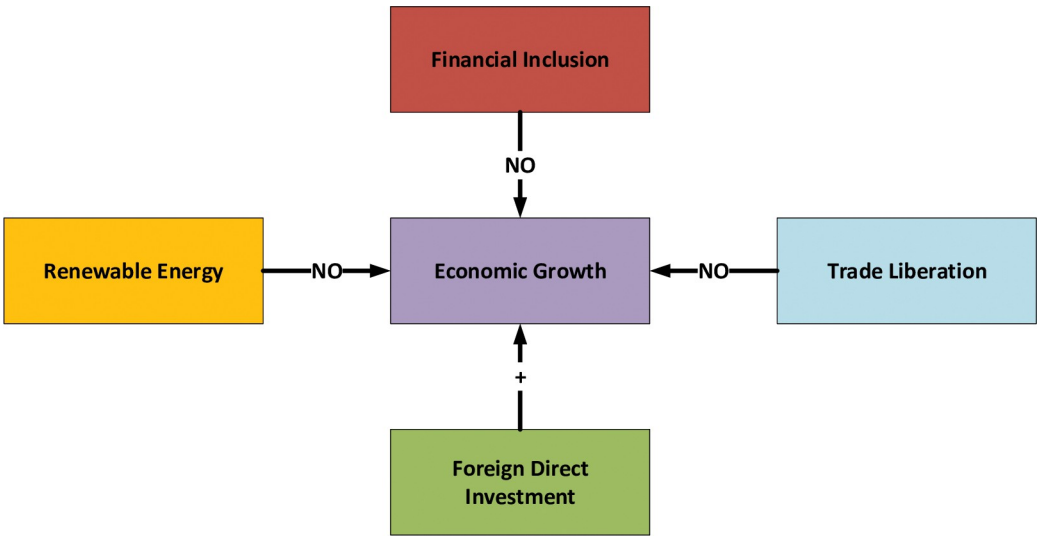

Fig 3. The direct effect on economic growth.

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which explains the interdependency of the two variables. The hypothesis suggests a bidirectional effect between energy use and economic growth which means the decrease or increase in one affects the other. The fourth way is the neutrality hypothesis which emphasizes on no causality effect between the two variables.

4.3.3 H3: Economic growth affects the level of carbon emissions. The result shows no significant effect of economic growth on carbon emissions. The outcome contradicts with the studies of Shahbaz et al. [83] whose study revealed that the quality of the environment is sacrificed to achieve economic growth in South Africa, and Adebayo [84] study that revealed how economic growth deteriorates environmental quality through a positive effect on carbon emissions. The literature explain how economic growth at the initial stage deteriorates the environment, and later turns to improve environmental quality at a certain level. However, several studies have indicated a positive effect of economic growth on carbon emissions. A study by Gao [81] indicated that the higher the economic growth the higher the carbon emissions. The finding implies that economic growth has a positive association with carbon emissions. In addition, a study by Ali et al [85] on Malaysia revealed that there is an increase in carbon emissions as the result of economic growth in the long-term but negative insignificant in the short-term. However, Sinha & Shahbaz [86] study on India captured a positive significant effect of economic growth on carbon emissions in both the short and long terms. Economic growth over the past decades has given birth to better healthcare, good living, and rise in income nevertheless, economic growth has effect on the environment which could be negative [22]. Zhang et al [87] revealed that economic expansion-related activities have a strong connection with environmental degradation through the emissions of greenhouse gas. The pursuit of industrial development and modern technologies are as the result of economic growth and these turn to cause environmental degradation when not tackled with caution [88]. The connection between economic growth and environmental degradation is better explained by the Environmental Kuznets Curve hypothesis which explains that at the initial stage, the pursuit of economic growth causes carbon emissions and the effect turns to change when economic growth is attained. Nevertheless, the outcome of our study reveals otherwise.

4.3.4 H4: Foreign direct investment improves economic growth. The result reveals a significant positive effect of foreign direct investment on economic growth. The result

indicates that the foreign capital inflow helps to build the economy. The finding of our study is supported by the study of Asafo-Agyei and Kodongo [89] whose finding confirmed that FDI improves economic growth. The impact of FDI cannot be undermined in any economy either developing or developed economy. Foreign investors support local industries to grow by investing in them, expose the local industries to modern technologies to improve on productivity, and help in knowledge exchange. These factors help in building a economy and a country. In support of our findings, it is argued that capital inflow from foreign investors in the form of foreign direct investment improves economic growth in many developing economies. The transfer of technology, development of industries and infrastructures, and further create an opportunity for local firms to grow and expand the local market [90]. In the view of Shahbaz et al [91], revenue from foreign capital inflow promotes macroeconomic activities in the country which in the long-term affects economic growth. However, according to Gao [81], a case study done from 2003 to 2014 on developing economies revealed that despite the economic benefits of foreign direct investment, it comes with environmental consequences.

4.3.5 H5: Trade liberation facilitates economic growth. From the result, trade liberation is insignificant to affect economic growth. Trade is one aspect of developing a country. The imports and exports in the country help develop the economy as it provides local industries with foreign market. Whenever, a country produce more than its consumption, there should be a market to sell the surplus and trade openness provides that platform. Trade liberation is the internationalization of the local market by encouraging higher production opportunities to meet customer demand beyond local borders [92]. Trade liberation has a crucial role to play in developing countries' economic growth. It expands local market, improves export-focused industrialization, and promotes regional and global trade relations. Trade liberation helps in allocating available resources to scarce places. Trade liberation encourages several economic activities which are accompanied by higher energy demand [93]. In this regard, a study outcome indicated that the availability of energy sources in a country has the tendency to expand its trade and speed up economic growth [94]. Nevertheless, our finding shows that trade liberation has no effect on economic growth.

4.3.6 H6: Foreign direct investment has an effect on carbon emissions. The result shows that foreign direct investment causes environmental degradation since it has a positive significant effect on carbon emissions. The outcome of the study is supported by Abdouli and Hammami [95] whose study revealed that the rise in FDI harms the environment. Their finding implies that FDI causes carbon emissions. In addition, the study by Do and Dinh [96] in Vietnam supported the argument that FDI does not contribute to the fight against climate change but rather worsens the situation. However, the finding of the study is contradicted by the study of Rafindadi et al. [97] whose study revealed that FDI helps promote environmental quality. Upon the positive impact FDI has on the economy, its effect on the environment cannot be disregarded. Depending on the level of environmental regulation in a country, FDI can either promotes or deteriorates the environment. Foreign direct investment is argued to have either positive or negative effects on the environment. The two hypotheses used to explain these two effects are the haven and halo pollution hypotheses [63]. The social responsibilities attached to foreign investors together with the environmentally friendly projects have made societies picture them as means to environmental sustainability [98]. Doytch [99] study on high income nations revealed that most of these countries in the form of foreign direct investment send their high emissions industries to countries with flexible environmental regulations. Several studies have provided empirical evidence to expose the influence of foreign direct investment on carbon emissions, such studies are [100, 101]. To further support our result, Tiwari et al [102] argued that foreign direct investment encourages the use of renewable

energy by investing in economies that turn to increase their consumption over fossil fuel to promote environmental sustainability.

4.3.7 H7: Financial inclusion encourages economic growth. The result shows that financial inclusion is not significant to affect economic growth. The result of our study is contradicted by the study of Kahouli and Chaaben [103] whose result indicated that financial development has a positive and significant effect on economic growth. In addition, Chen et al. [104] study revealed that financial inclusion boosts economic growth. The outbreak of COVID-19 pandemic has caused greater harm to many economies in developing countries. As a way of tackling the effect of the pandemic, policymakers have increased their interest in green economic recovery strategies [81]. The relevance of financial inclusion in a country's economic growth cannot be overlooked. The World Bank explained financial inclusion as the access to financial goods and services without limitations to fulfill financial needs by either persons or businesses [105]. Easy access to affordable and reliable financial services is recommended for economic development in countries battling economic growth. Financial inclusion policies when considered and implemented effectively increase investments, improve economic activities, and reduce poverty [106]. Therefore, there is a possible rise in fixed capital formation whenever there is a rise in financial inclusion. However, the effect from our study indicates an insignificant effect of financial inclusion on economic growth.

4.3.8 H8: Renewable energy consumption helps to improve trade liberation. Renewable energy consumption is insignificant to affect trade literation. The level of renewable energy development has no effect on trade liberation. The outcome of the study is supported by the finding of Bhowmik et al. [107] study that revealed that trade openness does not have any significant effect on energy use. However, the result is contradicted by the study of Najarzadeh et al. [108] whose result indicated a negative correlation between trade and energy use. The connection between energy use and trade liberation can be examined in different ways such as, the energy provided to fuel machines and equipment during production process has the tendency to increase trade liberation. Energy is further required in the production of raw materials which facilitates import and export of the final goods. In this regard, energy can be argued to play a vital role in expanding trade in a country [94]. A study Tiba et al [109] produced a two-way causality between energy consumption and trade liberation. However, the study of Al-Mulali et al [17] produced a one-way effect from trade liberation to renewable energy consumption. In addition, a long-term association was revealed between trade liberation and renewable energy within 23 topmost renewable energy countries [110].

4.3.9 H9: Renewable energy promotes financial inclusion. The outcome of the study reveals a negative significant effect of renewable energy on financial inclusion. The result implies that the level of renewable energy consumption reduces financial inclusion. In the view of Lei et al. [111] financial inclusion helps coordinate the market by providing credits which in the long-run affects energy use. In this regard, Sadorsky [112] findings revealed that financial inclusion promotes the use of energy.Several studies have identified the impact of financial inclusion on renewable energy consumption. According to Tiwari et al [102], financial development paves the way to redistribute the funds aimed at fossil fuel to renewable energy development. Financial inclusion impacts on the development of renewable energy can be felt when maximum attention is given to financial institutions. Financial inclusion has the potential of alleviating energy poverty [113]. Contrary, evaluating the impact of financial inclusion on energy consumption, a study by Ouyang & Yang [114] revealed that financial inclusion limits energy consumption.

4.3.10 H10: Financial inclusion has effect on carbon emissions. The result indicates a positive significant effect of financial inclusion on carbon emissions. Financial inclusion does not promote environmental sustainability. The study of Ahmed and Jahanzeb [115] indicated

that financial development interferes with carbon emissions. Nevertheless, the study of Jalil and Feridun [116] indicated that financial development helps promote environmental quality. The impact of financial inclusion can be felt when institutions are working effectively. This comes to play when people have access loans and other financial assistance which motivate them to use renewable energy. When it gets to this point, then financial inclusion will improve environmental quality. The debate on financial inclusion and environmental sustainability to examine if financial inclusion reduces, increases, or has no effect on environmental sustainability is ongoing [117]. As a means of fighting against global warming, recent studies on financial inclusion revealed the impact of financial inclusion on environmental sustainability. Most of the studies revealed a close connection between financial inclusion and environmental sustainability. The connection has been captured to be positive, negative, or insignificant. The difference in results can be attributed to different methodologies, proxies, countries, and duration [118]. A study Le et al [119] on Asian countries revealed that an increase in financial inclusion threatens environmental sustainability. Similarly, a study by Chaudhry et al [120] highlighted that the improvement of financial inclusion promotes greenhouse gas emissions. However, there is empirical evidence that supports the fact that financial inclusion is needed to promote environmental quality and it is argued by Zhao & Yang [121] as low-carbon solutions and useful mechanisms for environmental protection. Zhao et al [122] revealed that financial inclusion helps in energy poverty reduction which contributes to carbon emissions mitigation. Renzhi & Baek [123] further provided empirical evidence to support the notion of the relevance of financial inclusion in carbon mitigation.

4.4 Indirect effect

Table 6 shows the indirect pathway of the variables. The dependent variables for the indirect analysis are economic growth and carbon emissions. The results show that financial inclusion has no indirect significant effect on carbon emissions through economic growth. The results further show that trade liberation through foreign direct investment has no indirect effect on carbon emissions. In addition, foreign direct investment through economic growth has no significant effect on carbon emissions. However, renewable energy has a negative significant indirect effect on carbon emissions through economic growth. The result implies that when economic growth improves, renewable energy will be able to promote environmental sustainability through economic growth. The results for the indirect effect on economic growth indicate that trade liberation has no indirect effect on economic growth through foreign direct investment. Renewable energy through financial inclusion does not affect economic growth indirectly.

4.5 Granger causality test

The results presented in Table 7 show the outcome of the Granger Causality Test and Figs 4 and 5 give the summary of the discussion. The test is to examine the effects of the variables on

Table 6. The indirect effect from the PLS-SEM estimation.

Indirect Effect	Coefficient	Prob
ln*fi*→ln*e*→ln*c*	0.0021	0.967
ln*t*→ln*f*→ln*c*	0.0486	0.629
ln*f*→ln*e*→ln*c*	0.0816	0.362
ln*r*→ln*e*→ln*c*	-0.5828	0.002
ln*t*→ln*f*→ln*e*	0.3077	0.763
ln*r*→ln*fi*→ln*e*	0.0039	0.989

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Table 7. The Granger causality test outcome.

Effect	f-statistics	Prob	Effect	F-statistics	Prob
ln*r*→ln*fi*	4.57219	0.0258	ln*r*←ln*fi*	0.23043	0.7966
ln*r*→ln*t*	0.52136	0.6006	ln*r*←ln*t*	2.88820	0.0760
ln*fi*→ln*c*	3.74239	0.0450	ln*fi*←ln*c*	10.9935	0.0009
ln*e*→ln*c*	1.93217	0.1709	ln*e*←ln*c*	0.31373	0.7342
ln*f*→ln*c*	1.39189	0.2688	ln*f*←ln*c*	3.82394	0.0368
ln*r*→ln*c*	1.58490	0.2266	ln*r*←ln*c*	0.37160	0.6937
ln*fi*→ln*e*	0.08889	0.9155	ln*fi*←ln*e*	0.99685	0.3938
ln*t*→ln*e*	1.57296	0.2320	ln*t*←ln*e*	0.62367	0.5461
ln*f*→ln*e*	0.73223	0.4933	ln*f*←ln*e*	2.91144	0.0777
ln*r*→ln*e*	2.90767	0.0779	ln*r*←ln*e*	2.83581	0.0824
ln*r*→ln*f*	2.79106	0.0822	F to r	0.20997	0.8121

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each other. The expected effects are; unidirectional, feedback, and neutral thus no effect. From the results, renewable energy consumption has a unidirectional causality on financial inclusion. The result implies that renewable energy causes financial inclusion therefore the higher the demand for renewable energy, the higher the increase in financial inclusion. Trade liberation has a unidirectional causality on renewable energy. When there is an improvement in trade, the desire for sustainable energy increases which results in higher demand for renewable energy. There is a feedback causal relationship between financial inclusion and carbon emissions. The two variables affect each other, the rise in one causes the rise in the other, and therefore, the two variables are interdependent. Economic growth and carbon emissions have no causal effect. There is a unidirectional causal effect from carbon emissions to foreign direct investment. The rise in carbon emissions affects the level of foreign direct investment. Again, the results reveal no causal relationship between renewable energy and carbon emissions. This outcome implies that a rise or decrease in demand for renewable energy has no effect on carbon emissions as well as the rise or decrease in the level of carbon emissions does not affect the demand for renewable energy. In addition, financial inclusion and economic growth have no

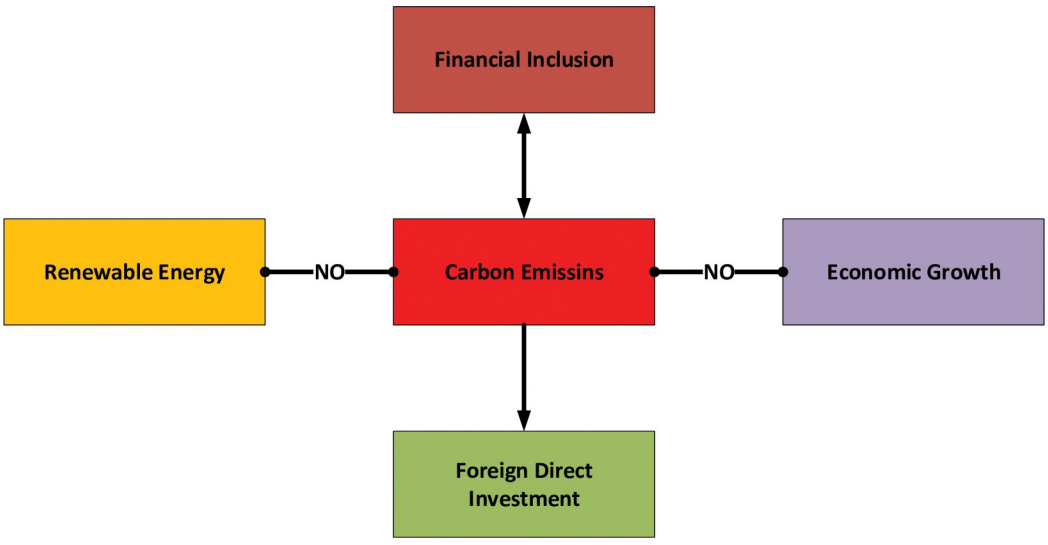

Fig 4. The Granger causal effect on carbon emissions.

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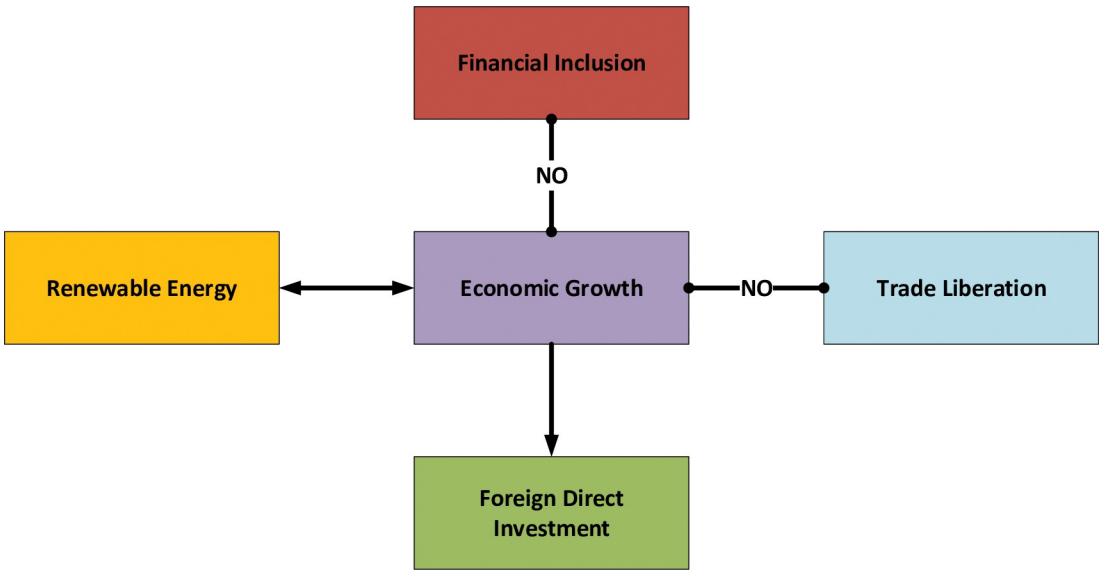

Fig 5. The Granger causality effect on economic growth.

https://doi.org/10.1371/journal.pone.0295563.g005

causal effect. Trade liberation and economic growth have no causal relationship. However, there is a unidirectional causal effect from economic growth to foreign direct investment. This outcome reveals that the level of economic development influence foreign investors. Furthermore, there is a feedback causal relationship between renewable energy and economic growth. The rise or decrease in renewable energy affects economic growth and vice versa. Lastly, renewable energy has a unidirectional causal effect on foreign direct investments. The rise or decrease in renewable energy determines foreign direct investment.

4.6 Robustness check

The results presented in Table 8 is the outcome of robustness check estimation for the effect of the variables on carbon emissions and economic growth. It could be seen that, the effects presented in the table reflect the effects we had for the main estimation (Table 5). The results show that renewable energy use worsens the environment since it has positive effect on carbon emissions. However, renewable energy use is not significant to affect economic growth. Foreign direct investment has a positive and significant effect on both carbon emissions and economic growth. Despite FDI improves the economy through the introduction of new technologies, knowledge exchange, and investors, it deteriorates the environment. Trade

Table 8. Generalized method of moments estimation.

	Dependent variable: Carbon emissions		Dependent variable: economic growth	
	Coefficient	t-statistics	Coefficient	t-statistics
lr	0.2346*	0.6668	-0.2348	-0.1474
lf	0.1962***	4.9765	0.3758**	2.3806
lt	0.3916*	1.8662	0.5813	0.7400
le	-0.0169	-0.4684		
lfi	0.9400**	2.4659	0.4713	0.2523

***, **, and * denote 1%, 5%, and 10%, respectively

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openness has a positive and significant effect on carbon emissions. The result implies that trade activities in the country harm the environment. Trade openness has no significant effect on economic growth. Financial inclusion promotes environmental degradation as it has a positive and significant effect on carbon emissions, but it is insignificant to affect economic growth. Economic growth has no significant effect on carbon emissions.

5 Conclusion and policy implications

The debate on global warming continues to be a global concern despite the efforts and involvement of state actors, non-governmental organizations, environmentalists, and foreign investors. The desire to achieve the Sustainable Development Goal (SDG 7) (affordable and clean energy) and SDG 13 (Climate action), studies on energy and global warming are crucial for policymaking. Therefore, this study tries to add to the body of existing literature by employing the Granger causality test and Partial Least Squares Structural Equation Modeling to examine the direct and indirect effects of renewable energy on economic growth and carbon emissions. In addition, Generalized Method of Moments is employed as the robustness check of the study. The data for the study is from 1990 to 2021. The results of the study are categorized into two thus the rest from the PLS-SEM estimation and the Granger Causality estimation. Firstly, the results from the PLS-SEM revealed two directions of effects thus the direct and indirect effects. The direct effect shows that renewable energy consumption causes carbon emissions, reduces financial inclusion however has no effect on economic growth and trade liberation. Financial inclusion and foreign direct investment have positive effects on carbon emissions. Trade liberation and financial inclusion have no significant effect on economic growth but foreign direct investment affects economic growth positively. Economic growth is irrelevant to explain carbon emissions. The second direction reveals the indirect effect of the study and the results showed that only renewable energy has an indirect negative effect on carbon emissions through economic growth.

Secondly, the results from the Granger causality test revealed that renewable energy has a unidirectional causality relation with financial inclusion and foreign direct investment and further has a feedback causality relationship with economic growth. However, there is a unidirectional causal effect that runs from trade liberation to renewable energy. In addition, there is a feedback causal effect between financial inclusion and carbon emissions, a unidirectional effect running from carbon emissions to foreign direct investment, and a causal effect from economic growth to foreign direct investment.

Based on the result of the study, these various policy implications are recommended to ensure a sustainable environment. Firstly, the Granger causality test revealed a unidirectional causal effect from trade liberation to renewable energy. The results of the study recommended that government should capitalize on the impact trade liberation has on the environment to promote low-carbon technologies. One way governments can go about this is to revise trade policies that limit the flow of exchange of goods and services and make attractive policies to motivate the trading of low-carbon technologies. This would increase the desire of local industries to use renewable technologies in their productions. Secondly, renewable energy from our results has a feedback causal relationship with economic growth and indirectly reduces carbon emissions through economic growth. Governments should not focus on only shifting state resources on economic indicators and neglecting that of renewable energy. There should be a balance in the allocation of state resources to balance results. These two variables complement each other therefore must be put on the same scale. This is needed to explore the best out of the two.

Although the purpose of the study is achieved, future studies can consider these limitations of our study to expand the scope. Since government institutions have a role to play in the

transition to clean energy, future studies can consider government institutions as one of the variables. In addition, level of education is also important to determine economic growth and the type of energy to use in a country, and it is very recommendable for future studies. Data availability and the objective of this study limited us to include these variables in our study.

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Writing – review & editing: Justice Gyimah.

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