Energy 239 (2022) 122199

Contents lists available at ScienceDirect

Energy

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

Energy transition and diversification: A pathway to achieve sustainable development goals (SDGs) in Brazil

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A R T I C L E I N F O

Article history:
Received 29 April 2021
Received in revised form
26 August 2021
Accepted 26 September 2021
Available online 1 October 2021

Keywords:
Renewable energy
Fossil fuels
FDI
Income growth
ARDL
Brazil sustainability

A B S T R A C T

This is a study of Brazil's sustainable development with respect to its environmental performance amidst its great emission and renewable energy potentials. Brazil has striking features of large renewable sector and at the same time identified as among the highest carbon emission countries in the likes of India and Russia. Following the position of Brazil in both emissions ranking and its potentials in curbing the emission through renewable source, we utilized Brazil data of 1970–2018 for a scientific research into the possibility of achieving sustainable development in Brazil. Instruments such as renewable policies (renewable energy consumption and fossil fuels), foreign direct investments (FDI) and income growth (GDP per capita, 2010) are utilized in this study. We adopt scientific methods like structural break test, autoregressive distributed lag (ARDL) bound test and granger causality in this study. This will give a clear and holistic insight into the best strategy for achieving sustainable development in Brazil. Findings from both ARDL short run and long run established a U-shape environmental Kuznets curve (EKC) instead of the popular inverted U-shape EKC. A negative and significant relationships are found between renewable energy consumption, FDI and carbon emission (CO_2), while a positive and significant association is established between fossil fuels and carbon emissions. This points that renewable energy and FDI are impacting positively on Brazil's environment quality while fossil fuels are impacting negatively on the environment. Findings from granger causality support the findings from ARDL by establishing both two ways and one way nexus among the energy policies (renewable and fossil fuels, FDI and income growth). The findings show that policies to curb carbon emission and achieve sustainable development should be framed around the energy policies (energy transmission to more clean energies).

1. Introduction

The concept of development was reduced to the concept of economic growth in the early 1950s, the understanding that development will only occur with economic growth has dominated this period. In the 1970s, the idea that the high growth rate achieved by Western countries did not bring development together and that this type of growth had negative effects on human and environmental factors led to the emergence of the concept of sustainable development. It is understood that solutions should be sought with the understanding of sustainable development for problems such as waste of non-renewable resources, environmental pollution, energy crisis, and poverty problems [1] (see Fig. 1).

A sustainable economy is an economy that ensures its social, economic and environmental development at an optimal level and can continue this without consuming existing resources. These concerns, which were initially ignored by most people and seen as abstract, have resulted in a wider environment with the global perception of environmental problems, that is, the concept of climate change as everyone knows. Conferences and climate agreements organized by the United Nations have been the biggest indicator of the climate and environmental problems being perceived as a major problem by developed countries [8].

Although the problem is noticed by the developed countries, the industrialization, growth and urbanization steps of the developing countries in the last thirty or forty years have seriously damaged the environment in most of these countries. The migration of the increasing population in these countries to the cities and the uncontrolled spread of the cities that became metropolitan as a result,

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https://doi.org/10.1016/j.energy.2021.122199
0360-5442/

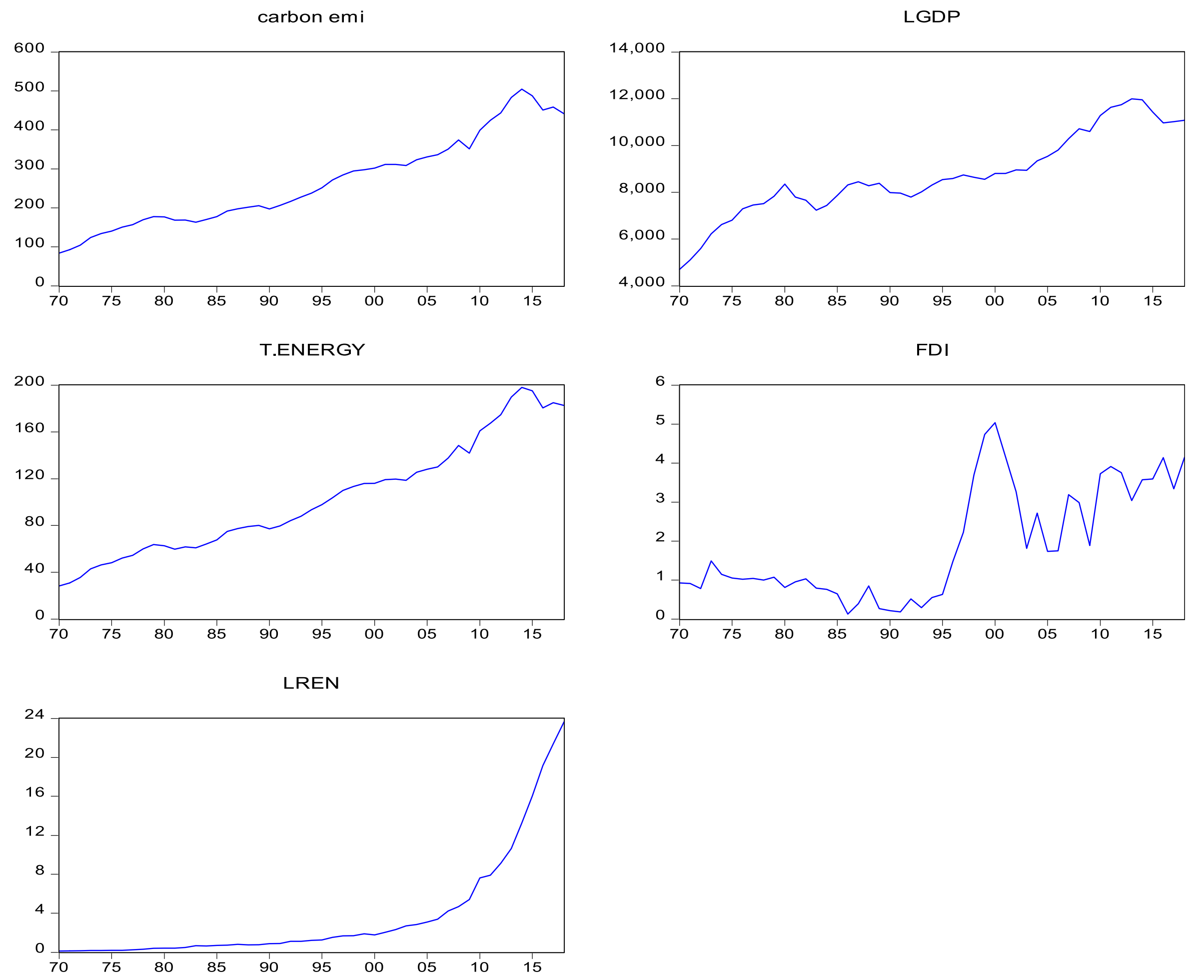

Fig. 1. Trend of the instruments (CO_2, GDP, FDI, T. ENERGY-FF and RE) within the chosen period of this study.

the destructive effects of industrial activities, the chemicals used in the agricultural lands have adversely affected the environment and the biosphere. In this respect, the realization of economically, socially and environmentally sustainable development and ensuring this without usurping the rights of the environment and future generations are among the main issues of both developed and developing countries [9].

Technological innovation, FDI and energy consumption with effective policies play important role in sustainable development. Technological innovation and renewable energy can play an important role in achieving sustainable services and products for growth where income is distributed equally to all and natural resources are passed on to future generations [10]. In studies on the effects of FDI on the environment, the results may vary according to the development level of the country of origin and the host country (pollution haven and pollution halo hypotheses) [11,12]. for Indonesia).

The current study seeks to investigate the best means of achieving sustainable development in Brazil. Brazil is chosen as a case study in this research because of its position as among the fastest and largest developing economies in the global economy. Also, Brazil despite being a developing nation has been identified as among the countries with the largest renewable energy sectors (Timperley, J [2,14]. In Brazil's energy mix, renewable energy source and hydropower dominate the major part of energy sector with hydropower dominating in electricity sector of the country. Part of Brazil's pledge to the Paris Agreement is to reduce carbon emissions by 37% and 43% in 2030 and 2035 respectively as against the 2005 carbon emission. These features of Brazil posed as good prospects in achieving sustainable development inclusive of moderate environment performance. However, Brazil has been fingered as among the major emitters of carbon globally. In fact, Brazil is ranked 6th in global carbon emissions irrespective of its potentials in achieving sustainable development goals through its renewable energy advantage [14]. This contradicting stand of Brazil in both renewable energy capacity and its carbon emission potential has paved way for this study. No doubt, previous literature (Akadırı et al., 2021; [15], 45 but contradict findings from Alam et al. [16]; Pereira Jr et al. [17]; Pereira Jr et al. [18]; Lima et al. [19] and Pao et al. [20] have studied Brazil but most of these literature based their research in panel studies which might not give an in-depth and holistic view of Brazil like that of a country specific study. Our study is a Brazil time series study which intent to expose the functionality of Brazil's sustainable development with the selected instruments (renewable energy policies, FDI and income growth). The uniqueness and novelty of our study is based on the contribution to the literature in answering the following questions which are meant to close the gap, thus a. *can Brazil achieve energy efficiency and security through energy transition and diversification (i.e. doubling the percentage of renewable energy source in the total energy use)? b. can Brazil achieve carbon mitigation through clean energy adaptation and c. sustainable development (UN SDGs-5→12)?d. Does renewable energy adoption in Brazil has effect towards carbon reduction?* To holistically investigate the sustainable development of Brazil, we adopt some scientific and empirical approaches such as structural break test, autoregressive distributed lag (ARDL) and granger causality. Also, instruments such as renewable energy policies (renewable energy and fossil fuels consumption), foreign direct investment (FDI) and income growth are adopted for effective and efficient exposition of the Brazil sustainable development.

The remaining part of this study are: section 2. Empirical and theoretical literatures, section 3. Data, methodology and modelling, section 4. Empirical findings and discussion and section 5. Conclusion and policy recommendation.

2. Empirical and theoretical literature

In the current literature, the relationship between renewable energy consumption, foreign direct investment, technological innovation and sustainable development is frequently discussed. Although there is no consensus, it can be said that renewable energy consumption, foreign direct investment and technological innovation positively affect sustainable development. When we examine these studies, it is seen that most of them are studies that investigate whether the relationship between environmental degradation and economic growth supports the Environmental Kuznets Curve (EKC) hypothesis.

The Environmental Kuznets Curve hypothesis suggests that environmental degradation increases in the early stages of economic development, and an inverse relationship occurs after per capita income reaches a certain level. Considering the studies dealing with the EKC hypothesis, it is understood that the findings vary according to the countries, periods and econometric methods.

Murshed et al. [21]; using the Panel Data Analysis method, confirmed the EKC hypothesis for Bangladesh, India, Nepal and Sri Lanka, but not Pakistan. According to the findings, it has been determined that the RECdecreases the ecological footprint, but it has been determined that financial development, urbanization and international trade exacerbate the ecological footprint. Hao et al. [22] and Yao et al. [23] obtained results confirming the existence of the EKC hypothesis for China, Germany and 17 developed and developing countries in their study using the Panel Data Analysis method. Özokcu & Özdemir [24]; who applied the same method to 26 OECD countries and 52 emerging countries, revealed that the results do not support the EKC hypothesis. In the studies in which the ARDL method was used; Gyamfi et al. [25]; Marques et al. [26]; Sarkodie & Strezov [27]; Shahbaz et al. [28]; Aiyetan & Olomola [29]; Lorente & Álvarez-Herranz [6]; Alam et al. [16] tested the EKC hypothesis for E7 countries, Australia, China-Australia-Ghana-USA, Vietnam, Nigeria, 17 OECD countries, India, Indonesia, China, and Brazil, respectively, and consequently confirmed the existence of the hypothesis in these countries. Studies that test the EKC hypothesis with methods other than the econometric methods mentioned above can be divided into two groups as country groups and specific countries. Hove & Tursoy [31] and Armeanu et al. [32] tested the EKC hypothesis for 24 developing countries and EU-28 countries, respectively. As a result of Hove & Tursoy's studies, it was found that financial growth and industrialization increased carbon emission, although REC reduced carbon emission, so it was determined that the EKC hypothesis was not valid in 24 developing countries. Armeanu et al. [32]; on the other hand, findings regarding the existence of EKC hypothesis for EU-28 countries have been reached. Yang et al. [33]; in their studies specifically for Russia, predicted that if the economic growth rate of Russia remained constant, the country would reach the turning point in 10 years according to the EKC hypothesis.

Looking at studies investigating the impact of foreign direct investment on sustainable development, Nepal et al. [34]; Sabir et al. [35]; Pazienza [36] and Ridzuan et al. [37] found that FDI investment inflows reduce CO_2 emissions. Adeel-Farooq et al. [38]; in their study using data from 76 countries, concluded that investment from developed countries positively affects the environmental performance of developing host countries, but concluded that investments from developing countries reduce the environmental performance of the host country. Ayamba et al. [39] found that FDI does not affect the environmental performance of countries in the long term, but Aust et al. [40]; in their study of 44 African countries, concluded that although FDI has a positive effect in the areas of renewable energy and basic infrastructure, it may have some negative environmental consequences for countries. Amoako & Insaidoo [41] and Shahbaz et al. [28,42] found that FDI increases role CO_2 emissions.

Another pillar of the sustainable development literature is the studies that reveal the existence and direction of the causality between energy consumption and economic growth. Although the number of studies in this field is quite high, it can be said that they are similar in terms of their results. Mohsin et al. [43]; Zafar et al. [4]; Zafar et al. [45]; Sharma et al. [46]; Güney & Kantar [3]; Güney [48]; Akadiri et al. Akadiri et al. (2019), Sinaga et al. [49] and Lyeonov et al. [50] showed that there is a bilateral positive relationship between EC and economic growth and sustainable development.

In the literature, the relationship between technological innovation and sustainability is relatively limited to renewable energy consumption and FDI. In their study for China, Wang et al. [51]; Cheng et al. [52] and similarly Yu & Du [53] stated that innovations in energy technology play an important role in reducing CO_2 emissions. Wang et al. [54]; in their study using the data of OECD countries, reached the conclusion that technological innovation has a positive effect on Green Total Factor Productivity. On the other hand, in Omri's [10] study for 75 high, middle and low income countries, he concluded that technological innovation only contributes to environmental performance and economic growth in high-income and middle-income countries. Likewise, Santana et al. Santana et al. (2015), in their studies with the data of G7 and BRICS countries, it was observed that technological innovation had a positive effect on the sustainable development of the BRICS group in both social and environmental aspects, but in G7 countries, technological innovation only contributed to social development and did not affect environmental performance. As a result, it can be said that the examined countries show different results according to the developmental stages.

If we compare the studies in the literature for different regions or countries, Udemba et al. [55] studied India, which has a high carbon emission rate. In this study investigating the relationship between energy consumption, climate problems and economic growth, the following conclusion was reached; that there is a negative relationship between carbon emissions and economic growth and trade openness. Contrary to the findings for India, in their study with data from OECD countries, Baloch et al. [56] concluded that financial development and globalization, and thus trade openness, reduce carbon emissions. Joshua et al. [57] and Joshua et al. [5] in their study examining South Africa, concluded that the consumption of coal, which is a non-renewable energy, causes carbon emissions and economic growth increases carbon emissions As can be seen from study of Adedoyin et al. [59]; economic growth has also led to environmental degradation in Sub-Saharan countries, which have had a striking economic growth rate in the last 10 years. In addition, Ali et al. [60] in their recently published study, they concluded that the consumption of electrical energy is effective in the sustainable growth of Nigeria and emphasized the need to control the environmental effects of energy consumption, which has such a large role in growth.

3. Methodology, modeling and data

3.1. Data and modelling

We adopted Brazilian annual data spanning from 1970 to 2018 to research the test the sustainability development goals (SDG) of the country. This is done through the nexus of income growth policy, energy policies, foreign direct investment, inflow (FDI) and the environment. For proper investigation and establishing the link between the environment and the mentioned policies, we applied the following instruments: renewable energy and non-renewable energy (all measured in million of oil equivalent), income growth (GDP per capita constant 2010), foreign direct investments, inflow (FDI %GDP) and carbon dioxide emission (CO_2). The data and instruments applied in this study are sourced from World Bank Development Data and 2019 British Petroleum database. All series are in natural logarithm form except FDI. The summary and definition of the instruments are presented in Table 1 below (see Table 2).

Following the theories of this present study, the modelling is based on ARDL-bound testing and EKC. Environment Kuznets curve (EKC) is adopted for to test the possibility of inverted U-shape relationship between economic growth and environment in Brazil's sustainable development. This will aid in exposing the impact of economic growth in determining the environment performance of the country. Also, autoregressive distributed lag (ARDL) is adopted in our research because of its ability to accommodate the series and model without sample size and order of integration bias. The ARDL model framework according to Pasaran and Shin, Pasaran and Shin, (1992) and Pasaran et al. Pasaran et al. (2001) with inclusion of both periods (short and long run) and the error correction model (ECM) is as follows:

$$
\begin{aligned}
CO_{2t} = {} & \beta_0 + \beta_1 CO_{2t-1} + \beta_2 GDP_{t-1} + \beta_3 GDP^2_{t-1} + \beta_4 RE_{t-1} \\
& + \beta_5 FF_{t-1} + \beta_6 FDI_{t-1} + \sum_{q=1}^{P=1} \delta_1 \varDelta CO_{2t-i} + \sum_{q=1}^{P=1} \delta_2 \varDelta GDP_{t-i} \\
& + \sum_{q=1}^{p=1} \delta_3 \varDelta GDP^2_{t-i} + \sum_{q=1}^{P=1} \delta_4 \varDelta RE_{t-i} + \sum_{q=1}^{P=1} \delta_5 \varDelta FF_{t-i} \\
& + \sum_{q=1}^{P=1} \delta_6 \varDelta FDI_{t-i} + ECM_{t-i} + \varepsilon_t
\end{aligned} \tag{1}
$$

where CO_2, GDP, GDP^2,RE, FF and FDI represent carbon dioxide emission, income growth and squared income growth, renewable energy, fossil fuels and foreign direct investment, inflow. All the stated instruments are expressed in log form except FDI. β_i and $\delta_i = i = 1, 2, 3$ *etc* are the long run and short run coefficients respectively. Δ and ECM_{t-i} represent 1st Diff and error correction model (evidence of speed of adjustment from short run disequilibrium) respectively. Cointegration is tested with ARDL-bound testing by comparing the F-tests and the critical values of upper and lower bounds. Test for cointegration is expressed with null-H_0: $\beta_i = 0$ and alternative-H_1: $\beta_i \neq 0$ hypotheses. Null hypothesis suggests non-cointegration while alternative hypothesis is rejecting null hypothesis. If the F-stats is greater than the critical value of upper bounds, null hypothesis will be rejected (cointegration exist) and vice versa.

Apart from ARDL-bound testing, we equally utilized structural break test and granger causality tests for robust check and confirmation of the findings from other approaches. Another method is descriptive statistics which exposes the distributive nature of the data.

4. Empirical findings and discussion

4.1. Descriptive statistics

Descriptive statistics is among the methods applied in this study to expose the normality in data distribution. From the results of the Kurtosis and Jarque-Bera, we find the data normally distributed and with light tails. Hence, the outcomes of the kurtosis are all well below 3 except for the case of renewable energy, and all the probability values of the outcome of Jarque-Bera are above 0.05 except for the case of renewable energy. This shows that data is fit for symmetric analysis.

4.2. Stationarity tests

Again, unit root test is among the approaches adopted on this study to expose the stationarity and order of integration among the series. Though, the key method (i.e. ARDL-bound testing) we adopted in our study is neutral to the rigorous conditions in testing further analysis such as cointegration, but clear understating of the trend of the series and order of integration will aid in justification of our estimations and recommendation. Hence, we adopt both conventional (augmented Dickey Fuller-ADF, 1979; Philip and Perron, 1990 and Kwiatkwoski et al., 1992), and the structural break tests with Zivot and Andrew, 1992 for testing the stationarity and order of the series. Structural break is adopted to help in exposing the impacts structural events with dates (e.g. Macroeconomic and natural events) in the economy which are capable of leaving a shock to the economy thereby affecting the working of the instruments in studying the economy. It equally act like a robust check on the findings from the traditional unit root test. Findings from the conventional unit root test display a mixed order of integration with majority being stationary at 1st Diff with I (1) order of integration except for the renewable energy. This same findings are observed from the case of structural break test where stationarity is observed from 1st Diff with break dates as follows: 2010 for CO_2, 1984 for GDP, 2004 for Renewable energy, 2010 for fossil fuels and 2001 for FDI. The break date are accommodated within the period of this research 1970–2018. No doubt, events such as 2008/9 global financial meltdown could be part of the events that contributed in the shock that affected the instruments in this study. The results of both the conventional and structural

Table 1
Definition of the instruments.

Instruments	Short form	Definitions/measurements
Carbon dioxide emission	CO_2	Million of carbon dioxide equivalent and sourced from British Petroleum data
Renewable energy consumption	RE	Million of oil equivalent and sourced from British Petroleum data
Non-renewable energy consumption	FF	Million of oil equivalent and sourced from British Petroleum data
Economic growth& increasing economic growth	GDP and Squared GDP	GDP per capita constant, 2010 sourced from World Bank data
Foreign Direct Investment, inflow	FDI	FDI % GDP sourced from World Bank data

Source: Authors Compilation

Table 2
Descriptive statistics.

Variables	LCO_2	LGDP	LGDP2	LFOSSIL	FDI	LREN
Mean	266.0672	8713.425	78,985,781	102.7250	1.905559	3.736751
Median	237.6446	8445.712	71,330,051	93.49599	1.148893	1.219221
Maximum	504.6100	11993.48	1.44E+08	198.1443	5.034129	23.64732
Minimum	84.11140	4704.318	22,130,604	28.24734	0.128665	0.116462
Std. Dev.	116.2340	1767.990	31,366,877	48.38633	1.437923	5.757669
Skewness	0.468620	0.098629	0.547483	0.455921	0.585018	2.149801
Kurtosis	2.140178	2.649916	2.498565	2.124030	1.924132	6.737300
Jarque-Bera	3.302834	0.329667	2.961212	3.264173	5.158223	66.26021
Probability	0.191778	0.848035	0.227500	0.195521	0.075841	0.000000
Sum	13037.29	426957.8	3.87E+09	5033.524	93.37239	183.1008
Sum Sq. Dev.	648496.5	1.50E+08	4.72E+16	112379.4	99.24592	1591.236
Observations	49	49	49	49	49	49

Source: Authors computation

Table 3
Unit root Test.

Variable	Unit root at level		Unit root at 1st Diff		Remarks
	Intercept	Intercept and trend	Intercept	Intercept and trend	
PP					
CO_2	−0.586	−2.164	−5.525***	−5.458***	I (1)
GDP	−1.966	−2.597	−4.823***	−4.871***	I (1)
RE	14.74	8.770	−1.391	−2.562	MIXED
FF	−0.181	−2.052	−6.171***	−6.103***	I (1)
FDI	−3.335	−2.561	−6.842***	−6.793***	I (1)
ADF					
CO_2	−0.520	−1.773	−5.441***	−4.281***	I (1)
GDP	−2.159	−2.733	−4.823***	−4.871***	I (1)
RE	2.453	1.121	−0.591	−0.837	MIXED
FF	−0.115	−1.793	−6.155***	−6.085***	I (1)
FDI	−1.307	−2.453	−6.842***	−6.793***	I (1)
KPSS					
CO_2	0.888***	0.168***	0.060	0.063	I (1)
GDP	0.851***	0.099	0.161	0.101	I (1)
RE	0.661**	0.202**	0.609**	0.197**	MIXED
FF	0.894***	0.176**	0.078	0.061	I (1)
FDI	0.651**	0.099	0.066	0.041	I (1)

Note: The signs *, ** and *** represent significant levels at 10, 5 and 1%. PP= Philips perron, ADF = Augmented Dickey Fuller, KPSS= Kwiatkwoski Philips-Schmidt-Shin.
Source: Authors computation with Eviews

Table 4
Zivot Andrew structural break Test.

Variables	ZA	P-Value	Lag	Break Period	CV@1%	CV@5%
CO_2	−4.511	0.068*	4	1987	−5.57	−5.08
GDP	−4.113	0.004***	4	2010	−5.57	−5.08
RE	−1.929	0.609	4	2008	−5.57	−5.08
FF	−2.970	0.000***	4	2010	−5.57	−5.08
FDI	−4.028	0.007***	4	1996	−5.57	−5.08
1st Diff						
DCO_2	−4.917	0.000***	4	2010	−5.57	−5.08
DGDP	−5.708	0.051**	4	1984	−5.57	−5.08
DRE	−5.202	0.086*	4	2004	−5.57	−5.08
DFF	−8.274	0.000***	4	2010	−5.57	−5.08
DFDI	−7.851	0.004***	4	2001	−5.57	−5.08

Note: The signs *, ** and *** represent significant levels at 10, 5 and 1%. ZA = Zivot Andrews, LG = lag, P-Value = probability value, CV = critical values.
Source: Authors computation with Eviews

break tests are shown in Tables 3 and 4 below.

Next, estimation and analysis after the unit root test is the cointegration and dynamic of interactions among the instruments through ARDL model of carbon emission. This approaches does not require any special criterion before executing. The findings from both bound approach of cointegration, short run and long run dynamics and the diagnostic tests (serial and autocorrelation, Durbin Watson, heteroscedasticity etc.) are all displayed in Table 5. Findings from Breusch-Godfrey serial correlation, Breusch-Pagan Godfrey Heteroscedasticity and Durbin Watson tests are 0.408 [0.527], 0.988 [0.479] and 2.13 which confirm the non-existence of the above mentioned econometric issues in the estimations. This disassociate the model adopted in this analysis from specification, multicollinearity and serial correlation problems. Also, the stability of the model is confirmed with recursive estimation. The cumulative sum and cumulative sum square tests from recursive estimation attest to the stability of the model with the blue lines well bounded with red lines in the outcomes. The results are shown with Figs. 2 and 3 immediately after Table 5. The goodness of fit of the model is confirmed with the Residual values (R^2 = 0.978 and Adj R^2 = 0.974). This shows the ability of the explanatory instruments (GDP, GDP^2, RE, FF and FDI) to explain the dependent instrument (CO_2) at 97% while the remaining part or variation from the dependent instrument is explained by the error term. The error correction model of this estimation appears with negative coefficient (−0.473) and significant at 1% level. This confirmed the capacity of the model to correct itself from short-run disequilibrium and hence, establish long run equilibrium among the instruments at 47%. Optimal lag selection is performed with Akaike Information Criterion (AIC) and the lag is 2. The result will be available on request. Findings from bound cointegration estimation reject the null hypothesis at F-stats = 6.5 and T-stats = −6.7 against the critical values of upper bounds at 5.2 and 5.1. Hence, cointegration

Table 5
ARDL Dynamic estimates of carbon emission (CO_2) Model.

Variables	Coefficients	Std. Error	T-stats	P-value
Short-run				
DCO_2				
DGDP	−0.042	0.009	−4.644	0.000
$DGDP^2$	2.57E-06	5.46E-07	4.707	0.000
DRE	−4.307	0.819	−5.262	0.000
DFF	2.514	0.103	24.51	0.000
DFDI	−1.343	0.602	−2.230	0.033
ECT	−0.473	0.071	−6.701	0.000
Long-run				
CO_2				
GDP	−0.020	0.010	−2.024	0.051
GDP^2	3.02E-07	4.80E-07	0.620	0.533
RE	−2.580	0.577	−4.474	0.000
FF	4.480	0.432	10.38	0.000
FDI	−2.838	1.371	−2.071	0.046
Constant	37.05	17.94	2.066	0.047
R^2	0.978			
Adj.R^2	0.974			
Durbin Watson stats	2.13			
Bound test (long-path)				
F-stats	6.5	K = 5@1%	Lower bound = 3.9	Upper bound = 5.2
T-stats	−6.7	K = 5@5%	Lower bound = −3.1	Upper bound = −5.1
Wald Test (Short-path)				
F-stats	252.5***			
P-value	0.000			
Serial correlation Test				
F-stats	0.408	PV = 0.527		
R-square	0.575	PV = 0.449		
Heteroscedasticity Test				
F-stat	0.988	PV = 0.479		
R-square	12.16	PV = 0.433		

*Note: The signs *, ** and *** are the significant levels at 10, 5 and 1 percent.*
Source: Authors computation

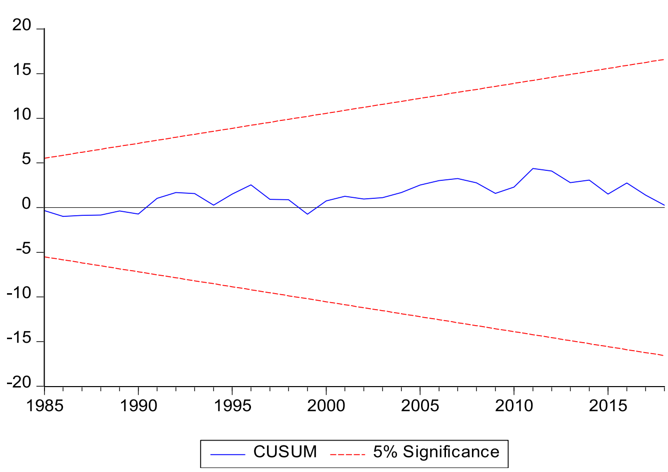

Fig. 2. Cumulative sum.

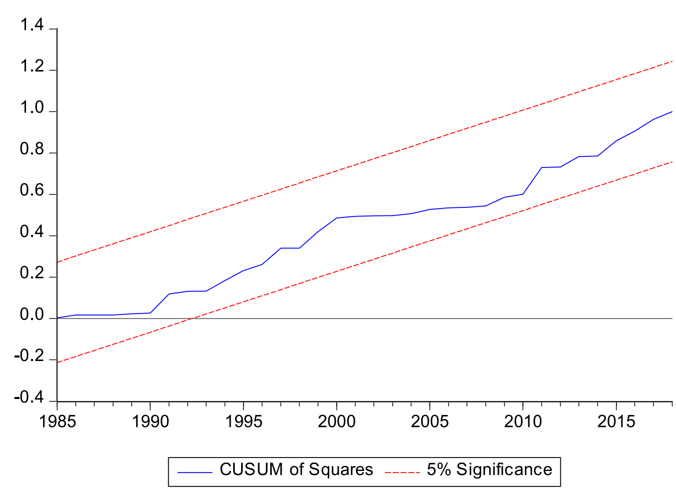

Fig. 3. Cumulative sum square.
Source: Authors computation

is confirmed in this study suggesting the possibility of long run relationship among the instruments. We proceed with the findings from both the short run and long dynamics of ARDL as follows: from both periods (short and long run), negative and positive link is found among income growth, squared income growth and carbon emissions (CO_2) at 1% significant level. This debunk the existence of inverted U-shape EKC for Brazil. This suggests that income growth of Brazil was actually impacting the environment development positive till it gets to a certain point where the relationship overturned with increase in economic growth leading to poor Brazilian environment quality. Statistically, in the short run a percent change in economic growth of Brazil will lead to 0.042 and 2.57E-06 (0.00000025) decrease and increase in carbon emission in Brazil. This same pattern is established in the long run at −0.020 and 3.02E-07 (0.0000002) for GDP and squared GDP respectively. This finding aligns with the finding from Akadırı et al. Akadırı et al. (2021) and Kostakis et al. [15], but contradict findings from Alam et al., [16]. Also, in both periods (short run and long run), negative and significant relationship is found between renewable energy, FDI and carbon emission (CO_2) depicting renewable energy and FDI impacting positively on Brazil's environmental development. This shows that the two policies (renewable energy and FDI) will be good for policy framing in mitigation of carbon emission for Brazil. These support findings from Pereira et al., [17]; Pereira et al. [18], and Lima et al. [19], for renewable energy in Brazil, and Pao et al. Pao et al. (2021) and Udemba et al. [12], for Indonesia; Udemba, [61]; Udemba [62], for FDI. Statistically, in the short run, a percent increase in renewable energy and FDI will decrease carbon emission by 4.307% for renewable energy and 1.343% point for FDI respectively, while in the long run, the decrease in carbon emission due to renewable energy and FDI are at −2.580 and −2.838 respectively. However, fossil fuels is found having positive and highly significant relationship with carbon emissions. This suggests that fossil fuel consumption in Brazil contributes to the degeneration of environment quality through increase in carbon emission. This equally supports the findings from Sasana, [63]. Hence, a percent increase in fossil fuels consumption will cause 2.514 and 4.480 increase in carbon emissions in short run and long run respectively. The findings from both short run and long run ARDL dynamics suggest that renewable energy and FDI policies as potential mitigating forces to environmental degradation.

4.3. Diagnostic tests

Cumulative Sum and Cumulative Sum Square Tests.

4.4. Granger causality test

After, the ARDL bound test for cointegration with short run and long run dynamics, we utilized granger causality test for a robust check of the findings and for forecasting purpose. It is worthy to state here that ARDL is limited to the relationship amongst the instruments without much insight to the direction of the inference and the originator of the relationship among the instruments. Granger causality test has the power to determine the direction (i.e. uni-directional and bi-directional) of the relationship between the instruments. It exposes the nexus among the instruments. Findings from granger causality are as follows: two-way granger causality between renewable energy and carbon emission, unidirectional transmission from carbon emission to FDI, from income growth to renewable energy consumption, and from fossil fuels to renewable energy, and from fossil fuel to FDI. Findings from granger causality display nexus among renewable energy, FDI, income growth, fossil fuels and carbon emissions which exposed the interdependent relationship among the instruments. This is a pointer that energy policy (renewable energy), FDI and income growth will circumvent the adverse effect of fossil fuels and carbon emissions on Brazil environment. The result is shown in Table 6 below. Moreover, VECM Granger causality analysis/Block Exogeneity Wald Tests was conducted in complimentary and as a robust to the pairwise granger causality test. The result is shown in Table 7. The condition for the use of pairwise granger causality is because of the integration of almost all the series to order of I (1) except for the case of renewable energy that revealed mixed order of integration. Though the exposition from the block exogeneity test supports the findings from pairwise granger causality but the objectives of this study as highlighted on the introductory section are made open and supported with the findings from the pairwise granger causality. Hence, the need to present the two estimations for in-depth and clear insight into this study.

5. Conclusion and policy recommendation

Following the target to mitigate climate change on global scale through national determined contribution (NDC), we consider Brazil a good location for this research. Brazil is unique in both global economic position as a developing economy and its energy cum environmental development. The country is among the countries with the largest renewable energy sector with about 70% of renewable energy in its energy mix. This notwithstanding, Brazil is among the first 7 largest emitters of carbon emission. This is not farfetched from the excessive deforestation and land use act of the country. Most of the emissions in Brazil are from land use and buildings, transport and agriculture which are equally contributing towards climate and contrary to its pledge in Paris Agreement. Against this backdrop, we applied different methods (structural break, ARDL-bound and granger causality) to study the sustainability development of Brazil amidst this contradicting forces of renewable energy policy and enlarging of carbon emission. Our analysis and emphasis are based on the findings from ARDL and granger causality This study has implication to the sustainable development goals in the neighboring and emerging countries who may wish to adopt the findings and policies of this study to improve their environment sustainability.

Findings from ARDL estimation displayed U-shaped EKC instead of inverted U-shape. The findings also exposed negative relationship between renewable energy consumption, FDI and carbon emissions depicting positive impact of renewable energy and FDI on Brazilian environment, while positive link is exposed between fossil fuels and carbon emission. Findings from granger causality exposed two way ganger causality between renewable energy and carbon emission while one way granger causality is seen passing from carbon emission to FDI, from income growth to renewable energy consumption, and from fossil fuels to renewable energy, and from fossil fuel to FDI. Hence, a nexus is established among the energy policies (renewable and fossil fuels, FDI and income growth. The findings show that policies to curb carbon emission and achieve sustainable development should be framed around the energy policies. The following can be considered realizable policies to mitigate carbon emission through a trade-off of fossil fuels with renewable sources: 1. policy that will encourage both private and public sectors to engage on intense energy diversification to more renewables, hence according to our finding, renewables are greater force in mitigating carbon emission in Brazil, 2. subsidies such as tax cut and credit to renewable energy firms to encourage expansion and energy transition to more clean energy sources., 3. Policies to encourage and enhance technological innovation on the renewable energy sector which will reduce the rate fossil fuel utilization in the process of renewable energy production and deployment., 4. Policy to regulate the activities of foreign investors in Brazil especially from energy and transportation sectors and encourage them to adopt a more clean energy use and economic activities void of contaminating the environment. There is a need for the Brazilian authorities to reconsider land use act in the country in a way to curtail the excessive rate of deforestation in the country. Also, environmental tax policy such as higher taxation to pollution intensive firms and placing a ceiling by which firms are not allowed to exceed in their productive behavior, and if exceeded will amount to tax penalty. From the findings and policies recommended on the present study, incidence of carbon emissions can be

Table 6
Pairwise Granger causality analysis.

Null Hypothesis	F-Stat	P-value	Causality	Decision	Direction
Variables					
LGDP → L CO_2	1.068	0.307	NO	ACCEPT H_0	NEUTRAL [*LGDP* ≠ *LCO_2*]
L CO_2 → LGDP	0.734	0.396			
LFOSS → L CO_2	0.467	0.497	NO	ACCEPT H_0	NEUTRAL [*LFOSS* ≠ *LCO_2*]
L CO_2 → LFOSS	0.207	0.651			
LREN → L CO_2	3.907	0.054**	YES	REJECT H_0	BI-DIRECTIONAL [*LREN* ↔ *LCO_2*]
L CO_2 → LRE	3.461	0.069*			
FDI → L CO_2	0.037	0.848	YES	REJECT H_0	UNI-DIRECTIONAL [*FDI* ← *LCO_2*]
L CO_2 → FDI	4.822	0.033**			
LFF → LGDP	0.978	0.328	NO	ACCEPT H_0	NEUTRAL [*LFOSS* ≠ *LGDP*]
LGDP → LFF	1.002	0.322			
LRE → LGDP	0.005	0.943	YES	REJECT H_0	UNI-DIRECTIONAL [*LREN* ← *LGDP*]
LGDP → LRE	3.496	0.068*			
LFDI → LGDP	0.550	0.462	NO	ACCEPT H0	NEUTRAL [*FDI* ≠ *LGDP*]
LGDP → LFDI	2.647	0.902			
LRE → LFF	2.553	0.117	YES	REJECT H0	UNI-DIRECTIONAL [*LREN* ← *LFOSS*]
LFF → LRE	3.106	0.085*			
FDI → LFF	0.256	0.615	YES	REJECT H0	UNI-DIRECTIONAL [*FDI* ← *LFOSS*]
LFF → FDI	4.831	0.033**			
FDI → LRE	0.111	0.740	NO	ACCEPT H0	NEUTRAL [*FDI* ≠ *LRE*]
LRE → FDI	2.147	0.150			

Note: The numbers inside bracket are the p-values of the parameters. The numbers that are written in bold colors represent the parameters that are significant in the causal relationship among the variables.
Source: Authors' computation

Table 7
VECM Granger causality analysis/Block Exogeneity Wald Tests.

Variables	L CO_2	LGDP	LFOSS	FDI	LRE
L CO_2	Ω Ω	2.149 [0.3415]	0.391 [0.8223]	0.403 [0.817]	3.600 [0.1653]
LGDP	**6.33[0.0421]**	Ω Ω	**6.843[0.0327]**	0.711 [0.7008]	**40.09[0.000]**
LFOSS	4.057 [0.132]	1.394 [0.4980]	Ω Ω	0.153 [0.927]	4.469 [0.1070]
FDI	0.603 [0.740]	0.1739 [0.9167]	1.332 [0.514]	Ω Ω	**8.630[0.0134]**
LRE	**5.815[0.0546]**	0.767 [0.6814]	3.516 [0.1724]	0.8972 [0.639]	Ω Ω

Note: The numbers inside bracket are the p-values of the parameters. The numbers that are written in bold colors represent the parameters that are significant in the causal relationship among the variables. **Source:** Authors' computation.

reduced to the global recognized and accepted level of less than 2 °C and above 1.5 °C, especially, among the emerging and developing countries in the categories of Brazilian economy. Hence, this study has implication to the countries with same feature like Brazil and its relevance and will add to the current literature.

Conclusively, our study has not closed the door to this research topic but encourage more studies with other policy related instruments such as institutional quality and democracy.

Compliance with ethical standards

Author wishes to inform the Editor/Journal that there are no conflicts of interest at any level of this study.

Funding

Authors declare non-funding for this present research.

Declaration of competing interest

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

Acknowledgements

This manuscript has not been submitted to any journal for publication, nor is under review at another journal or other publishing venue and there is no conflict of interest for this is a single author's contribution.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.energy.2021.122199.

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